NATO Science for Peace and Security Series - B:
Physics and Biophysics

Nuclear Power and Energy Security

Edited by
Samuel Apikyan
David J. Diamond

Springer

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Nuclear Power and Energy Security

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Series B: Physics and Biophysics

Nuclear Power and Energy Security

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CONTENTS

CHAPTER II – THE CASE FOR NUCLEAR ENERGY

Preface

The basic logic is very simple. Countries around the globe have a need for more electrical generating capacity because of increases in population and increases in energy use per capita. The needs are constrained by the requirement that the base-load energy source be economical, secure, and not emit climate-changing gases. Nuclear power fits this description. Therefore, many countries that have not had a nuclear power program (or only had a small program) see a need to develop one in the future.

However, the development of a national nuclear energy program is not so simple. The purpose of the NATO Advanced Research Workshop on Nuclear Power and Energy Security was to contribute to our understanding of how these programs might evolve. The workshop took place 26–29 May 2009 in Yerevan, Armenia. Approximately 50 participants discussed the infrastructure that is needed and some of the reactor options that might be considered. The papers in this book helped define the discussion that took place.

The infrastructure that is needed includes a legal framework, a functioning regulator, a plan for waste disposal, a plan for emergency response, etc. These needs were explained and just as importantly, it was explained what international, bilateral, and regional cooperation is available. Although there were many countries represented, the Armenian experience was of particular interest because of where the meeting was located.

The papers on reactor options covered both innovative and evolutionary designs. Of particular interest with the latter are small or medium size reactors that apply proven pressurized-water reactor design principles.

The participants judged the workshop to be a success because of the valuable information that was provided and the stimulating discussions that took place. Another workshop along these same lines would be beneficial not only for those who participated in this workshop but for participants from other countries as well. In the meantime, it is hoped that this book will be of value to those people working in countries to develop a new or expanded nuclear power program.

As before, this 4th NATO workshop was expertly organized by the Advanced Science and Technology Center, ASTEC, in Yerevan, Armenia. It's our pleasure to thank the Organizing Committee for the logistic organization of the meeting as well as the Local Organizing Committee members. Special thanks to K. Yerznkanyan, A. Makaryan, T. Apikyan, M. Hovhannisyan, R. Dallakyan, E. Sevikyan for their assistance before and during the meeting.

David J. Diamond
Samuel A. Apikyan
Editors

The RA President's Message to Participants 4th of the NATO "Nuclear Power and Energy Security" Meeting

It's my great pleasure to welcome the guests and participants of the 4th NATO "Nuclear Power and Energy Security" meeting.

The ever-expanding usefulness of nuclear energy as of a sustainable and reliable source of energy in the modern world has also caused some challenges connected with the peaceful and safe utilization of nuclear energy. Meeting these challenges is a shared concern and consequently it requires the expression of joint determination, consistent efforts and mutual support. This is the only way in which we can enjoy the fruits of the greatest scientific achievements of humankind.

Taking into consideration all these challenges the government of the Republic of Armenia continuously keeps the peaceful and safe utilization of nuclear energy in the centre of attention. Armenia has started the realization of the project on building a new power-generating unit which will play a significant role in the context of our country's mid-term and long-term economic progress and ensuring energy security of our country.

Taking the opportunity we would like to thank IAEA and the presidents and specialists of all those countries who assisted Armenia in the process of safe utilization of the existent nuclear power station and contribute to the efforts aimed at building another one.

Being a country which produces nuclear energy Armenia has attained much experience in this sphere and encourages specialists of the corresponding field to contribute their scientific potential and experience to ensuring regional and international security. In this regard, I also attach importance to the activities of the "Advanced Science and Technology Centre (ASTEC)" founded through state support as well as to the cooperation with international research centres.

Welcoming again I wish the participants good luck, efficient discussions and great perspectives in the process of all-inclusive cooperation. I do hope that the conference will become a great impetus in the sphere of nuclear cooperation and will enable us to discover new scientific potential which will contribute to the regional and international security.

Opening Remarks NATO Advanced Research Workshop "Nuclear Power and Energy Security" 26–29 May 2009, Yerevan, Armenia

David J. Diamond

Co-Director of the Workshop, Brookhaven National Laboratory, U.S.A.

Good morning. As co-director of this NATO workshop, it is my pleasure to extend a welcome to you. I thank you all for coming here to discuss issues related to the building of nuclear power plants in countries with few or no existing plants. We are here to look at the motivation for using nuclear power in those countries and to explore the advantages and disadvantages of such action. We will examine the requisite governmental and industrial infrastructure needed for the development of nuclear power in those countries. These are not simple issues and that is why countries with considerable experience in nuclear energy are present to be part of this dialogue.

Before I provide some remarks on nuclear power within a global perspective, I wish to thank my co-director Professor Samuel Apikyan of the Advanced Science and Technology Center, ASTEC, and his staff. They have put together the technical program and have arranged for a critical mass of experts from many countries. They have also arranged a complementary social program which will provide additional opportunity for communication and learning – and which will be fun as well.

Nuclear energy is needed throughout the world to help provide for the increase in electrical capacity the world needs, and to help eliminate our dependency on fossil fuels. Consider what is expected by 2050, only 40 years from now. There will be more than two billion additional people on the planet at that time. Although in some countries, like the U.S., there is a need to decrease the per capita electricity consumption, in many countries it is necessary to increase per capita energy consumption because we know that economic prosperity in developing countries is linked to the access to energy. The countries with the need to develop at the fastest rate, like India and China, contain a large share of the earth's population. Projections are that the increase in the world's electrical generating capacity will range between 1,900 and 6,300 GWe by 2050 depending on the assumptions one uses.[1] These numbers are staggering.

To provide the necessary additional energy many different sources must be used. However, we know that the more fossil fuels we use, the more the earth's climate will change. The biggest cause of climate change is anthropogenic; it's from what we humans do. Electricity production accounts for 27% of the anthropogenic CO2 in our atmosphere and that is one of the important climate-change or greenhouse gases. Climate change is a topic with many unknowns but we do know specific things: The polar icecaps are getting smaller at a faster rate than was projected only a few years ago. In Canada, it is now projected that 78% of British Columbia pine will have died by 2013 because of climate change. Permafrost is becoming less permanent and releasing more methane, another greenhouse gas. We don't know whether crop yields will increase or decrease globally but we suspect that overall water supplies will diminish, extreme weather events may increase in intensity, and harmful ecological changes will occur.

One way to stem the tide of global climate change is nuclear energy. It is a mature technology that is currently providing 16% of the electricity around the world. There are approximately 440 units operating in 31 countries. Many of these countries continue to grow their nuclear generating capacity (e.g., China, Finland, France, India, Japan, Korea, and Russia) and there are more than 40 nuclear projects under construction. Other countries with operating plants have plans to expand in the near future (e.g., Brazil, Canada, Romania, Switzerland, United Kingdom, and the United States). In the U.S. we have license applications for 26 new units. Right here in Armenia, the location of an operating VVER-440 reactor, there are plans for another unit that are seriously being pursued. There is also considerable planning in countries without existing plants, such as, Albania, Egypt, Georgia, Indonesia, Kazakhstan, Turkey, the United Arab Emirates, and Vietnam, to name only a few.

Many countries have committed to limiting their emissions of climate-changing gases. The new President and Congress in the U.S. are particularly interested in changing previous policy and moving to dramatically reduce our "carbon footprint." Currently, in the U.S., nuclear energy contributes 74% of the emission-free electricity being used. Public support for nuclear energy has increased after discussions of climate change. In a survey of 14 countries, public support for nuclear increased 9–19% points after the argument linking nuclear energy to its impact on climate change was introduced.2 Another survey of 20 countries, most with nuclear power plants, found that 29% of the more than 10,000 respondents favor the increased use of nuclear power outright, and an additional 40% would support the expansion of nuclear power "if their concerns were addressed," for a total of 69%.3

But the motivation for expanding the use of nuclear energy in many instances comes from economic considerations and considerations of energy security rather than because of its benign carbon footprint. Due to its capital costs, nuclear energy is not cheap, but in many industrialized countries, it is competitive with coal and to a lesser extent, with natural gas. A survey in 2005 placed levelized costs for all three in the range of 20–60 USD/MWh.4 The absolute values may change with time but the relative values which demonstrate nuclear's competitiveness with these fossil fuels has not changed. Note that these numbers are usually not compared with renewable energy sources such as solar photovoltaic panels and wind turbines, as these technologies are still relatively expensive and investments must also be made in smart transmission grids to significantly expand the use of these renewables. They also are not considered competitive with nuclear and fossil fuels because they do not yet provide base-load energy.

The economics of nuclear energy improve relative to fossil fuels if external costs are considered. An external cost arises when "the social or economic activities of one group of persons have an impact on another group and when that impact is not fully accounted, or compensated, by the first group."5 A review of external costs for current and advanced electricity systems shows that these costs, which consider waste treatment and disposal, and transport of fuel and waste, are small except for those technologies that use fossil fuel.

Nuclear energy accounts for the cost of most waste directly in internal costs. The waste from fossil fuel plants consists of ash, and gaseous effluents that have health effects and impact climate change. The so-called "polluter pays principle" has been adopted in many parts of the world. In the U.S., the Environmental Protection Agency has recently proclaimed greenhouse gases a threat to public health, clearing the way for future regulation of them. A vigorous debate is underway within the U.S. Congress to determine what form a "carbon tax" will take. It is estimated that if the external costs of producing electricity from coal were factored into electricity costs in the European Union, 20–60 €/MWh would have to be added to the price.6

The matter of energy security can also be considered an external cost, but it is easy to understand without quantifying the effect in terms of cost. There is a risk involved in placing too much reliance on one technology because of the potential of finding a problem which cripples that entire technology. An example is supply of fuel which is problematic for those countries that do not have indigenous resources. This means that if a country does not have its own fossil fuels, it must question how much it wants to rely on the availability of these resources from outside suppliers. This would be a consideration if the country were not a producer of its own uranium fuel as well. (Currently there are 18 countries that are capable of supplying fabricated nuclear fuel.) Energy security also means one has to look beyond 2050 to understand potential scarcity of fuel on a global basis. There is a large uncertainty in future fossil fuel supply that does not exist with uranium fuel.

The situation I have described with respect to economics does not necessarily apply to a country with little existing nuclear infrastructure. To support a nuclear energy program a country must invest large amounts of money to assure that they have the trained personnel needed for construction, operation, and oversight of a nuclear power plant. There must be a functioning regulator and a legal framework, a plan for waste disposal, a plan for emergency response, etc. These costs can become "show-stoppers" by which I mean the cost and time needed are too large, relative to the benefits, to allow the country to continue along this path. One way to improve this situation is to do things on a regional rather than a single-state basis. The recent announcement of a joint nuclear energy program by Croatia and Albania is an example of this. The activities of the International Atomic Energy Agency (IAEA) are another way to ease the burden.

The purpose of this NATO workshop is to contribute to the critical assessment of how to prepare for a new national nuclear energy program, and to make recommendations for future action. In addition, our goal is to promote close working relationships between technical people from different countries and with different professional expertise. In particular, the countries that are involved in this workshop are those from NATO and those from the Partner countries such as those in the Commonwealth of Independent States.

A NATO workshop is not an international conference or symposium but rather a forum for advanced level, intensive discussions. The presentations that we will hear in the next four days are part of the growing font of knowledge on the subject of how to develop a national nuclear energy program. We will hear about the infrastructure that is needed and how the IAEA and countries with existing experience are helping to provide that infrastructure to those working toward a nuclear energy program. We will hear about the experiences of several countries embarking on new nuclear development, with an emphasis on how progress is being made in Armenia. We will also hear about the potential for using small and medium size reactors; something not being pursued by the countries with large nuclear programs.

We must take this opportunity to appreciate what is being said, to understand how it might apply to our own situation, and to create a dialogue with each of the participants so that we learn from each other now and in the future.

It is appropriate that we have come to Yerevan in Armenia, a cradle of civilization. We who work in nuclear technology have come a long way from our cradle. It is essential that we use our knowledge so that nuclear technology can play an important role in supporting our global civilization and moving the inhabitants of our planet toward lives in peace and prosperity.

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[1] Nuclear Energy Agency (NEA), "Nuclear Energy Outlook 2008," pg 90, 2008
[2] Ibid., Fig. 12.7.
[3] American Nuclear Society, *Nuclear News*, p 17, April 2009.
[4] NEA, op. cit., Fig. 6.8.
[5] NEA, op. cit., p 147.
[6] NEA, op. cit., Fig. 4.23.

CHAPTER I
DEVELOPING THE NECESSARY INFRASTRUCTURE

IAEA ACTIVITIES IN SUPPORT OF COUNTRIES CONSIDERING EMBARKING ON NUCLEAR POWER PROGRAMME

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Introduction

The IAEA annually updates its projection of the use of nuclear power in its Member States by collecting information from them. The 2008 projection [1] is that by the year 2030 installed nuclear capacity will increase by 30–100%. The low projection is an aggregation of data on plants already being built or planned or firmly committed and the high projection includes, in addition, plants that are reasonably expected to be constructed.

Although most of the new capacity addition is coming from existing nuclear power countries, especially from Chin and India, there will certainly be newcomer countries starting operation of nuclear power plants by 2020.

Today there are more than 60 countries, who have, through various channels, informed the IAEA that they are considering embarking on a nuclear power programme. They are considering nuclear power as one of the options to meet their growing demand for energy, consistent with their need for energy security while taking into account global environmental concerns. The accumulated experience and the good operational performance of existing nuclear power plants in 30 countries have, no doubt been, factored into their analyses. For instance, more than half (57%) of the recent increase on global nuclear electricity (40% from 1990 to 2005) came from increased availability of existing plants, while new capacity addition and power uprating contributed 36% and 7%, respectively. A key factor in increasing plant availability has been sharing information on best practices.

S.A. Apikyan and D.J. Diamond (eds.), *Nuclear Power and Energy Security*,

Infrastructure building for safe, reliable operation of nuclear power plant

Challenges for expansion and introduction of nuclear power

The IAEA considers the following eight issues to be the key challenges that need to be addressed for the successful expansion and introduction of nuclear power in the near-term [2].

1. Safety and reliability
2. Economic competitiveness and financing
3. Public acceptance
4. Uranium resources
5. Fuel and waste management
6. Human and industrial resources
7. Proliferation risk and security
8. Infrastructures, especially in new countries

While "hard" infrastructure such as physical facilities and equipment associated with the delivery of electricity, and the transport of the material and supplies to the site, need to be considered, the concept of infrastructure discussed here is mostly focussed on "soft" issues required for the successful introduction of nuclear power and to support its safe, reliable and efficient use. These issues can be grouped under the following topics: National position and commitment, Legal and regulatory framework, Human resources development necessary to implement nuclear power programme, National industrial capability, Stakeholder involvement and others.

IAEA's role

IAEA has a role under its statute to foster and enlarge the role of atomic energy in contributing to peace, health and prosperity throughout the world. At the same time, the IAEA has a leadership role in ensuring that, wherever nuclear energy is used to produce electricity (or for district heating, desalination, or hydrogen production), it is used safely, securely, and with minimal proliferation risk. As well the IAEA has a unique role in ensuring that the needs of developing countries are taken into account.

Most of the newcomer countries considering a nuclear power programme are developing countries and for these countries IAEA support is implemented through the Technical Cooperation (TC) mechanism, for which the IAEA has a different funding system from its Regular Budget.

The IAEA's support for infrastructure building is basically intended to assist capacity building in the newcomer country so that they can stand by themselves. It includes

- Providing tools and information for informed decision-making including guidance documents, information forums, and analytical tools and

- Assisting the process by offering "Review Services" such as site evaluation, infrastructure status review

Practically, assistance is given in the form of review mission, workshops, seminars and scientific visits. Popular topics include but are not limited to the following: Review of Feasibility Study, Review of draft Nuclear law, Regulatory framework and organization, Site survey and site evaluation, Human resources development plan, Bid tendering and evaluation, Technology assessment, Owner/Operator's competence building, Regulator's competence building.

In providing guidance, the IAEA recommends:

- Energy Planning to define the potential role of nuclear power
- Developing a full understanding of the obligations and necessary long-term commitment that follow from a decision to use nuclear power, including safeguard agreement, Additional Protocol, various conventions on safety, responsibilities of the government and the owner/operator
- Using IAEA guidance documents & services
- Balanced development of sound infrastructure for safe, reliable and efficient use of nuclear power
- Exploring regional co-operation

Existing and new IAEA guidance documents and tools

Since early 1980s, a considerable number of IAEA documents had been released to guide introduction of nuclear power in the newcomer countries. Although not intended specifically for newcomers, there are plenty of standards, guides, international instruments, technical reports that provides important information in considering nuclear power programme and national infrastructure building available in Series information form; IAEA Nuclear Safety Standards Series, IAEA Nuclear Security Series, IAEA Nuclear Energy Series, IAEA International Law Series, IAEA Safeguard Information Series, IAEA Nuclear Verification Series and others, all of which are available on IAEA web site [3].

In providing guidance with focus on newcomers in the contemporary situation, the approach the IAEA has taken since 2005 are:

1. Providing holistic guidance to support balanced development of various elements of infrastructure in a way there is no important missing points
2. Utilizing accumulated experiences and lessons learned of 30 nuclear power operating countries and
3. Introduction of phased approach to enable progressive development of the country's nuclear infrastructure

The IAEA brochure titled "Considerations to launch a nuclear power programme" (2007 March) and IAEA Nuclear Energy Series Document NG-G-3.1 "Milestones in the development of a national infrastructure for nuclear power" nuclear (2007 September) discuss complex and interrelated nineteen infrastructure issues, recommend phased approach for progressive development of infrastructure and clarified conditions that are expected to be met at the end of each phase (milestone). Considering a lengthy time required for introduction of nuclear power (15 years on an average), a preparatory period for introduction of nuclear power is splitting into three phases, as is shown in Figure 1. The 19 issues are the followings but they are not listed in the order of priority; National Position, Legal Framework, Regulatory Framework, Radiation Protection, Financing, Human Resource Development, Safeguards, Security and Physical Protection, Emergency Planning, Nuclear Fuel Cycle, Nuclear Waste, Environmental Protection, Nuclear Safety, Sites & Supporting Facilities, Stakeholder Involvement, Electrical Grid, Management, Industrial Involvement, Procurement.

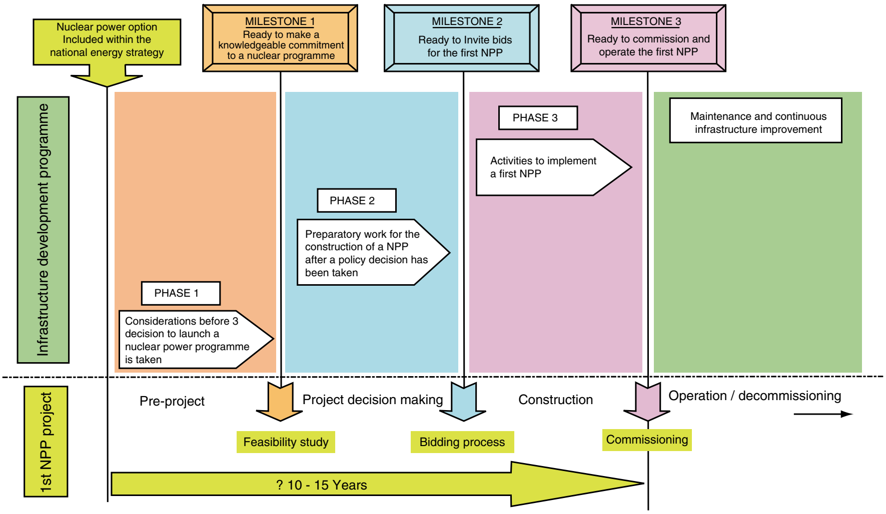

Figure 1. Infrastructure development programme

Following the completion of the “Milestone” document, the IAEA Member States requested additional guidance on how to assess the progress of their infrastructure development. A new document titled “Evaluation of the status of national nuclear infrastructure development” (NE Series NG-T-3.2) was published in 2008 November to enable continuous self assessment by the newcomers by providing detailed basis for evaluation over the 19 topical issues of infrastructure in Milestone 1 and 2. Member State’s continuous self-assessment against the evaluation basis is intended to help identify gaps and areas needing assistance from outside and for wise and effective investment in that country.

Further the IAEA has many guidance documents published recently and in the pipeline on various topics such as regional sharing of nuclear infrastructure [4], management of nuclear power plant project [5], financing, national organization to lead national nuclear programme, workforce planning, interface with electricity grid, alternative approach for contracting and ownership, stakeholder involvement etc. The recently published INSAG-22 defines elements of safety infrastructure under phased approach [6].

IAEA's INPRO (International Project on Innovative Nuclear Reactor and Fuel Cycles) was established in 2001 in response to IAEA General Conference Resolution [7] as a forum by technology holders and technology users to consider jointly the actions required to achieve desired innovations in nuclear reactors and fuel cycle systems. Among 28 members of INPRO, five member countries are not yet operating nuclear power but are aspiring to introduce nuclear power (Belarus, Chile, Indonesia, Morocco and Turkey). INPRO assessment methodology and its manual [8, 9] can be applied for screening a nuclear energy system (NES) to determine whether it represents a sustainable energy system for a given state. The assessment requires a holistic analysis in seven areas, namely, Economics, Environment, Waste Management, Safety, Proliferation Resistance, Physical Protection, and Infrastructure. Such an assessment can assist with developing a comprehensive understanding of the significance and depth of the long term commitment required by a decision to adopt nuclear power. Several countries have used the INPRO methodology for assessing NES, and a report summarizing the results and lessons learned from these assessments is to be published later this year.

In 2007, INPRO embarked on a new 2 year activity on common user considerations (CUC), to identify commonalities in the expectations of the NES that developing countries would like to deploy. INPRO has reached out also to 26 countries that are not members of INPRO in developing the CUC. A report summarizing the CUC for future nuclear energy systems to be deployed by technology user countries has been recently published [10]. The requirements/expectations identified by participants in the CUC exercise were consistent with the requirements set out in the INPRO manual and thus CUC served to validate the INPRO methodology.

In addition to summarizing the expectations of the countries surveyed, the report indicates that more than 50% of the user countries surveyed plan to operate nuclear power plants by 2030, thus providing a total nuclear capacity higher than the IAEA projection. In the framework of selected assumptions and limitations, expectations from users indicate the number of new units; 38% of the additional units are in the small (<300 MW(e)) and medium (<700 MW(e)) range and 62% are in the 1,000 MW(e) or larger range (Figure 2).

Today, the INPRO program includes continued development and application of the assessment methodology, collaborative studies on future energy scenarios and the role of nuclear energy, on proliferation resistance, on specific technical innovations, and on innovations in institutional arrangements to facilitate the adoption of nuclear power by newcomer countries. An important aspect of the program is the INPRPO dialogue forum which promotes the exchange of views between technology users, particularly potential new users, and technology developers.

The IAEA's assistance to its Member States includes capacity building for informed decision-making, which includes Energy Planning through the analysis of projected demand and supply as well as energy supply options. Various Energy

Planning tools are provided and used in many countries. Further, considering that the nations that had pledged to take part in Agenda 21 [11] are encouraged to promote Agenda 21 at the local and regional levels within their own countries by measuring a country's state of development and monitoring its progress, a set of Energy Indicators for Sustainable Development (EISD) was established in 2005 [12] in order to serve this purpose by the concerted efforts of the UN-related organizations, International Energy Agency and other organizations. The EISD is a set of indicators intended for the users, which are nations; (a) to analyze the past trends and current situation, (b) to diagnose to help specify objectives and measure distance to target, and (c) to formulate strategy by exploring options [13].

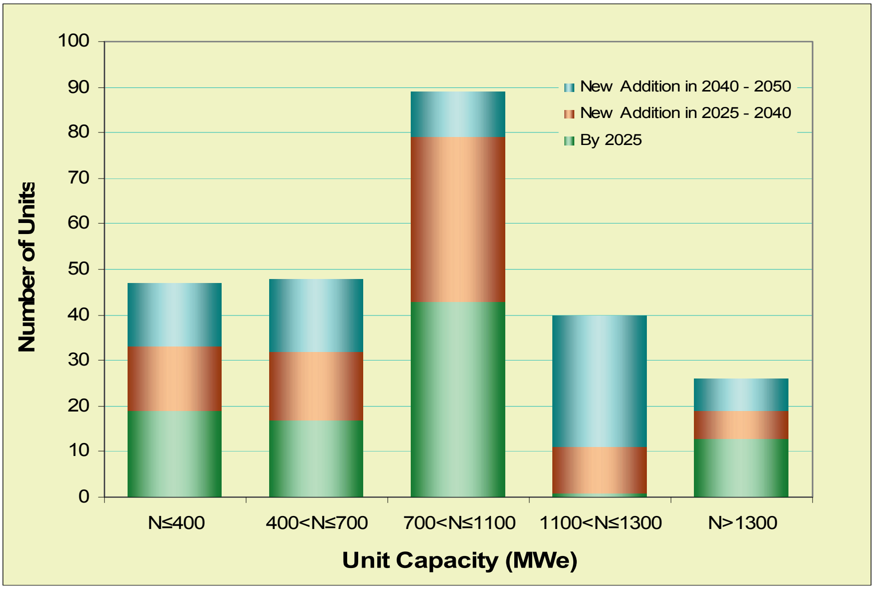

Figure 2. Expectation for the number of new units in 31 technology user countries surveyed

It is expected that the newcomers would make informed decision-making on going to nuclear power by fully understanding the necessary obligations and national long-term commitment, by confirming viability of nuclear power options in the country's energy plan through Energy Planning and long-term strategic assessment using IAEA guidance and tools (INPRO methodology, Energy Planning tools, EISD).

In the past, the IAEA's TC projects addressed specific needs (such as site review, support to legal arrangement, human resources development, establishing a regulatory scheme) of the Member States for its preparedness to implement a nuclear power programme and did not necessarily address the whole spectrum of preparedness in the country. Because of a wide spectrum of inter-linking infrastructure issues that need to be addressed to secure safe and reliable operation and keeping the international safeguard regime, it is necessary for both (the IAEA and the TC recipient countries) to take a holistic approach so that there may be no missing parameters. Also, there have been cases where inter-departmental cooperation did not work well enough to provide this holistic service.

In the light of this, an inter-departmental standing group called NPSG (Nuclear Power Support Group) was established in 2006, primarily to assure coordinated assistance to newcomers in nuclear infrastructure building.

Infrastructure status assessment and IAEA's assistance

As mentioned already, the infrastructure assessment methodology is intended for use in the newcomer's self-assessment. However, the IAEA, upon request from its Member States, can provide holistic review of infrastructure preparedness of the requested country by sending multi-disciplinary INIR (Integrated Nuclear Infrastructure Review) mission. A guideline for this INIR mission (preparation by the IAEA and host country, team, conduct of the mission, evaluation result report etc.) was also published in 2009 April. It must be noted that INIR mission covers only phase 1 and 2 and is not intended to duplicate or replace with already available services such as listed below:

Regulatory Framework and Activities: IRRS – Integrated Regulatory Review Service Operational Safety)

Engineering and Technical Safety: DESAR – Design/Engineering/Safety Assessment Review Services

Security: INSServ – International Nuclear Security Advisory Services, IPPAS – International Physical Protection Advisory Services

Safeguard: ISSAS – State System of Accounting for & Control of Nuclear Material

The IAEA consider its involvement by INIR mission could add values, by providing objective view on the status of nuclear infrastructure and by clarifying areas of further assistance.

The nature of INIR mission is (a) holistic peer review by multidisciplinary international experts led by IAEA staff, and (b) initiated upon request by the Member State. The outcome from INIR mission will be: Evaluation of status for each infrastructure issue such as no actions needed, minor actions needed, significant actions needed and suggestions for action plan.

The review will be consisting of preliminary and follow-up missions by two to four persons staying for 1 week. Considering that this mission is intended to assist national infrastructure building, it is advisable that the mission is invited towards the end of phase 1 or the beginning part of phase 2, but intensive review at the end of phase 2 (before bid invitation) by –six to eight persons for 2 weeks will be very beneficial to evaluate readiness to construct of the first nuclear power plant in the country. The information of readiness will enhance confidence building in the country and internationally including potential worthiness to bid and creditworthiness for the project by stakeholders.

Conclusion

The IAEA supports in a variety of ways in establishing an appropriate infrastructure necessary to secure safe and reliable operation and still maintaining the international safeguards regime, especially in developing countries which are considering introduction of nuclear power programme. The TC projects to support introduction of nuclear power has been formulated and its number increased significantly recently. Various guidance documents have been published by the IAEA recently to enable progressive development of national infrastructure. The IAEA guidance documents constitute a basis of advises to newcomer countries. The recently formulated important mission is INIR mission to review the status of national infrastructure in the context of measuring the distance to the expected milestone.

Finally, it is expected that the newcomers would make informed decision-making on going to nuclear power by fully understanding the necessary obligations and national long-term commitment, by confirming viability of nuclear power options in the country's energy plan through Energy Planning and long-term strategic assessment using IAEA guidance and tools.

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CREATING A NATIONAL NUCLEAR REGULATORY AUTHORITY

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For a number of reasons, countries throughout the world are now considering the development of new nuclear power programs. Whether it is to meet increased power requirements, lack of indigenous resources or environmental concerns, these countries are looking at nuclear power as a solution to their increasing energy needs. Such an undertaking will require a concerted effort by national industrial firms and several branches of government.

This paper will look the various phases that encompass the development of a nuclear power program from the perspective of the human resources development. In short it will consider the following issues:

- Planning a Human Resource Development strategy
- Establishing organization, roles and responsibilities
- Establishing an Human Resource Development vision, mission, goals and objectives
- Collecting and evaluating data for an HRD needs and resource assessment
- Conducting a Human Resource Development needs and resource assessment
- Determining short-, medium-, and long-term needs
- Developing an implementation plan to address education, training, recruitment, retention and knowledge management
- Establishing systems that monitor, evaluate and anticipate HRD needs as the nuclear program evolves
- Funding and financing short- and long-term Human Resource Development efforts

Regulation of a nuclear power reactor is a complex and demanding undertaking. It proceeds in phases, starting with the selection of a suitable site for construction; and ending many decades later with the decommissioning of the plant after its useful life has expired and disposition of the spent nuclear fuel. The regulatory authority must have the stability and credibility to sustain itself throughout this cycle.

The first stage is the approval of the selected site as being suitable for a nuclear power plant. The regulator also ensures that the site is suitable for development of an evacuation plan, in case an accident happens.

S.A. Apikyan and D.J. Diamond (eds.), *Nuclear Power and Energy Security*,

Next the regulator must license the design of the reactor itself. Given the complexity of nuclear reactor designs, licensing is an intensive, multi-year effort, and requires the support of many different technical disciplines.

Construction of the plant can usually begin before the licensing review is complete. During construction, the regulator must conduct inspections to assure that the plant is built to high quality standards, and in accordance with the design documents.

When the licensing is complete and the plant has been constructed to acceptable standards, the regulator will authorize operation of the plant. This requires that the regulator has confirmed and certified that the organization has a strong operating organization, sufficient trained staff and good work procedures.

Operation of a nuclear power plant could continue for 40 or 60 years, and in some cases, longer. The regulator must maintain vigilance to assure that the plant is operated in a high-quality, safe manner. This requires frequent inspections and ongoing technical analyses.

At the end of plant life, the regulator assures that the site is decontaminated, so that it can be returned to other uses. They also ensure that all spent fuel has been disposed of in accordance with national laws and policies.

Generally, the regulation of nuclear reactors can be incorporated into an existing agency with authority for radiation protection. This means that a whole new management structure will not be needed. It is good to separate the nuclear agency from the ministry of energy from the very start. This gives the agency much more latitude to question the safety and security aspects of decisions that are being made about reactor design and operation. This type of independence is a major lesson learned from decades of experience in western countries. It took the United States 20 years to achieve the independence that we are advocating here.

An important ingredient in the success of a regulatory agency is to foster public confidence in their effectiveness. This is best accomplished by allowing the public to understand what issues the regulator is dealing with and what decisions they are making. Transparency in dealing with the public is paramount to the successful operation of the regulatory authority. The agency must have the credibility to challenge reactor vendors and operating companies on matters of public safety and security. This means that the agency must have the full range of technical disciplines to understand this technology.

Based on analysis conducted in both large and small countries, as well as adding in our own experiences, it appears that about 40 technical staff are needed to license the first reactor. Once you have a program in place, the second reactor only requires an additional 30 staff to license. Oversight of an operating reactor site, with one or more reactors of similar design requires about 30 technical staff So, if you have completed the licensing of a first plant, and are starting to license a second one, you should have about 60 staff on board; 30 for the operating plant, 30 for the new one. Of course, these are just estimates.

Staffing is one of the key issues and determining the make up of the regulatory authority is critical to its success. In addition to project management skills, you will need legal experts to develop the safety requirements and to interpret them in every day situations. Nuclear experts include scientists who can do calculations of nuclear chain reactions, analyze the thermal and fluid behavior of the reactor, calculate the likelihood and consequences of accidents and estimate public health effects. You will need all the engineering disciplines: structural, mechanical, electrical, metallurgy, instrumentation, chemical, etc. Operations experts include human factors experts, fire protection engineers, quality assurance specialists, and security experts. Radiation experts protect workers and the public from radiation in and near the plant. Earth scientists include geologists, seismologists, meteorologist and hydrologists. They assure that the plant is designed and operated so that it will withstand earthquakes, floods, tsunami, hurricanes and tornadoes. These are some of the skill sets required for the regulatory authority and this list must be tailored to the needs of your country and situation.

The next question relates to the staffing timeline, or how soon do each of these disciplines need to be available to the regulator. Our analysis indicates that you need support staff first. This includes the project managers and legal staff. You will also need to concentrate on the earth sciences and other disciplines needed to evaluate the site. Next you need the nuclear professionals to perform the preliminary license review for issuing the construction permit. This category includes reactor physicists, thermal hydraulicists, safety system analysts and risk analysts. The full license review and the inspection of construction requires hiring people who represent all of the engineering disciplines: mechanical, electrical, I&C, materials, structural, etc. Operations experts are needed to assure that the plant is ready to operate. This category includes security experts, radiation protection, emergency preparedness, human factors, technical specifications and so on. Based on this analysis, you would need to hire about five people a year, which is an achievable goal in most countries.

The qualification of the regulatory staff starts with the assumption that they have the basic educational credentials in their respective disciplines, however, nuclear regulation is a unique business and becoming a regulator requires special training and experience. The regulatory authority must provide classroom instruction to staff; both at the beginning of their careers and on a continuing basis. For a new regulatory authority, foreign assignments are a good way to gain experience and knowledge. The best training is on-the-job experience (OJT). This should be gained under the guidance of more experienced staff.

No regulatory agency can hire all the staff they will need. There are several strategies the agency can use to meet their obligations. Many countries have an organization that acts as a technical support organization (TSO). This might be a university or national technical laboratory. The TSO provides highly specialized skills that are needed infrequently. An example would be seismic hazard assessment. This is a rare skill that few people world-wide have. The TSO can also augment the normal capabilities of the staff during times of high demand. Commercial contractors, both inside and outside the country can be used to augment staff capabilities. The regulator should make sure that the government provides resources for the TSO and funding for the contractor support. Help can also be gotten from other countries and the IAEA. These can also be called upon for special inspections and for response to operating events. The regulator should begin early to develop these international relationships. Another important aspect of creating a regulatory agency is to develop requirements and guidance. There are three levels of such documents. National laws set the legal groundwork for the authority of the agency. They also set the basic requirements for protecting the public health and safety and national security. In most countries, the regulatory agency has the power to enact binding regulations. These are legal requirements, and have the force of law. Violation of these requirements can result in fines or criminal punishment.

Because the regulations can be interpreted in many ways, agencies issue guidance on acceptable ways to comply. The guidance is very extensive and detailed. Compliance with the guidance is not mandatory; however, licensees follow the guidance in order to promote consistency and efficiency. A healthy nuclear power program requires an independent, technically credible regulator, with legal authority to take action in the interest of public health and safety, as well as in the interests of national security.

The regulator must have the stability and credibility to sustain its mission throughout the life cycle of the nuclear plant. The regulator needs a competent and diverse technical staff and they must provide ongoing training opportunities. The regulator must take advantage of technical support from a variety of sources. Putting all these disparate pieces together can be challenging, but essential to establish a functional and dynamic regulatory authority.

BUILDING SAFEGUARDS INFRASTRUCTURE

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Introduction

Much has been written in recent years about the nuclear renaissance – the rebirth of nuclear power as a clean and safe source of electricity around the world. Those who question the nuclear renaissance often cite the risk of proliferation, accidents or an attack on a facility as concerns, all of which merit serious consideration. The integration of three areas – sometimes referred to as 3S, for safety, security and safeguards – is essential to supporting the clean and safe growth of nuclear power, and the infrastructure that supports these three areas should be robust. The focus of this paper will be on the development of the infrastructure necessary to support safeguards, and the integration of safeguards infrastructure with other elements critical to ensuring nuclear energy security.

Building safeguards infrastructure

What is meant by safeguards infrastructure?

The term safeguards infrastructure will be used in this paper to mean the organizational and institutional elements needed for the operation of an effective system of material control and accounting that includes both the national authority and the nuclear facility or facilities within the country. A number of elements are important to the creation of an infrastructure that supports the effective implementation of nuclear material accountancy and control, including: national legislation, a State System of Accounting and Control (SSAC), written procedures, technical competency and instrumentation, and human resources. Effective safeguards infrastructures incorporate guiding principles for detecting and preventing unauthorized use, independence between safeguards staff and operational staff, the use of audits to promote transparency, a commitment to organizational and individual development, and transparent engagement with the global community.

When addressing international safeguards specifically, with the aim of providing assurance on the non-diversion of nuclear material by the state, there are three main elements of safeguards that a state will consider: the requirements on it under its legal obligations (in most cases, a State's comprehensive safeguards agreement, possibly complemented by an Additional Protocol to that agreement), the verification aspects of these agreements, and the opportunities to request (or provide) assistance in implementing its obligations. This notion of infrastructure can be mapped as in the notional diagram in Figure 1.

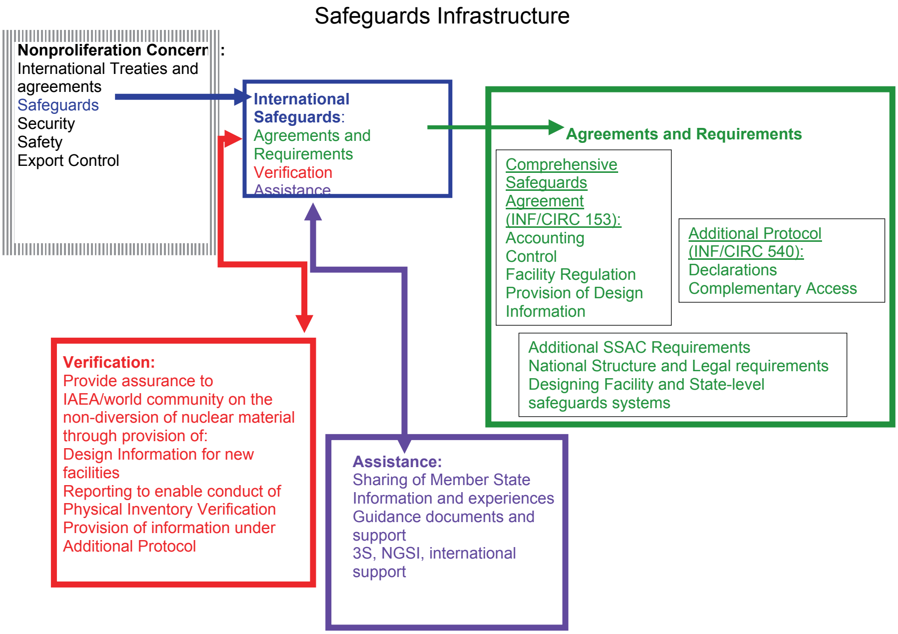

Figure 1. Basic elements of safeguards infrastructure for international safeguards

The International Atomic Energy Agency (IAEA) provides a guide for putting these and other elements in place as a country progresses toward nuclear power in its comprehensive guide, "Milestones in the Development of a National Infrastructure for Nuclear Power.[1]" This guide identifies three major milestones in establishing a new nuclear power program. The first milestone is reached when a country is ready to make a knowledgeable commitment to a nuclear program. At this milestone, the recommended safeguards considerations include having a comprehensive safeguards agreement (or small quantity protocol) and Additional Protocol in force, the state having an established SSAC, and safeguards-specific national legislation. At the second milestone, the point where the country is ready to invite bids for a nuclear power plant, the guide recommends having completed the preliminary provision of design information to the IAEA. By the time the country is ready to commission and operated the new plant – the third milestone – domestic and international safeguards should be applied to all nuclear material, all

[1] This guide is available on-line: http://www-pub.iaea.org/MTCD/publications/PDF/Pub1305_web.pdf

nuclear material and fuel cycle information should have been provided to the IAEA, and the operators and regulators should be fully trained.

Attaining these milestones establishes the fundamental elements of safeguards infrastructure for a country. Additional developments in infrastructure may be needed as additional fuel cycle activities and research are added. These developments may include measurement instrumentation, automated surveillance and data collection systems, facility-specific verification tools, and training for regulators in advanced systems.

Building this level of infrastructure can be daunting to a state that is new to the nuclear arena or has limited resources for infrastructure development. In recent years many countries have begun to reach out to their neighbors to share their experiences and provide support in strengthening safeguards. This type of outreach began several decades ago when the U.S. Department of Energy (DOE), initiated s a scientist-to-scientist engagement program referred to as the ‘sister laboratory’ program. Building on the tenets of that program, the International Safeguards and Engagement Program (INSEP) continues to work with partners to building safeguards infrastructure.

Building safeguards infrastructure and INSEP

INSEP is part of a larger office within the National Nuclear Security Administration (NNSA) dedicated to Nonproliferation and International Security. INSEP’s mission is to collaborate with global partners to strengthen international safeguards at all stages of nuclear development. To do this, the program brings together scientists from DOE national laboratories and experts from partner countries to collaborate on safeguards topics, providing U.S. professionals the unique privilege of being engaged with partners on a wide range of safeguards problems.

With those states that are seeking to begin or expand a nuclear power program, INSEP has engaged in technical areas such as Legal and Regulatory Development, AP Implementation Assistance, Human Resource Development, Reactor Operations, Radiation Protection, Health Physics and Radioactive Waste Management.

In those states that operate nuclear fuel cycle facilities, as well as with two entities that represent a larger network of joint safeguards oversight (EURATOM and ABACC), INSEP pursues technology development efforts aimed to increase the effectiveness and efficiency of the IAEA and the application of international safeguards. This includes advanced non-destructive assay systems, secure and robust surveillance systems, and innovation verification tools for IAEA inspectors.

What unifies the elements of the program are its enduring partnership relationships, a shared emphasis on continuous improvement and commitment to providing assurance of a state’s adherence to non-proliferation norms, elements of a safeguards culture that will be discussed further.

Building safeguards infrastructure and the next generation safeguards initiative

In 2007, DOE launched a new effort to strengthen and revitalize safeguards. The Next Generation Safeguards Initiative (NSGI) is a response to the concerns that, even as the nuclear renaissance is gaining in momentum around the world, safeguards resources both at the state and IAEA level are dwindling. NGSI endeavors to develop the policies, concepts, technologies, expertise, and infrastructure necessary to sustain the international safeguards system as its mission evolves over the next 25 years.

One of the principal objectives of this initiative is to establish and strengthen international safeguards through the development of national infrastructures for nuclear energy and nonproliferation. To reach this objective, NGSI has outlined the following near-term goals:

- Cooperate with states in developing legal frameworks, regulatory structures and operational best practices
- Cooperate with states in developing safeguards technical capacity, including improvement of SSAC authorities and capabilities and implementation of the AP
- Cooperate with states in developing sustainable and effective human resource systems that support the implementation of safeguards
- Work with IAEA and international partners to respond to safeguards technical challenges in foreign facilities

These goals integrate with the other principle objectives to establish a broad base from which to strengthen safeguards worldwide.

Integration of safeguards with broader nuclear objectives

There is an underlying recognition within the NGSI that safeguards are an integral part of a larger concern for non-proliferation, and, as such, do not stand alone. The integration of safeguards, safety and security – the 3S principle – is an elegant formulation of this concept. A 3S-based infrastructure is an effort proposed by Japan aimed at raising the awareness of the importance of 3S and promoting a 3S infrastructure through international cooperation and assistance. This initiative embraces, among other principles, the right of each state to define its national energy policy, the recognition that the peaceful use of nuclear energy accompanied by demonstrated commitment to implement 3S provides a sound basis for international transparency, and that international cooperation can greatly contribute to the development of a safe and secure nuclear energy infrastructure.[2]

[2] These principles are set forth in the G8 summit report, “International Initiative on 3-S based nuclear energy infrastructure” available online at http://www.mofa.go.jp/policy/economy/summit/2008/doc/pdf/0708_04_en.pdf

This integration is also strongly emphasized by the IAEA milestones document, where safeguards infrastructure is one of 19 issues to be considered in developing a nuclear power program. Many of the other issues, such as management, legislative and regulatory frameworks, human resources development and security and physical protection, are critical to the effectiveness of safeguards. In addition, the assumption that the government will study and implement a nuclear power program through the establishment of a cross-cutting organization (referred to as the 'Nuclear Energy Programme Implementing Organization, or NEPIO) also acknowledges the importance of the integration of interrelated interests to ensure a broad base of support for safety, security and safeguards.

Both of these initiatives place safeguards, and the development of safeguards infrastructure, into a larger context (Figure 2), which could be represented graphically like this:

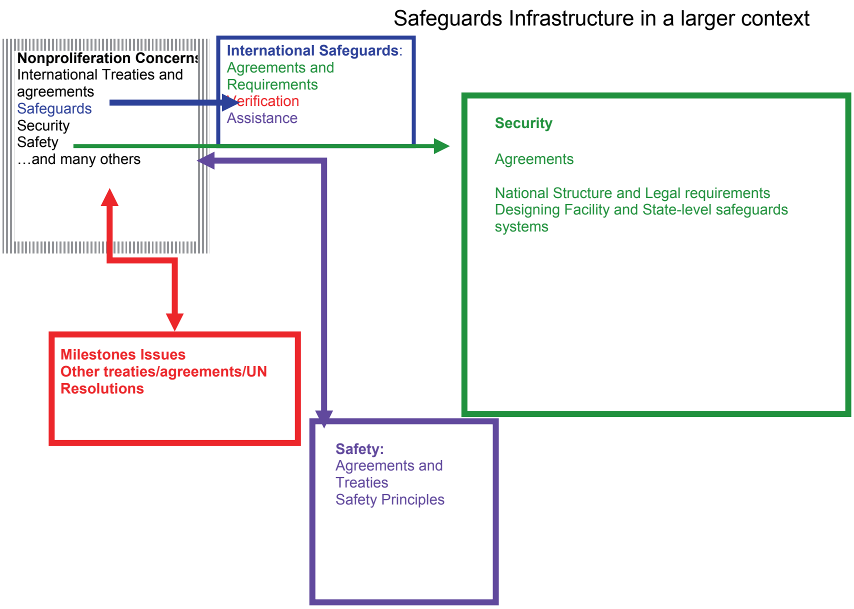

Figure 2. Safeguards infrastructure in a larger context

Conclusion

The objective of this paper has been to provide a working definition of safeguards infrastructure, and to discuss examples of how 'building safeguards infrastructure' is presented in several models. The guidelines outlined in the IAEA Milestones document provide a clear path for establishing both the safeguards and the related infrastructures needed to support the development of nuclear power. The model employed by INSEP, engaging with partner states on safeguards-related topics that are of current interest to the level of nuclear development in that state, provides another way of approaching the concept of building safeguards infrastructure. NGSI is yet another approach that underscores five principal areas for growth, as well as the U.S. commitment to working with partners to promote this growth both at home and abroad.

It is also apparent that an effective safeguards infrastructure also should be integrated with other critical elements of nuclear energy considerations, including safety and security. This integration requires additional high-level commitment to planning, communicating and promoting overall good practice within the nuclear energy domain. This commitment forms a basis for a culture within the nuclear domain that embraces safety, security and safeguards.

Safeguards culture is a concept worth exploring in the context of building safeguards infrastructure. The promotion of safeguards culture has to do less with the implementation of various projects than with the parallel undertaking of promoting the priorities and behaviors that encourage a safeguards mentality. At the most basic level, for safeguards to take root and flourish, a culture that encourages it is necessary.

Culture, as commonly used, denotes a set of shared values, objectives and practices that characterize a particular group. Safeguards culture, then, could be thought of in terms of similar principles such as the shared commitment to nonproliferation and the peaceful use of nuclear energy; a shared belief in the necessity of practices and expectations that provide complete assurance to the national authority, the IAEA and the world community regarding the declaration and use of nuclear material; and practices such as continual evaluation and organizational learning that improve the effectiveness of the overall system.

These principles can be thought of as resting on two pillars of a state's performance: reactive processes and proactive processes. Reactive processes are those steps an institution takes to fulfill its nonproliferation obligations and to ensure compliance with treaties and agreements. Proactive processes are those that an institution takes to improve its system, to anticipate future needs and to adapt as an organization to a changing environment, whether such an adaptation is due to the growth of the nuclear power industry in the state, or in response to new requirements based on additional treaty obligations. Whether reactive or proactive, the same principles that hold a national culture together will help to hold the state's safeguards culture together – commitment, shared values and expectations, continuous improvement and learning, and individual concern for and participation in a collective institution.

REGULATORY CHALLENGES RELATED TO THE LICENSING OF A NEW NUCLEAR POWER PLANT

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Abstract Assuring the safety and security of nuclear power plants is recognized world-wide as a challenge for all stakeholders. Particular attention goes to plants planned to be built in countries with not sufficiently developed industrial and regulatory infrastructure and experience. A construction and commissioning project, which is usually an international undertaking, gives opportunities to all national stakeholders to develop further their organisations and competences.

In the present paper the duties of a regulatory body are recalled as well as the human resources and competences needed for the licensing of a new nuclear power plant. The regulatory body and its technical safety organization(s) should be strengthened and the international cooperation should contribute to this in a systematic and coordinated way. In particular, the donor country should support the necessary development of the regulatory competences and of an effective safety assessment process supporting the national licensing process. Appropriate support can be provided by the International Atomic Energy Agency (IAEA) and through other bi-lateral or multi-lateral programmes.

Introduction

Several countries have recently expressed their interest in building and operating their first nuclear power plant. This constitutes a big challenge for each of these countries. It is essential that the licensee and the Nuclear Regulatory Authority (NRA) can work together in order to warrant a sufficient level of safety, security and non proliferation. An important contribution to this general objective needs to come from international organisations, of which the NSSS supplier, the architect engineer and the bi-lateral and multi-lateral funders of regulatory cooperation projects are main players.

It should be recalled that the principles, regulations and guidelines of the IAEA and related to nuclear power are an excellent basis for the development of a nuclear regulatory framework. The same is valid for radiation protection and security.

S.A. Apikyan and D.J. Diamond (eds.), *Nuclear Power and Energy Security*,

In countries where the duties of the nuclear regulatory body are performed by more than one organisation, it will be necessary to have an appropriate interface between these organisations.

It should also be reminded that regulatory bodies in non-nuclear safety areas, like boiler and pressure vessels, electric power distribution inside facilities, hoisting and lifting equipment, civil construction, fire protection, environmental aspects other than radioactive impact etc. will have to carry out their tasks as well. Waste management is an issue to be tackled early enough and the creation of a national waste management agency is necessary.

Roles and competences of the nuclear regulatory body

These roles are, generally speaking, contribution to the nuclear framework, establishment of rules and guidelines, performing licensing activities, review and assessment of safety justifications, inspection and enforcement, information to the public.

The regulator needs to be competent and independent from external pressures in order to be able to carry out its duties in an objective way, with added value for safety, security and safeguards. This usually results in the definition of additional license conditions to be included in the construction or operating license. Therefore the NRA needs to have sufficient human and financial resources.

It is reasonable to consider that new countries will not have the time, resources and competences to develop a complete system of requirements, except the fundamental ones which need to be incorporated in the requests for tendering and in the national licensing requirements.

It may be useful for the NRA to create or use one or more Technical Safety Organisations (TSOs) which can deliver expert services, especially in review and assessment of the safety cases submitted for siting, construction and operation.

Existing national organisations can contribute to several specialised tasks, which are not routinely performed in NRAs or TSOs, but this is definitely country dependent. Examples are universities, laboratories, research centres, organisations which are specialised in areas like transport, geology, hydrology, surveillance of the country etc. There should be enough resources to receive consultancy from these external experts in specific areas. If appropriate such organisations may be called in from abroad.

National infrastructure

The country is responsible for creating or reinforcing its Governmental and regulatory infrastructure for nuclear and radiation safety. It is important that a clear goal setting is carried out and that the global objective to be reached by the NRA (and its TSOs) after a number of years is well defined. This needs legal development in the first place. Here it is advisable that international experience is used and that, where needed, international experts provide their advice directly to the people having the mandate to develop laws, decrees, regulations and guidelines.

The human and financial resources for the NRA need to be assured and they will develop with time, depending on the work load related to review and assessment and to inspection and enforcement activities. The hiring and training of personnel is an important challenge and the setting up of a hiring process is recommendable, whereby international experience can be used.

The training of new staff and the further competence development of senior staff needs to be organised.

The NRA needs to provide feedback on the use of the financial resources. This can be done in reports to their own board or to the concerned ministry/minister.

Stakeholders

It is important to consider the cooperation between the main stakeholders: the government, national institutions (ministries) involved in environmental issues and waste management/storage, the NRA, the TSO(s), the operating organisation (licensee), the industrial organisations. The latter are important not only for building and testing the nuclear unit, but certainly also for delivering specialised services during operation and shutdown. It is therefore necessary to gradually build an industrial environment inside the country, ready to comply with at least the urgent needs of the utility.

Licensing process: a common undertaking

The licensee and the NRA need to design their interface such that important licensing steps are identified and well prepared in advance, through delivery of safety justifications by the licensee and feedback by the NRA. In the licensing process both parties have their specific responsibilities and need to remain independent. It is important that there is an atmosphere of mutual respect for the roles carried out by the staff of both organisations. The organisation of regular licensing meetings is a useful way to consolidate what has been agreed upon and what still needs to be done.

The implementation of a nuclear project and its licensing

A nuclear project needs 5 years or more to produce a running power plant with sufficient qualified personnel. During this period there are roughly four important phases: siting, design, construction and installation, commissioning and operation.

The involvement of the country of origin is very important. Indeed, the industrial Contractor needs to organise his activities in all these phases and subcontract activities to local and international organisations. This offers important opportunities for local organisations to get involved in production of hardware and software related to the nuclear power plant, learn the applicable technical criteria as well as Quality Assurance (QA) requirements.

The regulatory body can learn a lot from a dedicated and systematic technical support from the regulator from the donor country (preferably) or from a group of experts knowing well the design of the imported plant. Indeed, during a period of 5 years or more, the NRA has to acquire experience and knowledge, train new staff on the job and improve its organisation and operational procedures. Training in the country of origin or training in the country by experts coming from this country of origin is necessary for a number of essential technical and managerial areas.

The NRA should get acquainted with new technologies (safety related software, human and organisational factors, etc.), get competences in all major technical domains and know where to find back-ups for very specialised issues which are not routinely present in an NRA, use of experience feedback and manage its improvement plan using national and international organisations. The use of information technology can present a lot of advantages: on-line meetings, web conferences and e-learning.

In general, training can be organised in at least two ways:

- Training can be done abroad. This gives the advantage that the trainees can observe how other NRAs or TSOs work and that they can understand quickly the organisational and human factors needed by an NRA. It is evident that the technical training is essential. A prolonged stay (1–6 months) can be considered, depending on the subject, the knowledge and experience of the trainee and the available financial means.
- Training should certainly be done in the NRA's country. On the job training is particularly effective. This needs however regular/prolonged presence of the concerned trainers.

Of course, the support from the IAEA, other multi-lateral or bi-lateral support is to be considered. It is however essential that all support be well managed by the NRA, who can/should get support in this management task from the same expert/group of experts on a regular basis.

Conclusions

The author underlines the importance of the development of the nuclear industry as well as of the nuclear regulator of the country which will build and operate a nuclear power plant. This development should be done in an organised way, with sufficient interface between the licensee and the regulator. This aspect should be recognised fully by both licensee and NRA and therefore by the Contractor and his own country. The author is of the opinion that the regulatory authority and the related TSO(s) of the Contractor's country have an important role to play in the guidance of the NRA and its TSOs, so that enough confidence can be given to the review and assessment and to the licensing process implemented in the new nuclear country. Smaller countries operating already nuclear power plants could equally profit of such an approach in case they decide to build an additional unit.

INFRASTRUCTURE DEVELOPMENT THROUGH CIVIL NUCLEAR COOPERATION

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Abstract Due to growing concerns over electricity demand, energy security, and climate change, numerous countries are considering the construction of new nuclear power plants. Most of these will be built in nations with existing nuclear power programs, but an increasing number of States have expressed serious interest in developing new nuclear power programs. These countries will be faced with many challenges in establishing the robust infrastructures necessary for the safe, secure, and safeguarded deployment of nuclear power. Fortunately, there is much a State can gain through cooperation with other States with more developed programs. By sharing information on previous experience and established best practices, an emerging nuclear energy State can benefit from the lessons learned by its partners. Through a broad range of civil nuclear cooperation, the United States is helping new entrants develop the sound infrastructure necessary to deploy nuclear power plants with the highest standards of safety, security, and nonproliferation.

Introduction

Around the world, nuclear energy is enjoying a potential reemergence due to several global trends. First, the world's population is growing, developing, and industrializing at a remarkable pace. Growth is especially visible in developing and transition countries, where an unprecedented appetite for electricity increases by the day. Second, as demand for energy resources grows, many countries are seeking to diversify their sources of electricity to enhance their energy security. Third, the outlook for climate change has reached a critical tipping point, and world opinion has shifted in favor of clean energy technologies, including nuclear power, that produce more of the resource we want – electricity – while generating fewer of the byproducts we don't – particulates, carbon dioxide, and other air pollutants [1]. Most experts now agree that nuclear power – a viable and proven source of baseload electricity – will be an essential component in meeting growing energy demands over the next few decades.

S.A. Apikyan and D.J. Diamond (eds.), *Nuclear Power and Energy Security*,

The majority of the growth in the use of nuclear power will take place in countries with existing programs. In the United States, where 104 reactors currently supply nearly 20% of the nation's electricity, the Nuclear Regulatory Commission has received applications from 17 power companies for 26 new nuclear power reactors [2]. In the Republic of Korea, eight new plants are either under construction or in licensing review, in addition to the 20 currently producing nearly 40% of its electricity [3]. Japan, which derives about 30% of its electricity from 53 power reactors, plans to increase this share to 40% over the next decade [4]. Russia, which currently operates 31 power reactors, has announced ambitious plans to double its nuclear power generation by 2020 [5]. More ambitious still, China, which currently operates 11 power reactors, has projected a sixfold increase in its nuclear energy capacity by 2020, and possibly a further tripling by 2030 [6].

Yet, an ever-growing number of developing and transition States have announced an intention to develop their first nuclear power plant. At the April 2009 International Ministerial Conference on Nuclear Energy in the twenty-first century, IAEA Director General Mohamed ElBaradei reported that over 60 countries have informed his Agency they might be interested in launching nuclear power programs. Of those, at least a dozen are taking concrete steps towards new nuclear energy programs, he stated [7].

Signals of interest are coming from all regions of the globe [8]. In the Middle East, Egypt is seeking an international consultant to help construct its first power plant. Turkey, even further along, has identified a supplier to begin actual plant construction. The United Arab Emirates seems prepared to invest whatever is necessary to develop a world class nuclear power program within the next decade and has invited expressions of interest for the construction of its first plant. Jordan is in active discussions with eight supplier States and has worked with the United States and other partners on infrastructure assessment studies under the umbrella of the Global Nuclear Energy Partnership.

In Southeast Asia, Vietnam recently passed a new nuclear energy law and it hopes to begin constructing its first plant by 2014. Thailand has selected an international engineering firm to conduct a 20-month feasibility study. The Philippines is considering operating its Bataan plant, now mothballed for nearly 2 decades. Indonesia has expressed serious interest in expanding its nuclear infrastructure, which includes three research reactors, to accommodate its first nuclear power plant.

Elsewhere, Nigeria and Ghana have expressed serious interest in developing new nuclear power programs in Africa, and Chile is setting the stage to make a knowledgeable decision about whether to join other countries in Latin America in the pursuit of nuclear power. In Europe, Poland and Estonia are taking steps to develop their countries' first nuclear power plants, while the United Kingdom, Italy, and Sweden have reversed anti-nuclear power policies [9–11].

These are just a few examples of those countries that seem most committed to pursuing nuclear power. Interest in nuclear power is clearly percolating in all corners of the globe.

Causes for concern

This is not the first time we've witnessed great expectations for nuclear power [12]. In 1947, the American journal Business Week predicted that "all central power will be drawn from atomic sources" within a few decades. In 1954, the New York Times ran a headline quoting a U.S. official who prophesied that, thanks to the advent of atomic energy, Americans would one day "enjoy electrical energy in their homes too cheap to meter." While this initial enthusiasm would eventually prove to be wildly optimistic, nuclear energy did enjoy a period of rapid growth in the decades following the operation of America's first full-scale plant in 1957.

By the mid-1970s there were 55 nuclear plants operating in the U.S., with orders placed for up to 200 more. The majority of these plants were never built, however. Key reasons behind this were the decline in U.S. electricity demand and increased energy efficiency in the wake of the global oil embargo, and, to a lesser extent, increasing costs of reactor construction. It is not often recognized that between 1974 and 1978 more coal fired power plants (84) than nuclear power plants (80) were cancelled because of reduced capacity requirements [13].

The growth of nuclear power in the United States suffered a more sudden setback in 1979 with the world's first major nuclear accident at Three Mile Island. Although most plants under construction at the time of the accident were eventually completed, they were delayed significantly as regulators mandated and constructors and operators sought to install and operate new safety systems, many of which had to be retrofitted into plants in various stages of construction. This accident significantly knocked the wind out of nuclear power in the United States for nearly 3 decades.

Seven years later, the global use of nuclear power suffered a second blow when Unit 4 at Chernobyl exploded, as a combined result of design flaw and human error. At the time of this accident, nuclear power had grown to produce just over 15% of the world's electricity. This figure has been largely unchanged since, one indication of the negative impact this incident had on nuclear power [14].

These two examples demonstrate the devastating blow another major nuclear accident could deal to nuclear power worldwide. Many lessons have been learned as a result of these incidents, and tomorrow's Generation III and III+ reactor designs have significant safety improvements over today's Generation II. Furthermore, operators have learned that for nuclear power, safety and economics go hand in hand: A safe plant is an operating plant, and an operating plant makes money.

However, the possibility of an accident still exists. Therefore, as nuclear power gears up for a new generation of expansion, all eyes will be on the ability to safely operate these new plants, particularly those in States developing new nuclear power programs.

On September 11, 2001, the United States suffered the worst terrorist attack in its history. Although the phenomenon of global terrorism was not new, these attacks unmistakably demonstrated the degree of the threat we now face from those seeking to cause chaos and take human life.

In the ensuing years, many steps have been taken to heighten security at nuclear power plants, to secure fissile materials around the world, and to prevent the trafficking of materials which could be used for a radiological dispersion device – a dirty bomb – or worse, a nuclear weapon. Although once a rather remote prospect, the threat of "nuclear terrorism" now seems quite real. As a result, the importance of nuclear security, especially in States now just turning to nuclear power, has never been so great.

The proliferation risks associated with the nuclear fuel cycle must also be managed. Recent events in the DPRK and Iran have clearly illustrated the potential proliferation risks associated with the sensitive parts of the nuclear fuel cycle. By itself, a nuclear reactor used to produce electricity is of minimal risk. However, it does produce plutonium, which can be extracted through reprocessing if a country possesses such a facility. In addition to producing reactor-grade fuel, a uranium enrichment plant can be used to produce weapons-usable material. A relatively simple reconfiguration of an enrichment cascade could enable the production of high enriched uranium. The intrinsic and inescapable dual-use nature of certain nuclear fuel cycle technologies underscores the importance of strict nonproliferation controls over this technology. Because of this risk, it is important to limit the spread of these technologies, and existing and future facilities must be operated in an open and transparent manner and under appropriate international safeguards to ensure their peaceful applications.

Tangible commitments to nuclear standards

Due to the unique safety, security, and proliferation risks associated with nuclear technologies, the expansion of nuclear power must take place in the most responsible manner possible. This view is widely shared throughout the international community. During the past 3 years, the IAEA General Conference confirmed that the use of nuclear power must be accompanied by commitments to and ongoing implementation of effective levels of safety, security and safeguards [15–17]. In addition, the Leaders Declaration at the 2008 G-8 Hokkaido Toyako Summit clearly endorsed the importance of nuclear safety, security, and safeguards – the "3Ss" [18].

A broad range of treaties and conventions exists through which a State can make clear its commitment to the safe and secure development of nuclear power under the highest standards of nuclear nonproliferation. In order to instill confidence in developing nuclear power programs, the United States strongly encourages States to take the tangible step of adopting and adhering to these instruments. For example:

- The *Treaty on the Non-Proliferation of Nuclear Weapons* (NPT) [19] remains the cornerstone of the nonproliferation regime. Universal adherence to this treaty remains a fundamental objective of the United States. The successful conclusion of the recent Preparatory Committee meeting in New York bodes well for a successful Review Conference in 2010.

- States Party to the NPT are required to conclude IAEA *comprehensive safeguards agreements* [20], covering all source and special fissionable material in all peaceful nuclear activities within their borders. This is a vitally important step that some countries still need to take. The conclusion and implementation of an *Additional Protocol* [21] to a country's comprehensive safeguards agreement allows the IAEA to draw conclusions about the absence of undeclared nuclear material and activities in the State as a whole. Almost all States party to the NPT with nuclear power programs have Additional Protocols in force.
- The *Convention on Nuclear Safety* (CNS) [22] encourages members to establish, and adhere to, a set of internationally recognized nuclear safety benchmarks covering nuclear installation siting, design, construction, and operation, as well as availability of human and financial resources, safety and quality assurance verification, and emergency preparedness. The CNS provides a peer review process that allows States Parties to have access to "best practices" in nuclear safety. In addition, IAEA Safety Standards provide reliable guidance on how a State might implement its safety obligations. Among States currently either operating or constructing a nuclear power plant, only Iran is not a party to the CNS.
- The *Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management* [23] is designed to improve worldwide radioactive waste safety through international peer review of national programs and sharing of experience. The Joint Convention establishes a series of broad commitments for the safe management of spent nuclear fuel and radioactive waste without prescribing specific or mandatory standards on Contracting Parties. Like the CNS, the Joint Convention provides for a peer review process that allows States Parties to have access to "best practices" in spent fuel and radioactive waste management. Through its provisions, the Joint Convention complements other international conventions and serves to enhance and harmonize international cooperation in this important area.
- The *Convention on the Physical Protection of Nuclear Material* (CPPNM) [24] is the only international legally-binding treaty in the area of physical protection of nuclear material. It establishes measures related to the prevention, detection, and punishment of offenses related to nuclear material. Concerns about illicit nuclear trafficking of materials prompted the development of the 2005 Amendment of the CPPNM to cover nuclear material used for peaceful purposes in domestic as well as international use, storage and transport and to protect both nuclear materials and nuclear facilities used for peaceful purposes from sabotage. The CPPNM Amendment, once it enters into force, will clearly and methodically lay out the essential features of a basic national nuclear security infrastructure, based upon the experiences and best practices of the numerous parties involved with its establishment. It will also provide a basis for the criminalization of

certain additional offenses related to nuclear-materials or facilities, including an obligation to detain, extradite, or prosecute.

- Additional guidance for implementing effective measures of physical protection can be found in an IAEA document best known as *INFCIRC/225* [25]. This document is now being updated by international experts to reflect the requirements of the Amendment to the CPPNM and the lessons learned about the terrorist threat.
- The *Convention on Supplementary Compensation for Nuclear Damage* (CSC) [26] provides the framework for a global liability regime for protection of both the public and industry, that respects differences in national laws and procedures while providing compensation to the victims of a nuclear accident and protection to industry against excessive exposure to liability for damages. It will promote a new level of cooperation based on shared risk that will allow countries newly developing a nuclear power program to have access to the best available technologies to support that program. The Vienna and Paris Conventions on liability for nuclear damage have been important tools in this regard, but because of their provisions they are of only limited applicability as the basis for a global regime.

Adherence to these instruments yields several important benefits. First, it helps a State develop the infrastructure needed to deploy civilian nuclear power safely and securely. Second, it provides a clear signal to the international community that a State is prepared to handle this complex technology. What's more, it raises a State's profile among the many that will be competing for nuclear suppliers. It is becoming increasingly apparent that the global supply chain may soon struggle to keep up with the expansion of global demand. The more a nation demonstrates a commitment to the responsible pursuit of nuclear power, the more investors it will attract to its nuclear program.

The importance of sound infrastructure

Having made the commitment to these various instruments that address the issues of safety, security, and nonproliferation, a State must develop the requisite infrastructure to meets its obligations and to execute its nuclear program. This includes the development of laws, regulations, human resources, and funding and financing mechanisms. It also includes the ability to construct and safely operate a nuclear power plant and to responsibly handle nuclear and radioactive materials. The safe and secure development of nuclear energy, and the beneficial uses of nuclear materials, cannot proceed if any of these components is lacking. The United States is deeply committed to helping identify and address the civilian nuclear infrastructure needs of countries considering new nuclear energy programs. It was one of the moving forces behind IAEA General Conference resolutions in 2006, 2007, and 2008 supporting the Agency's role in nuclear power development [15–17].

The United States was also a major technical and financial contributor to IAEA workshops in December 2006, November 2007, and December 2008 addressing the introduction of nuclear power in emerging nuclear energy States. Through the course of these workshops, the IAEA released a series of documents to help country planners understand the numerous critical elements of nuclear power infrastructure. The first of these, *Considerations to Launch a Nuclear Power Program* [27], provides guidance for high-level government officials on the breadth of issues that countries new to nuclear power will face.

These issues were described in greater detail in *Milestones in the Development of a National Infrastructure for Nuclear Power* [28]. This very useful guidance document lists 19 different infrastructure areas that a State should consider in the pursuit of nuclear power. It established the level of capability a State should develop and the issues it should address in each area at three different milestones – readiness to make an informed decision to pursue nuclear power, readiness to issue a bid for a nuclear power plant, and readiness to begin operation of a nuclear power plant. A companion document *Evaluation of the Status of National Nuclear Infrastructure Development* [29] was recently released that offers guidance on assessing a State's progress towards these three milestones in each of the 19 infrastructure issues. The key word in all areas is "commitment" – the commitment to develop a nuclear program the "right" way, applying best practices and learning from others' mistakes.

These infrastructure elements are not isolated. They are clearly interlinked, and choices made in one *area* will affect the range of options available in another. For this reason, a carefully designed strategy should be developed in the early stages to ensure that resources are allocated carefully in a manner that address all issues over time without gaps and without significant duplication of effort.

Fortunately, in order to reap the benefits of nuclear power, a State need not tackle the entire process of designing a reactor, manufacturing the components, constructing the reactor, providing the fuel, and disposing of the waste. The most important capabilities that a country needs are careful planning and the ability to regulate, though it should be noted that one country has even "contracted out" the bulk of its regulatory effort. The remainder of the necessary steps of building and operating a nuclear plant and procuring nuclear fuel, can be contracted through international vendors and service providers. However, regardless of how a State conducts its nuclear program, it is ultimately that State's responsibility to plan carefully to meet its energy needs and to ensure the safety of its citizens.

The case for cooperation

The guidance provided in the Milestones document [28] explains, in general, what a country must do to develop a sound nuclear power infrastructure. However it was not designed to describe in detail how these steps should be taken. This is partly because the details will necessarily depend case-by-case on a State's starting conditions and national strategy. In addition, developing this road map is a sovereign responsibility and each State should take ownership in its development.

There is much a State can gain, however, through cooperation with other States with more advanced programs. By sharing information on previous experience and established best practices, an emerging nuclear energy State can benefit from the lessons learned by its partners. Only four nuclear power programs in the world developed without significant partnerships with other countries – those of the United States, Canada, the United Kingdom, and Russia. All the rest developed through cooperation with States already further down the road. And of those four, only Russia and Canada remain generally independent of outside participation in their programs.

Multilateral organizations can offer comprehensive and impartial assistance. They can be a focal point for helping a State identify its needs and they can be a bridge between the State and a donor State that may want to help meet those needs. The IAEA's growing infrastructure development program, within both its Department of Nuclear Energy and its Department of Technical Cooperation, are cases in point.

However, multinational organizations have their own shortcomings. They are often limited by scarce resources and bureaucratic rigidity. And the need for impartiality can translate into a paralysis of caution. Therefore, a key supplement to multilateral cooperation is bilateral engagement. By working one-on-one, advanced States can provide guidance to beneficiaries, often under more flexible, dynamic, and expeditious terms. In addition, there are certain areas of infrastructure development, such as the development of an independent regulatory body, more amenable to bilateral cooperation. For example, through bilateral fellowships and trainee programs, personnel in a developing State can gain this hands-on experience in fully functional nuclear facilities in a more advanced State.

U.S. civil nuclear cooperation

The United States was a pioneer of civil nuclear cooperation. In a dramatic speech [30] made at the United Nations on December 8, 1953, President Eisenhower noted "the United States knows that peaceful power from atomic energy is no dream of the future." He called for a mobilization of experts "to apply atomic energy to the needs of agriculture, medicine, and other peaceful activities." "A special purpose," he noted, "would be to provide abundant electrical energy in the power-starved areas of the world." In the years following this landmark "Atoms for Peace" speech, the United States laid the foundation for civil nuclear cooperation between the United States and many other countries. By 1960, we had concluded nuclear cooperation agreements with 44 States [31].

The United States continues to support the responsible development of nuclear power. In his first major nonproliferation policy speech delivered April 5, 2009 in Prague, President Obama stated "[w]e should build a new framework for civil nuclear cooperation, including an international fuel bank, so that countries can access peaceful power without increasing the risks of proliferation. That must be the right of every nation that renounces nuclear weapons, especially developing countries embarking on peaceful programs. And no approach will succeed if it's based on the denial of rights to nations that play by the rules. We must harness the power of nuclear energy on behalf of our efforts to combat climate change, and to advance peace and opportunity for all people" [32].

Moreover, at the April 2009 International Ministerial Conference on Nuclear Energy in the twenty-first century, in remarks delivered on behalf of U.S. Secretary of Energy Chu, U.S. Ambassador Greg Schulte stated that "[i]f deployed with the highest possible standards of safety, security, and nonproliferation, nuclear energy will play an essential role in combating climate change while advancing peace and promoting sustainable development worldwide. The United States is firmly committed to playing its part to usher in the responsible expansion of nuclear energy" [33].

The United States currently has formal agreements that provide a framework of cooperation with 48 States [34], plus Taiwan and the IAEA. In addition, several agencies of the United States Government can offer, subject to the availability of resources and commensurate with need, a broad range of expertise and a number of important functions to help States develop the necessary infrastructure for a civil nuclear power program.

The *Department of State* is the lead U.S. Government Agency for the negotiation of civil nuclear cooperation agreements. In addition, it is the largest contributor to the IAEA Technical Cooperation Fund. Specific types of assistance this agency can provide include the following:

- Funding IAEA Footnote A projects
- Sponsoring IAEA Fellowships and Traineeships
- Coordinating nuclear cooperation policies and
- Negotiating agreements for cooperation

The *Nuclear Regulatory Commission* (NRC) regulates the civilian use of nuclear materials for commercial, industrial, academic, and medical uses in order to protect public health and safety and the environment, and to promote the common defense and security. NRC was established as an independent agency within the U.S. government by Congress in 1974. Specific types of assistance and cooperation NRC can support include:

- Legal advice, support and information exchange on nuclear-related national legislation, rules and regulations
- Technical advice, support and information exchange on nuclear safety and security
- Technical advice, support and information exchange on nuclear reactor and facility licensing, design certification, operations, maintenance and decommissioning
- Technical advice, support and information exchange on safety and security issues associated with radioactive waste

- Technical advice and assistance on organizational issues in the new regulatory body and in obtaining and retaining skilled personnel trained in regulatory best practices
- Cooperative nuclear safety and security research and
- Technical training

The *Department of Energy* (DOE) can provide technical expertise through direct bilateral assistance and also through the international working groups, on infrastructure development and reliable nuclear fuel services, of the Global Nuclear Energy Partnership (GNEP). Specific types of cooperation include the following:

- Radioactive waste and spent fuel management
- Decontamination and decommissioning
- Site characterization
- Research and development on small-medium sized reactors
- Safety evaluations and
- Energy planning

The *National Nuclear Security Administration* (NNSA) is a semi-autonomous agency within DOE. The International Nuclear Safeguards and Engagement Program (INSEP), operated by NNSA, provide expertise on the peaceful uses of nuclear science and technology and nuclear infrastructure development. INSEP collaborates with foreign partners on topics such as:

- Legal and regulatory issues related to international safeguards
- State System of Accounting and Control and IAEA Additional Protocol implementation
- Safeguards training and equipment
- Intermediate- and low-level waste management
- Environmental monitoring
- Emergency management
- Research reactor operations
- Health physics, radiation protection and dosimetry and
- Human resource development

Through affiliated programs, NNSA also offers infrastructure development assistance in other areas related to safeguards, security and nonproliferation, including physical protection of nuclear material and facilities and export control and border security.

Finally, the *Export-Import Bank of the United States* (Ex-Im Bank) is the official export credit agency of the United States, whose mission is to assist in financing the export of a broad range of U.S. goods and services (including equipment for large infrastructure projects, such as nuclear power plants) to international markets. It supports U.S. exports and jobs by providing political risk insurance, direct loans, and loan guarantees in cases where there is official government-sponsored foreign competition or where private financing is unavailable. For nuclear power projects, loan guarantees covering all commercial and political risks are the primary support vehicle.

Currently, these agencies have in place technical cooperative arrangements with over 40 countries. Through these avenues of cooperation, U.S. experts are working closely with their counterparts from emerging nuclear energy States on nuclear power infrastructure, particularly in developing and maintaining effective nuclear safety and security regulatory frameworks and new reactor-related initiatives.

A case in point – the Republic of Korea

One of the best examples of a developing country pursuing a nuclear power program to a very advanced state with the support of nuclear cooperation is the Republic of Korea. Korea's current capability to construct power reactors is the result of a focused and persistent program spanning more than 5 decades [3, 35, 36]. Along the way, the United States was a key contributor to this program, with France and Canada also having important roles.

In 1956, the first U.S.–Korean agreement for cooperation entered into force. Although limited in scope, this agreement paved the way for the construction of the first reactor on the Korean peninsula 3 years later, the TRIGA Mark II in Seoul, which operated for over 30 years. The technical expertise accumulated through the construction and operation of this and its sister reactor, the TRIGA Mark III, provided the foundation for Korea's nuclear infrastructure. Between 1954 and 1969, the ROK sent over 300 people abroad for training assignments, most to the United States, with about two thirds of them returning.

In 1972, the United States and the Republic of Korea concluded a new, broader agreement for cooperation, which foresaw engagement across a broad range of areas, in particular the construction and fueling of nuclear power reactors. Korea's first power reactor was a U.S. turn-key plant, and Hyundai Heavy Industry supported Westinghouse in the construction of six of the next seven reactors. Again, Korea turned to nuclear cooperation for human resource development, with nearly 200 members of the Kori-1 staff receiving overseas training. However, in the mid-1980s, Korea signed a deal with the U.S. company Combustion Engineering for technology localization and start its ninth PWR, Korean companies took the lead in construction. As Korea's industrial base has grown, it has developed Korean versions of all major components that it once imported. In so doing, Korea has developed the Korean Standard Nuclear Plant, the OPR-1000, the APR-1000, and has now begun construction of the APR-1400, which it is marketing overseas. What's more, Doosan Heavy Industries and Construction Company has provided the reactor vessel to CANDU units constructed in China and will have a significant role in the construction of Westinghouse AP-1000 reactors in China and the United States.

As a result of hard work and determination, the Republic of Korea is quickly becoming a competitor in the international market for the supply of a complete nuclear power plant. The United States is proud of the role it has played in helping one of the world's most dynamic nuclear power programs forge ahead. This is without a doubt a testament to the mutual benefits associated with civil nuclear cooperation.

Conclusion

The world is developing at an astonishing pace, and the demand for clean and reliable sources of electricity has never been so great. Because it is a proven source of baseload electricity with negligible air pollution and carbon emissions, nuclear energy will be an important component in meeting the energy challenges of today and tomorrow. The expansion of nuclear power to States that don't currently have it is underway, and a number of States are on the path towards new nuclear power programs.

The safe, secure, and safeguarded operation of a civil nuclear power program is an immense undertaking that must be supported by a robust infrastructure with many diverse components. About 1 or 2 decades will be required to stand up such an infrastructure. Fortunately, guidance is available from numerous multilateral and bilateral channels to help States benefit from past experience acquired by others in the international community.

Bilateral civil nuclear cooperation is a valuable undertaking, especially for newly emerging nuclear energy States. The United States has a diverse range of experience to offer new entrants to nuclear power. Through the sharing of experience, lessons learned, and best-practices, the United States is committed to helping aspiring States with good nonproliferation credentials build their own capacity to pursue nuclear energy for peaceful purposes with the highest standards of safety, security, and nonproliferation.

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NUCLEAR SAFETY INFRASTRUCTURE

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Overview

Energy Security is an important issue facing many countries – and more and more countries have started looking towards Nuclear Power as one way to improve their energy security. Recent information from the International Atomic Energy Agency indicates that over 50 countries have now expressed interest in developing nuclear power programs.

In order for Nuclear Power to be able to continue to be a viable energy source, Nuclear Safety must be maintained at the highest levels. Since many of the countries looking towards nuclear power do not currently have a nuclear power program there is a great deal of interest regarding nuclear safety and establishing a strong nuclear safety infrastructure.

Nuclear safety is a very broad topic, and as described in the International Nuclear Safety Advisory Group booklet, INSAG-12, "Basic Safety Principles for Nuclear Power Plants", the objective of Nuclear Safety is:

> *To protect individuals, society and the environment by establishing and maintaining in nuclear power plants an effective defense against radiological hazard.*

The International Nuclear Safety Advisory Group has prepared a booklet focused on describing the nuclear safety infrastructure needs to make sure the fundamental safety principles are adequately implemented, INSAG-22, "Nuclear Safety Infrastructure for a National Nuclear Power Programme Supported by the IAEA Fundamental Safety Principles". In this booklet they define the Nuclear Safety Infrastructure as follows:

The set of institutional, organizational and technical elements and conditions established in a Member State to provide a sound foundation for ensuring a sustainable high level of nuclear safety.

Now that we have a common understanding of what is meant by Nuclear Safety Infrastructure, I will briefly discuss some of the key activities that need to be conducted to ensure an adequate nuclear safety infrastructure is in place during the five stages of the development of a nuclear power program:

- Thinking About Nuclear Power – Information and Data Gathering
- Decision to Proceed – Establish the Basic Nuclear Safety Infrastructure
- Implementation of the First Nuclear Power Plant – Key Nuclear Safety Activities

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- Operation of the Nuclear Power Plant
- Shutdown and Decommissioning – the final phase

Thinking about nuclear – information and data gathering

This is really the first step and this is where many countries are right now. They recognize the need for an economical and reliable source of energy to support the growing economy within their country and are considering nuclear power as a source for that energy. Even at this very early stage Nuclear Safety plays a key role in this process. In order to make a knowledgeable decision it is necessary to have a good understanding of the full scope of activities and resources necessary to support the construction and safe operation of a nuclear power plant including the radioactive waste and spent fuel management issues. In conducting this assessment, the government needs to be fully aware and willing to support the development of the basic nuclear legislation including various International Agreements and Conventions associated with the peaceful use of nuclear energy and nuclear liability. Another very important element to be considered at this early stage is how to develop or obtain the necessary human resources required to support the safe use of nuclear power over the entire lifetime of the project, including the long term storage or disposal of the spent fuel. Engineers from all disciplines, radiation protection specialists, health physicists, radioactive waste management experts, maintenance technicians, training specialists, and many other highly trained employees are required to safely operate and maintain a nuclear power plant.

This stage will typically take about 1–3 years to review information and conduct various studies including economic assessments, possible sites, reactor types and technology, and plans for developing human resources.

Decision to proceed – establish the basic infrastructure

Once a decision has been made to proceed with a nuclear power program a concentrated effort must be made to develop the necessary nuclear safety infrastructure.

Key activities include:

- Nuclear Legislation must be enacted
- Establishing the independent Regulatory Organization and Licensing structure
- Establishing the Operating Organization and structure – private or government

Government activities

The Nuclear Legislation should identify the various activities and facilities that will require a license and it should establish the licensing process and identify the regulatory authority. It should also appoint to this regulatory body the responsibility and authority to develop and promulgate detailed safety regulations, and for conducting safety evaluations and oversight of the identified facilities and activities. The Nuclear Legislation should also clarify that the primary responsibility for complying with the laws and regulations lies with the operating organization (the owner) of the licensed facility.

The government will also need to endorse or adopt various International Agreements and Conventions associated with the peaceful use of nuclear energy and nuclear liability if this action has not already been done.

Another very important item that the government should consider at this stage is how the regulatory body will be funded, directly by the government or by fees collected from the licensee. In addition, the process for decommissioning and waste disposal, including spent fuel, along with the means for funding these activities should be addressed at the government level during this stage.

The regulator

The Regulator has many key activities during this phase of the process including:

- To propose and promulgate safety regulations and guides that properly cover all foreseen nuclear activities in the country
    - Siting a nuclear power plant or waste disposal facility
    - Construction and operation of a nuclear power plant
    - Decommissioning of a nuclear power plant
    - Waste disposal and spent fuel storage
    - Control of radioactive sources
- To verify compliance with applicable legislation and regulations and to assess the safety of installations and activities through analysis, evaluations and inspections
- To enforce the application of such regulations in case of unanticipated departures or deviations

In order to ensure that the Regulator is effective, it must have adequate authority, sufficient financial resources and competent staff, and be independent of the operating organization and any government entity supporting the operating organization. Procedures and processes need to be in place to ensure that safety issues are addressed in a timely fashion with a priority based on risk. It is also important that the licensing and regulatory oversight processes be as open to stakeholder review as possible.

While it is recognized that it may not be possible to have all the expertise for every condition within the Regulator, it is essential that there are sufficient capabilities to adequately assess any advice or consultations received and to make competent and objective safety decisions.

Operating organization

The Operating Organization will have the responsibility for all the various activities associated with the siting and selection of the nuclear power plant.

With respect to selecting a site, detailed studies and characterization of the site will be necessary and most likely some kind of environmental assessment will be required to support the site selection.

The selection of the nuclear power plant will also require a significant effort; review of available reactor types and designs, preparation of tenders for the reactor design and construction, and preparation of the appropriate documentation to obtain a construction license or permit from the regulator. In the preparation of these tenders it is very important to make sure that all of the various regulatory requirements will be met and to clearly articulate the roles and responsibilities of the various organizations. This is especially important for all activities relating to safety and quality. It is also recommended that the tenders include specifications regarding technology transfer and training requirements.

While the operating organization will most likely hire consultants and outside experts to assist with most of this work, it is still necessary that the operating organization has the necessary competence and capabilities to oversee and accept the work and submit the appropriate information and applications to the regulator.

This stage can take 4–8 years (or more) and is heavily dependent on the availability of adequate resources, especially human resources. As discussed above both the regulator and the operating organization have a lot of work to do and they will both require staff with expertise over a broad range of topics in order to conduct or oversee all of these activities.

Implementation of the first nuclear power plant – key nuclear safety activities

Implementation of a nuclear power program includes the final site preparation, final design of the power plant and the actual construction of the plant. All of these activities are the responsibility of the operating organization; however most of the work will be performed by various contractors and vendors, and overseen by the regulatory authority. Even though the work may be performed by contractors, it is still the responsibility of the operating organization to ensure that all of the work is done properly and in accordance with all applicable regulatory requirements. This will require constant oversight and monitoring including many quality checks and reviews.

During construction, quality assurance (QA) in the design and in the manufacture, testing and assembly of systems, structures and components is a basic responsibility of the operating organization. This responsibility cannot be transferred, and a turnkey type of contract signed with the plant vendor does not diminish the operating organization's responsibility for QA during plant construction. Because fulfillment of the QA obligations is critically important, it is essential that a management structure for QA in the operating organization be independent from the management structure responsible for plant construction. The QA organization should have full authority to reject any design, part, component, system or structure that does not meet the standards or requirements for the project.

The regulatory body has the responsibility for verifying that the operating organization's QA program satisfies the established license conditions and that any departure or discrepancy is fully justified or corrected. It is recommended that the regulator review international construction experience to aid them in their oversight of plant construction.

Another key task for the operating organization is hiring and training the staff for operating and maintaining the plant. In particular those staff that are essential for the safe operation of the facility, including key management positions, will need extensive training and qualifications and will normally require some license or certification from the regulator. In addition, the plant engineering and most management positions along with the regulatory staff responsible for overseeing plant operation and maintenance will also need training regarding plant design and operation during this stage.

Also during this time the operating organization will need to finalize their radiation protection program and emergency preparedness plan. Both of these will typically need to be approved by regulatory authorities and local government officials, and must be in place before the fuel arrives on site.

While most of the activities during this stage are the responsibility of the operating organization, the regulator will also be quite busy during this stage. As mentioned previously, the regulator is typically involved in periodic independent inspections, tests and reviews during the construction period. The regulator should also consider exchanging information with regulators in countries that have already licensed a similarly designed plant. It is also important for the regulator to become familiar with the plant and its operation as it prepares for the transition into oversight of the operation of the plant.

Operation of the plant

The initial phase of plant operation is generally considered as the commissioning phase where the plant is fully transferred from the vender to the operating organization. This is a relatively short, 1–2 years, but very intense period of time where the plant goes through a series of tests and special operations to verify that everything is working as expected. These tests and activities also allow the operating staff to become more familiar with the plants operation.

All of the activities during the commissioning phase are subject to monitoring and review by the regulator. Typically the operating organization will identify the specific tests and activities to be performed along with the expected results in the license application which will need to be approved by the regulator. The commissioning phase also provides an opportunity for the regulator to transition from their construction and design review activities to their operational oversight and monitoring activities.

Based on recent experience and current design trends, the actual operational phase will most likely last 60 years or more. During operation it is vital that all of the safety infrastructure developed during the previous phases are continued and strengthened to support a robust nuclear safety culture.

Since the expected operating life of the plant can include several generations of workers, knowledge management is essential to ensure continued safe operation; it is important to incorporate the plant knowledge and experience into the plant training programs to effectively pass on this information to new workers.

Maintaining safety throughout the operational life of the plant requires a regular assessment of its safety performance and incorporating any lessens learned into future operations. Since it is reasonable to expect that the plant will undergo some changes or modifications during its operating life, it is also necessary to have an active configuration management program in place to ensure that plant modifications maintain or improve the original design intent, do not introduce any new safety risks, and that they are appropriately incorporated into plant procedures, drawings and training programs. Depending on the type or degree of the modification, there may also be a need to update the plant Safety Analysis Report and/or obtain regulatory approval for the change.

Waste management

Plant operation also means the generation of radioactive waste. Routine operations will result in the release of small quantities gaseous and liquid radioactive waste, primarily short lived radio-nuclides, into the environs. These releases need to be monitored through an effluent control and monitoring program to ensure that the releases are within the limits prescribed by the operating license. The regulatory body should closely monitor this program and make sure that the monitored release information is made available to interested stakeholders.

Small amounts of low and intermediate level waste from routine operation and maintenance activities and high level waste or spent fuel will also be produced. Typically the low and intermediate level waste is temporarily stored on site before it is transferred to a waste disposal site. This means that the waste disposal facility will need to be operational very shortly after the plant begins operation.

The spent fuel will typically be stored on site in the spent fuel storage pool for several years. The management of the spent fuel can include reprocessing and reuse, intermediate storage on-site (typically dry cask storage), and ultimately long term disposal in a geologically safe repository.

All of the activities associated with waste management fall under the jurisdiction of the regulator and need to be addressed in the appropriate license. In addition all of these activities are subject to routine monitoring or assessments from the regulator.

Shutdown and decommissioning – the final phase

As discussed earlier in Phase 2, there should be an understanding regarding how the plant decommissioning activities will be funded. One of the first activities will be the preparation of a decommissioning plan. This plan will typically be prepared during the final years of plant operation. The decommissioning plan is normally approved by the regulator and it will specify the safety requirements, primarily radiological protection, during the decommissioning activities. Typically there will be a special license or permit issued for the decommissioning activities to ensure appropriate safety measures are maintained.

After the plant is shutdown all the normal licensing requirements usually remain in effect until the fuel is removed from the reactor and the spent fuel storage pool. This will ensure adequate cooling for the fuel and maintain controls to prevent accidental criticality.

After the fuel is removed and the decommissioning activities are completed, there will remain the long term monitoring of the spent fuel until it is all disposed of in the long term geologically safe repository which will most likely have its own monitoring requirements.

Conclusions

The introduction of nuclear power in any country requires the early establishment of a long term nuclear safety infrastructure. This is necessary to ensure that the siting, design, construction, commissioning, operation and dismantling of the nuclear power plant and any other related installations, as well as the long term management of radioactive waste and spent fuel, are conducted in a safe and secure manner.

The decision to undertake a nuclear power program is a major commitment requiring strict attention to nuclear safety. This commitment is a responsibility to not only the citizens of the country developing such a program, but also a responsibility to the international community. Nobody can take on this responsibility or make the critical decisions except the host country. It is important to make sure that the decision making process and the development activities are done in as open a manner as possible allowing interested stakeholders the opportunity to review and comment on the actions and plans.

It cannot be overemphasized that everyone involved in a program to develop nuclear power carries a responsibility for ensuring safety.

While it is clear that the key decisions and activities are the responsibility of the host country, it is also very important to recognize that help is available. The IAEA, OECD-NEA, WANO and other international organizations along with countries with established nuclear power programs are available to provide information and assistance. In particular, the IAEA and OECD-NEA have published several documents regarding the development of a nuclear power program and they have been and continue to support many meetings and seminars regarding the development of nuclear power programs.

Last and certainly not least I want to stress the importance of the human resource in developing a strong nuclear safety infrastructure. It ultimately comes down to the people, the human resources, with appropriate education, training and background that are essential in establishing and following the various processes and procedures associated with a strong nuclear safety culture. So it is necessary for a country interested in nuclear power to start developing human resources very early on in the process.

UPGRADING NUCLEAR REGULATORY INFRASTRUCTURE IN ARMENIA

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Abstract Armenia is contemplating an upgrade to its national power generation capacity to meet replacement and future energy needs. Unit 2 of ANPP is scheduled for shutdown after replacement power generation capacities are in place. A recent alternative energy study indicates viability of the nuclear option to replace this capacity. Some technology-specific proposals are being considered by the Ministry of Energy of Armenia. It is likely that the reactor technology decision will be made in the not too distant future. The existing reactor continues to be operated in the regulatory framework developed in the Soviet Union and adopted in Armenia. Given the interest in the new reactor, Armenia launched a project to review the existing system of regulation and to bring it into harmony with modern practice in preparation for the new reactor project development. The new regulatory framework will be needed as a basis for any potential tendering process. The US NRC and ANRA have agreed to perform a review and update nuclear legislation and the system of regulation in this area. The first step in this process was to develop an action plan for such program. The action plan describes the overall strategy of ANRA to modify existing or develop new processes and requirements, identifies the major Laws that need to be reviewed given practical legal considerations to construct and operate the reactor and Armenia's international obligations under various conventions. This work included review of existing models of regulation in different countries with "small" nuclear program, including IAEA recommendations as well as existing legislation in Armenia in this area and development of a strategy for the regulatory model development. In addition, the plan to develop requirements for ANRA staffing and training needs to meet its regulatory obligations under the new reactor development process was developed.

Introduction

Options of nuclear power development program are being considered in Armenia. The dates of the program implementation are not determined, but decision on construction of a new reactor has been made. The site evaluation process for the new reactor also has started. Both the site and the design of the new reactor shall meet the national requirements on nuclear safety and environment protection and ensure the public safety. In this connection decisions for the site evaluation and construction shall be made based on the knowledge of all of the presented requirements.

The regulation and oversight in area of atomic energy use in Armenia are implemented by the State Committee of Nuclear Safety Regulation (ANRA). In 2008 the ANRA was reorganized from an Inspectorate within the Ministry of Nature Protection into the State Committee on Regulation of Nuclear Safety under the Government of the Republic of Armenia. The ANRA has a broad experience in oversight of the nuclear reactor operations. Atomic energy use started to develop in Armenia in early 1970s. Two VVER-440 type reactors were constructed in Armenia, which were successfully operated until 1989, when the Soviet leadership decided to shut down the units due to a strong earthquake occurred in the northern part of Armenia. When Armenia gained its independence, the Armenian Government made a decision to restart the Armenian NPP Unit 2 to overcome the energy crisis. At the same time the regulatory body (ANRA), was established. From that point on ANRA took an active part in review of safety justifications and conducted inspections of activities aimed at the unit restart. Following reactor restart ANRA regulated ANPP safety improvement issues. In its activities ANRA follows a set of standard documents (requirements, guidelines and procedures) developed as far back as during the soviet time, as well as documents of Russian Federation (RF). During the past several years some national documents were developed and put into force. The main one is the Law on safe utilization of atomic energy for peaceful purposes.

During decades passed after the accidents at “Three Mile Island” and Chernobyl NPPs, the international community reached essential success in defining stages and elements of the development of the national nuclear programs. The International Atomic Energy Agency (IAEA) has published numerous documents, which describe each aspect of the development of atomic energy, including the most important elements of the regulatory program in the field of safety. Several countries have significantly succeeded in developing new approaches to regulation [1]. They include the risk – informed and performance indicator based approaches, which allow a regulatory body in countries with a small nuclear program to efficiently use available limited resources.

New reactor designs such as light-water reactors with passive safety systems were designed in different countries, and some of them have obtained recognition in the form of design certification. Some countries demonstrated the standardization of designs and operational practices, which is considered a preferable approach for future nuclear programs.

In this context, ANRA has initiated activities on analysis and revision of existing regulatory documents aimed at bringing them in compliance with the advanced experience in the field of regulation and reactor technologies. These regulatory documents include the laws, binding technical requirements and guidelines.

The approach to revision of regulatory system was developed based on the review of the regulatory models in countries with a small nuclear energy program as well as from US NRC experience and IAEA guidance.

An action plan developed describes a general philosophy of updating the legislative framework for nuclear safety regulation in Armenia. It also presents a short characterization of elements of the updated regulatory pyramid, which is under development. The plan includes the list of documents subject to development with indication of main stages and schedule for their development.

Improvement of nuclear legislation in Armenia

Although programs for regulating the use of nuclear power in different countries vary in many parameters, each country should have its national legal system, within the framework of which a nuclear power plant shall be sited, designed, constructed and operated. Experience of other countries with small nuclear program shows [2], that all considered countries have a basic nuclear law, several regulatory documents and several tens of guidelines. The current situation in Armenia is as follows: there is a basic nuclear law, radiation safety requirements (rules and norms), safety requirements for transportation of radioactive and nuclear materials, requirements to physical protection and several tens of regulations on licensing of different types of practices.

The development of requirements on radiation safety, safe transport of radioactive and nuclear material and regulations on physical protection was conditioned in Armenia with the purpose of harmonizing its national requirements with IAEA recommendations. But those documents were not actually used for regulation of ANPP unit operation. Regulation of NPP was conducted on the basis of RF regulatory documents that «by default» were accepted in Armenia as the basis for regulation of ANPP operation. Such approach was justified taking into account that Armenia operated NPP designed to Soviet/Russian regulations.

Lack of an interrelated frame of the national nuclear regulation would create problems with regulation of a new NPP. Such situation also contradicts the IAEA requirements [3].

Nuclear legislation pyramid

Based on the experience of other countries with a «small nuclear program» it is proposed to use three key elements: laws, requirements and guidelines for the updated nuclear pyramid of documents in Armenia. These documents will form the first three levels of the legal pyramid. The fourth level documents will contain standards, developed mainly by the engineering community in specific areas in countries of nuclear technology origin. The proposed pyramid for nuclear legislation is presented in Figure 1.

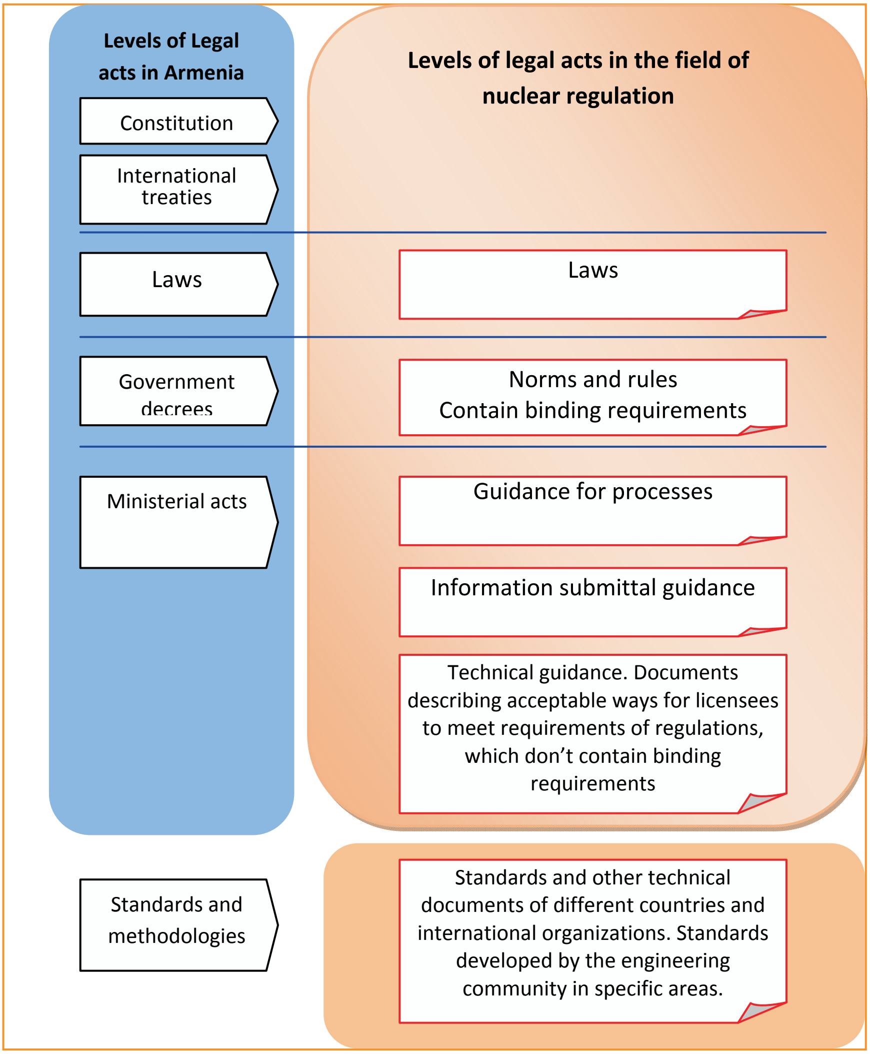

Figure 1. Nuclear legislation infrastructure and short description of each element

The Laws constitute the first level of nuclear legislation pyramid. Laws are put into force by the legislative power (parliament).

Norms and rules containing requirements are the second level of the pyramid. Norms and rules take into account the risk level and specify the minimum requested requirements to safety. Approval of norms and rules is within the government jurisdiction. Requirements containing in Norms and rules are binding, valid throughout of the Republic of Armenia and can be modified through amendments and (or) supplements made in relevant regulations. Requirements specified by regulations are established and will be applied equally regardless of the country of origin of supplied technology.

Regulations of foreign countries, and international and regional organizations may be used as a basis when developing rules and norms in a full or in part, if they meet Armenia's safety objectives.

Binding requirements to nuclear power installations will include technical requirements relevant to NPP, its site, design and operating personnel. Requirements will also define processes, which are to be followed during approval of the site, issue of license and prescriptions. Requirements will define information that is required by the regulatory body in support of regulatory processes such as requests for approval of site and for license, as well as information to be submitted to the regulator during NPP operation. Binding requirements will be formulated in a general form and will allow an operating organization to propose various ways of fulfilling them.

ANRA plans to implement four sets of regulations for new nuclear installations. They relate to evaluation and approval of the site, design, operation and decommissioning. These requirements would be of general nature. They would define objectives of the ANRA to safety and criteria used for evaluation of requirement fulfillment.

Guidance (third level of the pyramid) shall contain quantitative values of parameters and characteristics subject to technical regulation, recommendations for acceptable ways to ensure meeting safety requirements specified by regulations and are documents for benevolent use. These documents propose to licensees the acceptable ways of fulfilling binding requirements.

Several types of such documents are to be issued: Guidance for processes describes ways, which ANRA plans to apply when interfaced with applicants for a license and licensees. It is intended to develop guidance for each of the six basic regulation stages: site selection, licensing, construction, commissioning, operation and decommissioning. Information submittal guidance contains requirements on format and content of safety documents that are submitted in support of application for license as safety analysis reports and risk assessments.

Guidance for review describes methods of reviewing and assessing the information by ANRA. Guidance for review shall include risk-informed guides for defining priority during the review and assessment and for assigning resources to those areas, which are most safety significant. The guidance may contain references to the existing codes and standards developed by the engineering community in specific areas, including those issued by IAEA and other countries with advanced regulatory programs.

Terms and definitions are an important supplementary part of regulations. Success of the regulations depends on their adequacy to its content. In the past several years the number of terms and definitions in the IAEA documents has been decreased. This occurred due to the development of IAEA glossary. Development and implementation of the terms and definitions glossary in the field of use of nuclear power in Armenia would positively affect the process of development and use of regulatory documents.

Nuclear legislation development

After adopting the principal decision on construction of the new unit the established (appointed) operating organization organizes tender for potential suppliers of reactors and selects the project design that meets the country's needs and safety requirements. The next stage foresees adaptation of the plant design to specific conditions of selected site. Construction can be commenced after regulatory review of the design and granting the construction license. Operation of the plant can be started after construction is finished and operation license is obtained.

In the process of implementation of decision on construction of NPP the regulatory body fulfills a number of functions in a definite period of time. Figure 2 demonstrates approximate time frames for fulfillment of these functions.

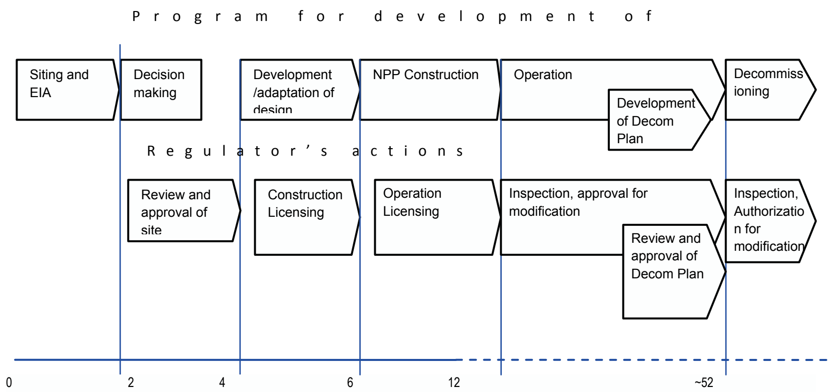

Figure 2. Approximate time frames for fulfillment of new nuclear unit program

Based on the time frame ANRA established priorities for development of new and revision of existing regulations. First priority is given to revision of the main nuclear law, site safety and design safety requirements and corresponding guidances: standard content and procedure of submitting of the Safety analysis report, site evaluation process, risk-informed guidance for review of site selection, technical guide for review of construction license application supporting documents, which will give guidance in defining priorities of analyses based on the risk assessment.

The second priority documents are regulatory documents with requirements to safe operation of nuclear facilities, guidance for inspections during the construction, guidance for the plant commissioning review.

Organization structure update of ANRA

ANRA's key objectives for the recent years were as follows: regulatory activity for the restart and operation of VVER-440 reactor, regulation of use of radioactive materials in medicine and industry. New objective related to licensing and regulatory activity of nuclear power reactors of new generation sets forth additional requirements to ANRA. This would require not only new regulations but also recruitment and training of additional qualified staff, and establishment of new technical resources.

Licensing and oversight of new generation reactors set forth new requirements to the level of staffing and qualification of the ANRA personnel.

ANRA initiated development of the staffing plan for the next 10 years. The new personnel would need a combination of relevant fundamental education, work experience and specialized training. The staffing plan describes technical resources needed by ANRA to implement their responsibilities for oversight.

A regulatory body cannot provide and maintain high level of expert knowledge and experience in all areas of science and technology. An important complement to the regulatory staff is the in-country technical support organization (TSO). The role of this organization is to provide the regulator with dedicated technical skills that are not available to the regulatory staff. The relationship between the regulatory body and the TSO is very close in Armenia. ANRA's TSO – Nuclear and Radiation Safety Center is young and growing organization which provides technical support to ANRA in several areas like thermal–hydraulic analyses, neutronic calculations, probabilistic safety assessment, seismic safety analyses etc. and has close cooperation with external technical support organizations like RISKAUDIT (EU), AdSTM (contractor of US NRC).

ANRA can derive essential benefit for its regulatory system from activity of countries with well-developed regulatory programs. The currently implemented Multinational Design Evaluation Program (MDEP) represents an official channel for exchange of information on design analyses. The MDEP program may also enable ANRA reference to inspections of vendors, which manufacture reactor major components.

During licensing and operation of a nuclear power plant the ANRA will periodically appeal to the international community for support in view of conducting reviews and inspections in highly specialized aspects. This would enable ANRA at its initial stage to avoid necessity of providing technical capabilities in the whole range of technical areas.

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SEVEN PRINCIPLES OF HIGHLY EFFECTIVE NUCLEAR ENERGY PROGRAMS

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Abstract This paper presents seven principles that demand consideration for any country using a nuclear power program or wanting to acquire such a program. These principles are assessing the overall energy system, determining effective use of financial resources for energy development, ensuring high safety standards, implementing best security practices, preventing the spread of nuclear weapons, managing radioactive waste in a safe and secure manner, and enacting a legal framework that encompasses the other principle areas. The paper applies management methods that underscore development of strong independent national capabilities integrated within an interdependent international system. The paper discusses the individual responsibilities of states in all seven principles and offers recommendations for how states can benefit from greater international cooperation in nuclear energy development.

Independence, interdependence, and dependence

In recent years dozens of countries have expressed interest in potentially acquiring their first nuclear power plants. They need guidance on how to decide whether such plants are the right choice for them, and if that decision is made, how to manage effectively the complex nuclear power plant acquisition process, and how to ensure that these plants are operated safely and securely. Before examining the criteria or principles for making this decision and managing a nuclear power program, it is important to understand what is driving many states to consider this power source. While overt and covert motivations for new nuclear power programs vary from keeping up with neighbors' programs to transitioning to a lower greenhouse gas emission energy system, a common overt motivator is to become more energy independent.

Energy independence, however, is a myth, especially in the nuclear sector. To see why, examine the experience of countries that presently use nuclear power to generate electricity. Practically all of them are not self-sufficient in providing for all the required components of a nuclear power program, including reactors, uranium, fuel manufacture, and training of personnel. Even France with a vertically

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integrated, largely government-owned nuclear industry that has extensive uranium enrichment capacity, power plant manufacturing, and thousands of indigenously trained workers still relies on external supplies of natural uranium as the feed stock for this industry. Moreover, the nuclear industry has developed into one of the most globalized industries. For example, no longer can the United States claim to have major nuclear companies that are solely U.S.-based. Since 2006, U.S.-based Westinghouse has merged with Japanese-based Toshiba, and similarly U.S.-based GE Nuclear has combined with Japanese-based Hitachi. Furthermore, the French nuclear industry giant Areva has formed alliances with several other nuclear companies and has major branches outside France. Thus, the reality is that the degree of interdependence and interconnectedness in the global nuclear industry and infrastructure continues to grow.

Energy interdependence should not be feared and can be a source of strength if managed properly. It is important to emphasize that interdependence does not necessarily equate to dependence. An interdependent national energy system can be a highly secure system as long as it is a well diversified one. While many politicians receive applause from constituents for pledging energy independence, they should realize that an energy mix that does not rely too heavily on one energy source often provides the best insurance against supply disruptions. Each energy source varies considerably in its requirements for ensuring safe and secure use and protecting the public and the environment. Here, the focus is on the special requirements for safe and secure use of nuclear energy.

Unique characteristics of nuclear energy

Nuclear energy is not just another way to boil water (or heat up another working fluid) to make steam to turn a turbine to generate electricity. (Here, nuclear fission is considered but not nuclear fusion.) Nuclear fission to produce nuclear energy has two unique hazards. First, nuclear fission creates radioactive fission products. These fission products can last from fractions of a second to billions of years. In general, the fission products of greatest concern are those with radioactive half-lives – the amount of time it takes for half of the substance to decay – on the order of the human lifespan because they release most of their radiation over that span. Two relatively abundant examples of these radioisotopes are cesium-137 with a half-life of 30 years and strontium-90 with a half-life of 29 years. After these radioisotopes have decayed to negligible amounts, longer lived radioisotopes with half-lives on the order of thousands to millions of years will dominate the radioactive composition of discharged material from a nuclear power plant. Consequently, the decision to develop a nuclear power program carries with it the responsibility to protect human health and the overall biota for more than thousands of years through safe and secure management of radioactive waste. In addition, states with nuclear power programs have the responsibility to protect against nuclear accidents that can disperse radioactive materials to the environment and to mitigate the consequences if that dispersal occurs.

The second unique hazard of nuclear energy involves the dual-use nature of the nuclear fuel making technologies of enriching uranium and reprocessing of spent fuel to extract plutonium. These technologies can help produce either fuel for commercial nuclear reactors or fissile material for nuclear weapons. In particular, an enrichment plant has done most of the work to produce highly enriched uranium suitable for weapons after enriching to low enriched uranium for fuel purposes. Presently, only a few countries use commercial reprocessing plants to separate weapons-usable plutonium from spent fuel. If a large expansion of nuclear power occurs, more countries may operate reprocessing plants. While it is possible and worthwhile to make enrichment and reprocessing more proliferation-resistant, there is no proliferation-proof system. Nuclear power producing states have the responsibility to ensure that their commercial nuclear programs remain peaceful and do not proliferate into weapons programs.

Seven principles of nuclear energy systems

A principled-based system is rooted in integrity, openness, transparency, and a win-win environment. Covey [1] has developed a principled-based system for personal growth that can provide guidance for developing a principled-based nuclear energy system. Covey identifies seven habits of highly effective people: be proactive, begin with the end in mind, put first things first, think win-win, seek first to understand and then to be understood, synergize, and finally sharpen the saw. The first three habits involve creating a strong independent person. The next three habits help the independent person make the connection to healthy interdependence. The final habit calls on the person to continually renew the habits. While being careful to not stretch the analogy between personal development and energy system development to the breaking point, it is worth examining each principle of highly effective nuclear energy systems in light of Covey's paradigms of independence, interdependence, and continual renewal.

The seven principles examined here involve the issue areas of energy system analysis, economics, safety, security, nonproliferation, waste management, and legal framework. For each of these issues, the individual state is ultimately responsible to upholding the principle but is embedded in an interdependent international system. As such, states have a common interest in assisting other states in meeting their collective responsibilities. In particular, states with mature nuclear power programs can and should play an active role in helping states without these programs think through the decisions involved in acquiring and managing nuclear power programs. The International Atomic Energy [8] has recently published a guidance document on the potential for sharing among countries with nuclear power programs. This document underscores that the "burden of infrastructure can be reduced significantly if a country forms a sharing partnership with other countries." Such sharing can reduce costs and spread economic benefits over many countries. This sharing can be a win-win situation in which two or more countries gain and no country loses. Also of note, the International Atomic Energy Agency and has recently published two other guidance documents [9, 10] offering advice for countries considering their first nuclear power plants.

Energy system analysis

Nuclear energy makes a significant contribution to world electricity generation (about 16%). Because nuclear power plants do not emit greenhouse gases (and the total nuclear fuel cycle is very low in such emissions), nuclear energy also makes a substantive contribution in reducing greenhouse gas emissions especially in comparison to replacing the approximately currently operating 440 commercial reactors with coal-fired power plants. (It would be very challenging to replace the existing nuclear power plants with the equivalent of other very low greenhouse gas emission sources.) Moreover, for countries that depend heavily on foreign oil or natural gas for electricity generation, nuclear energy can help displace use of these fuels and thus provide some relief of dependency on these outside fuel sources. However, nuclear energy so far only is used to produce electricity and has yet to make a significant contribution to the transportation sector. If and when cars and trucks use electricity or hydrogen to power fuel cells on a massive scale, nuclear energy can play a much more significant role in weaning countries off dependency on fossil fuels in the transportation sector. These macro-level and geopolitical considerations shape the positive perception of nuclear energy in governments' decision making.

But the high construction costs for nuclear power plants, the long preparation and planning time, and the necessary investments in a nuclear infrastructure tend to work against governments' decisions to pursue nuclear power. Governments also have the responsibility to factor in the unique attributes of nuclear energy that require additional costs to ensure safe and secure handling of radioactive waste and to protect against misuse of peaceful technologies in weapons programs. While it is beyond the scope here to discuss in detail planning considerations for countries' energy systems, it is worthwhile emphasizing that the first prerequisite for any country considering nuclear power is to conduct a thorough energy system analysis. This is a proactive approach that will assess what resources (energy supplies, technological infrastructure, and human capacity) a country has available to it presently and what it needs to acquire to meet its energy needs. Borrowing from Covey's principle of "begin with the end in mind," a country needs to determine as a prerequisite to this prerequisite where it envisions itself going in its energy development. It should seek to ultimately develop and reach a sustainable energy system, but the specifics of such a system will vary by country depending on the resources available to it.

Both the International Energy Agency (IEA) and the International Atomic Energy Agency can provide such planning assistance. But the IEA is too limited in its scope of member countries, and the IAEA is primarily focused on nuclear energy. What the international community needs is a world energy agency that would be global in scope and provide detailed energy planning. Notably, IAEA

Director-General Mohamed ElBaradei has suggested development of such an agency [4]. This agency would have to be able to perform lifecycle comparisons of differing energy development scenarios for any country.

Economics

Starting a nuclear power program can take 15 or more years depending on the status of a country's technological development. In addition, it will require substantial financial investment to build up a nuclear infrastructure. In particular, the educational system must have the necessary resources to make sure that the pipeline of technically skilled people will be ready for starting the program and ensuring its sustainability over many decades. Fortunately, countries do not have to build up this infrastructure on their own but can and should seek outside advice and support from countries that already have such programs.

Aside from acquiring the technological infrastructure, the biggest consideration is how to finance the construction of nuclear power plants. Financing poses a major challenge even for many countries that already have nuclear power plants. In general, the capital needed to build a nuclear power plant is significantly greater than that required to build a coal-fired plant and most certainly greater than that needed for a natural gas plant. But once the nuclear plant is built, its fuel costs are typically cheaper than the fuel costs for a coal or natural gas plant. In particular, the updated MIT nuclear power study [3] has estimated the overnight costs (assuming a plant can be built overnight and thus minimizing the financing costs) as $4,000/kW for nuclear, $2,300/kW for coal, and $850/kW for natural gas in the United States, the fuel costs as $0.67/mmBTU for nuclear, $2.60/mmBTU for coal, and $7.00/mmBTU for natural gas, and the resulting electricity base costs as $0.084/kWh for nuclear, $0.062/kWh for coal, and $0.065/kWh for natural gas. The MIT report estimates that a $25/t of CO_2 charge would make nuclear cost competitive with coal and also cost competitive with natural gas for consistently high gas prices. Thus, factoring in this external cost into the internal cost of fossil fuel electricity generation will level the playing field for no- and low-carbon emission sources, including nuclear energy.

Countries will also have to factor in decommissioning and spent fuel storage and handling costs when figuring out the lifecycle costs of nuclear power. These costs, to date, have been estimated as a relatively small fraction of the capital construction and fuel costs. Another decision is whether to pay the costs of a reprocessing or recycling program. While on purely economic considerations, reprocessing costs more than the once-through uranium fuel cycle, certain countries have made the decision to pay these extra costs because of the view that a reprocessing program could in the long term give them more energy independence, help save on waste disposal costs, and will be needed if uranium resources become scarce, which reprocessing proponents believe could happen by mid-century if nuclear power experiences a major global expansion.

Safety

An often said aphorism in the nuclear safety field is: "A nuclear accident anywhere is a nuclear accident everywhere." This lesson was learned after the Three Mile Island accident in 1979 in the United States and the Chernobyl accident in 1986 in Ukraine. Actually, many lessons were learned and considerable safety improvements have been made after those accidents. First, nuclear regulatory agencies in many countries became more effective as strong independent government agencies. Second, the nuclear industry formed peer-review organizations that sought to achieve excellence in nuclear plant operations and safety. Third, design changes and equipment in nuclear plants have improved. Fourth, training and management of plant operators significantly have improved.

Nuclear power plant safety, in general, involves engineering and institutional aspects. Prior to the TMI accident, the emphasis in nuclear safety was much more on defense-in-depth engineering. While this is still essential, the fundamental change after TMI was to build up institutional capacities. That is, the human element was the essential component in nuclear safety that did not receive adequate attention – especially in the United States – prior to that accident. As Rees [11] points out, utility managers and their staff had "fossil fuel mentality" before TMI. They thought of nuclear plants as just big fossil fuel plants. While they were cognizant of nuclear hazards, they had not developed a nuclear safety culture and had not instilled nuclear professionalism in their workforce. Soon after the accident, the industry responded by forming the Institute for Nuclear Power Operations (INPO). Over the past 30 years, INPO has served as a self-policing and peer review institution that has used peer pressure, confidential safety assessments, safety inspections, and a principled-based and results-oriented management approach to help nuclear power plant owners and operators achieve a high standard of safety while maintaining reliable operations. Similarly, after the Chernobyl accident, industry formed the World Association of Nuclear Operations (WANO), which has performed hundreds of peer reviews in nuclear power operating countries.

While INPO and WANO do not obviate the need for strong independent regulatory agencies, they do illustrate the power of "communitarian regulators" [11]. Notably, these organizations have not fallen into the trap of least common denominator standards, which can often happen in order to achieve consensus. They instead underscore the effectiveness of industry organizations that strive for excellence. Rees concludes that this approach has worked in INPO and WANO because much of the management was instilled with a commitment to excellence and high safety standards due to their leadership's training in organizations such as the nuclear navy where that culture is integrated into all work activities. Most importantly, nuclear power plant owners and operators realize that they are "hostages of each other" in the words of Rees and that one major accident at one plant can harm the prospects for all other plants. Concerning the economic costs of safety, utility executives appear to face the tension between keeping overall plant costs down and maintaining high safety. But this is largely a false dilemma because preventive maintenance and safety training pay off in the long term, not only for helping to keep an individual plant running longer but also to sustain the vitality of the overall industry.

For countries needing safety guidance for starting up nuclear power programs, they should use the IAEA Nuclear Safety Series [7]. They can and should also seek advice from mature regulatory agencies. In addition, they need to adhere to the nuclear safety conventions.

Security

In this section, the focus is on physical security, not energy security. While improvements in nuclear safety have built on more than 50 years of experience in the commercial nuclear industry, the standards of excellence emulated from other nuclear organizations, and the decades long experience of the IAEA in developing nuclear safety standards, nuclear security has not received as much attention and resources from the communitarian perspective. One major reason for this discrepancy is that safety has been subject and amendable to quantitative probabilistic risk assessments. In contrast, security threats are much more difficult to quantify because of intelligent adversaries and the paucity of data due to the few attacks or attempted attacks on nuclear facilities. Another major difference is that safety culture has evolved to become more open about admitting mistakes in a “no fault” environment that should work to correct mistakes without seeking retribution on workers who have made mistakes or whistleblowers. In contrast, the security field tends to be more secretive by design because of not wanting to leak potential security weaknesses to adversaries. Moreover, many in the security field have voiced concerns on a not-for-attribution basis that the level of professionalism and culture in their field has not reached the high level as obtained by the safety field.

While it took two major accidents to stimulate needed improvements in safety and more interdependent professional development, perhaps the attacks of 9/11, although not nuclear or radiological related, will have a similar effect on the security field. For example, many in the industry have recently begun working with the Nuclear Threat Initiative, the U.S. Department of Energy, and the International Atomic Energy Agency in the newly formed World Institute for Nuclear Security (WINS), which was inspired by WANO [2]. Peer reviews would help spur improvements in security and share lessons learned in order to develop better practices throughout the industry. The IAEA has also been developing the Nuclear Security Series, which is a companion to the safety series. However, the IAEA’s nuclear security program is relatively small compared to its safety program. The nuclear security program would benefit from sustainable and adequate funding. One possible way to do this would be to include the security program’s budget in the regular IAEA budget rather than fund it mainly from voluntary contributions. Further, major governmental parties to the Convention on Physical Protection of Nuclear Material (CPPNM) have recently agreed on an amendment to require stronger physical protection during domestic use of nuclear material among other needed improvements. But it will likely take many years for the amendment to achieve the requisite number of ratifications to enter into force. In sum, more international work is needed to implement better nuclear security practices.

Nonproliferation

The nuclear nonproliferation regime is a leading example of the power of interdependent action to protect individual states from the spread of nuclear weapons. This regime consists of multiple components that reinforce each other, including the Non-Proliferation Treaty (NPT), safeguards agreements and inspections, regional arrangements such as nuclear weapon free zones and bilateral and multilateral inspection regimes, including Euratom and the ABACC agreement among Argentina, Brazil, and the IAEA, export control regimes, and security assurances.

Second only to the UN Charter in universal application, the NPT includes all but four states: India, Israel, North Korea, and Pakistan. It has three main purposes: prevent the further spread of nuclear weapons, ensure access to peaceful nuclear technologies, and pledge countries to pursue nuclear disarmament and a treaty on general and complete disarmament. A renewed point of contention is the issue of access to peaceful nuclear technologies and the potential for misuse of those technologies in weapons programs. While the NPT does not explicitly guarantee that countries will have access to enrichment and reprocessing technologies, it does not explicitly rule out such access, and certain countries have interpreted the NPT to allow acquisition of these technologies. Recently, there has been considerable discussion about reinterpreting the treaty to limit access. This discussion has elicited push back from several non-nuclear weapon states in the developing world. They perceive that such reinterpretation will deny them their rights and thus infringe on their sovereignty. It is worth emphasizing that this right to peaceful nuclear technologies already comes with the responsibility to not acquire nuclear explosives and to maintain adequate safeguards on nuclear power programs. The International Atomic Energy Agency has the mandate to form safeguards agreements and to investigate countries' nuclear programs. Safeguards seek to deter diversion of peaceful technologies into weapons programs and to detect in a timely manner – to give enough time to interdict – such diversion. Concerns have been raised that safeguards as typically applied cannot detect or interdict in a timely manner. Notably, it can take as little as a few days to make highly enriched uranium or plutonium metal into a nuclear explosive, but safeguards inspections have not been applied at a frequency that could interdict such activity.

The most recent improvement to safeguards is the Additional Protocol to comprehensive safeguards agreements. The Additional Protocol was developed in response to the discovery in 1991 after the Gulf War that Iraq had been building a weapons program side-by-side with a peaceful program. Iraq had exploited a loophole in its safeguards agreement that limited inspectors' access to only declared nuclear facilities while undeclared facilities were considered off limits.

While the IAEA Board of Governors already had the authority in the IAEA Charter to order a special inspection of undeclared facilities, in practice the Board has been politically reluctant to call for such inspections. The Additional Protocol has provided the IAEA with the authority to transform its safeguards inspections from a focus on accountancy to an investigatory culture. That is, under the Additional Protocol, the inspectors are required to determine whether there are any undeclared facilities and nuclear materials. Although the Additional Protocol has been successfully applied to many countries, it is still far from being universally applied. The Board of Governors needs to make the Additional Protocol a requirement for all countries with significant use of nuclear power. Moreover, the Nuclear Suppliers Group should make the Additional Protocol a condition for export of nuclear technologies. In the spirit of continual renewal, countries should also work toward trying to improve safeguards beyond the Additional Protocol. It is also worth redoubling international efforts to strengthen the application of existing authorities, to develop additional authorities, and to improve enforcement mechanisms especially the UN Security Council [5]. Finally, industry can and should consider self-policing in the nonproliferation field similar to its successful efforts using peer review in the safety field [6].

Waste management

Each nuclear power producing state has the responsibility to safely and securely manage radioactive waste it generates. While a few countries have taken significant steps to opening up a permanent repository for high level nuclear waste, no country has actually opened up such a facility. Countries with small nuclear power programs could greatly benefit from working cooperatively with similar countries to site and build regional repositories. From the technical standpoint, this is a sound idea that has received support from numerous technical experts. But from the political perspective, this approach has confronted significant opposition. Nonetheless, it is worth pursuing as long as an equitable agreement can be reached. Such an agreement would provide the needed confidence that the site is safe and that the country hosting the site will receive fair compensation. Countries can and should share research and development on methods to reduce waste generation and more effective use of nuclear fuels. This activity ranges from research into reprocessing, fast reactors, and higher burn up fuels.

Legal framework

Overarching safety, security, nonproliferation, and waste management is a legal framework on the national and international levels. Each country with a nuclear power program has the individual responsibility to enact the appropriate legislation for implementing safety regulations, providing for adequate liability coverage in the event of an accident, ensuring safe and secure handling and disposal of radioactive waste, and securing nuclear facilities and materials. National legislation needs to be in harmony with international law, safety conventions, and treaty obligations. It is worth emphasizing that passage of a law and publication of regulations must go hand-in-hand with continual development of safety and security cultures.

Conclusion

In sum, planning for a nuclear power program and ensuring safe and secure use of nuclear power are complex endeavors. States should base their decisions on whether to proceed with nuclear energy development on sound and thorough energy system analysis and smart assessment of the capability to finance nuclear power plants comparing to other energy choices. Wise management of energy systems, especially nuclear energy systems, should build on a principled-based method that strives for excellence and that has a foundation of independent responsibility integrated to an interdependent international system. States seeking nuclear power programs should avail themselves of guidance from states with mature nuclear power programs. While energy isolation is not possible or desirable, a robust, well-balanced interdependent energy system provides the energy security that countries need.

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CHAPTER II
THE CASE FOR NUCLEAR ENERGY

NUCLEAR SAFETY AND ENERGY SECURITY

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Nuclear Power is being viewed by more and more countries as one of the key elements for maintaining or obtaining Energy Security. As more countries are looking towards nuclear power as a stable and reliable energy source there is also an increased focus on nuclear safety. In order for Nuclear Power to be able to contribute towards improving energy security, the safety of both new and older nuclear power plants must be assured. So, nuclear safety continues to be a very prominent topic in the ongoing discussions regarding nuclear power and energy security. This is especially true for those countries that are just now embarking or still investigating nuclear power as an energy source and for countries extending the life of older facilities is extended to maintain capacity.

As most of you are aware, nuclear safety became a very prominent topic in the early 1990s. At that time, several former Soviet Republics found themselves as newly independent countries operating nuclear power plants but with very little indigenous infrastructure to support their continued safe operation. There was considerable concern regarding the safety of many of these plants, and there were many who encouraged these countries to shutdown these plants due to the safety concerns. However, shutdown was generally not feasible since these plants provided a significant amount of energy to these struggling countries; almost 80% in Lithuania and more than 40% in Hungary, Bulgaria Slovakia and Ukraine.

The U.S. along with other countries, including the European Union, United Kingdom, Sweden, the IAEA and others established programs to help these countries improve the safety of their plants and strengthen the regulatory oversight of their operation. U.S. assistance was specifically focused to (1) enhance the operational safety of Soviet-designed reactors, (2) provide for risk-reduction measures for the least safe plant designs, and (3) enhance the capability of the regulatory organizations. These activities were all coordinated through the U.S. Department of State with DOE efforts aimed at the first two objectives and the U.S. NRC providing assistance with the third objective.

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Policy and technical experts quickly recognized that assistance efforts alone could not resolve the safety deficiencies inherent in these nuclear programs. The host countries had to develop their own capability to operate and regulate their nuclear power plants more safely and developing that capability became one of the key goal of the U.S. programs. As their economies improved, the host countries would then be able to sustain and extend improvements through their own efforts until they can reach internationally accepted standards in the operation and regulation of their nuclear programs.

Therefore, DOE's strategy was to work with the host-country nuclear power plant operators, regulators, and support organizations to provide them the knowledge, technology, equipment, and capability needed to achieve a self-sustaining nuclear safety improvement program. A substantial element of this strategy was the transfer of manufacturing technologies, training methodologies, and safety assessment capabilities to host countries. Technology transfer methods included information exchanges, technical collaborations, personnel exchanges, licensing of U.S. technologies, and formation of joint U.S./host-country companies.

DOE's approach has been to work cooperatively with the host countries to prioritize the safety needs and obtain the political commitment from the host country and, equally important, the commitment of the leaders of their nuclear industry, to ensure sustainability after the U.S. assistance ends. The United States coordinated its safety assistance activities with those of the International Atomic Energy Agency (IAEA), the Nuclear Safety Account at the European Bank for Reconstruction and Development (EBRD), and those of other donors through the G-7 Nuclear Safety Working Group and the European Union's Technical Assistance to the Commonwealth of Independent States (TACIS) Program.

To accomplish the mission of enhancing operational safety and reducing the risks at these plants, DOE established five key areas of activities:

- Operational Safety – technology transfer and training focused on improving the day-today operation and management of the plant. Specific projects: procedures, including Symptom-based emergency procedures, Quality Assurance, Operator Exchanges, improved Management and Operation Practices (Good Practices from World Association of Nuclear Operators [WANO]).
- Training and Simulators – technology transfer of modern training techniques (Systematic Approach to Training) to enhance the effectiveness of the training to plant personnel. In addition, simulators were provided, including technology transfer on simulator development, and training on how to effectively use simulators to enhance the training of the control room operators.
- Safety Maintenance – technology transfer to improve maintenance practices including providing advanced maintenance tools such as:
    - Non-destructive Examination Equipment
    - Pipe Lathe/Weld-Preparation Machines
    - Valve-Seat Resurfacing Equipment
    - Insulation Analysis Equipment (Infrared Detectors)
    - Vibration Monitoring and Shaft Alignment Equipment

- Safety Upgrades – technical assistance and hardware to address specific risks or design deficiencies. These activities were generally design specific and included:
    - Fire Safety improvements
    - Circuit Breakers – including technology transfer on circuit breaker fabrication
    - Emergency Power Supplies – batteries, diesel generators
    - Safety Parameter Display Systems
    - Plant Computer Upgrades
    - Main Steam Isolation Valves
    - Confinement leak tightness improvements
- Safety Analysis – technology transfer and training on modern safety analysis tools and methodologies. The focus has been to transfer safety analysis capabilities to the host country, both deterministic and probabilistic analyses. Technical assistance to enable the host country to establish a long term licensing basis for the NPPs. This area has been coordinated with the U.S. Nuclear Regulatory Commission (NRC) efforts to assist the regulatory organizations in establishing a set of licensing criteria.

While each individual area was critical, a positive synergistic impact resulted as progress was made in all of these areas collectively. Clearly, two overall factors are important to safety: (1) skilled operations staff, provided with the information they need to do the job and trained to handle emergencies; and (2) advanced equipment and techniques that ensure correct operation of the plant safety systems are evaluated and maintained effectively to ensure correct low-risk operations.

Accomplishments

The U.S. nuclear safety assistance activities have had a direct and substantial impact on improving safe operations of 67 Soviet-designed commercial nuclear power plants in Armenia, Bulgaria, Czech Republic, Hungary, Kazakhstan, Lithuania, Russia, Slovakia, and Ukraine. The U.S. Department of Energy worked with these host countries both to improve safe nuclear operations and in some cases assist in plant shutdown. Independent international safety reviews have identified significant progress in the Eastern European countries to improve the safety of their nuclear power plants since the early 1990s. In addition, all of the probabilistic risk assessments conducted at these plants show a major reduction in the frequency of core damage accidents since U.S. assistance to improve safety at these reactors began.

Improved operational safety follows from the combined efforts to improve operator performance. These efforts include providing simulators for operators to practice handling emergency scenarios, developing emergency operating instructions that guide operators calmly through emergencies, providing safety parameter display systems that give operators immediate graphical information on the status of plant systems and training the operators on the safety basis for the plants they operate. Together, these efforts provide an operations staff trained to international standards and able to make informed decisions, both during day-to-day operations and under the stress of an emergency situation.

Improving and maintaining the plant safety systems to international standards provides additional assurance that the plant will operate safely and that the emergency equipment will indeed perform as intended when called upon. Therefore, efforts to install new safety equipment, improve maintenance, evaluate risks, and prioritize safety upgrades all contribute to improving plant safety.

In addition to our efforts to assist the host country improve plant staff capabilities and the effectiveness of plant safety systems, another key element of the U.S. assistance has been the technology transfer of safety analysis capabilities. Our focus in the safety analysis area has been to provide the advanced methods and procedures so they on their own could conduct safety evaluations of their plants and therefore obtain a long term operating license from the regulatory organization. This typically is a Safety Analysis Report which provides the licensing basis for the plant. The NRC conducts a similar activity, providing technical assistance to the host country to review the Safety Analysis Report. The operating license is very important – it provides a common basis for both the regulator and operator to work from relative to operational practices, safety limits and safety deficiencies. In addition, the systematic approach to conducting a thorough Safety Assessment including Probabilistic Risk Assessments can identify safety risks or deficiencies that were not previously identified through the generic reviews performed in the mid-1990s for the various Soviet reactor designs and can also help prioritize future safety upgrades.

Improvements in safety

A primary indicator of nuclear plant safety is the frequency of core damage accidents. Fortunately, there have been very few of those – so we rely on calculations to provide us with a core melt probability, or risk, numbers. While a complete Probabilistic Risk Assessment has not been conducted for every one of the 67 reactors, those that have been performed show a significant reduction – one to two orders of magnitude – in the probability of a core melt accident since the assistance programs began.

In addition to looking at the data from the various Probabilistic Risk Assessments, we also looked at trends in minor events, which serve as precursors indicating the likelihood of a more severe accident. Minor events show a similar favorable trend since 1992. As depicted in Figure 1, there has been a decrease in the number of events at Soviet-designed nuclear power plants in Russia and Ukraine since the DOE assistance activities began in 1992. The vast majority of these events are rated as Level 0 Deviations on the 7-level International Nuclear Event Scale (INES) and represent quite minor events. The number of events in Russia and Ukraine exceeding INES Level 0 (classified as INES Level 1 Anomalies or INES Level 2 Incidents) also has decreased significantly during this period.

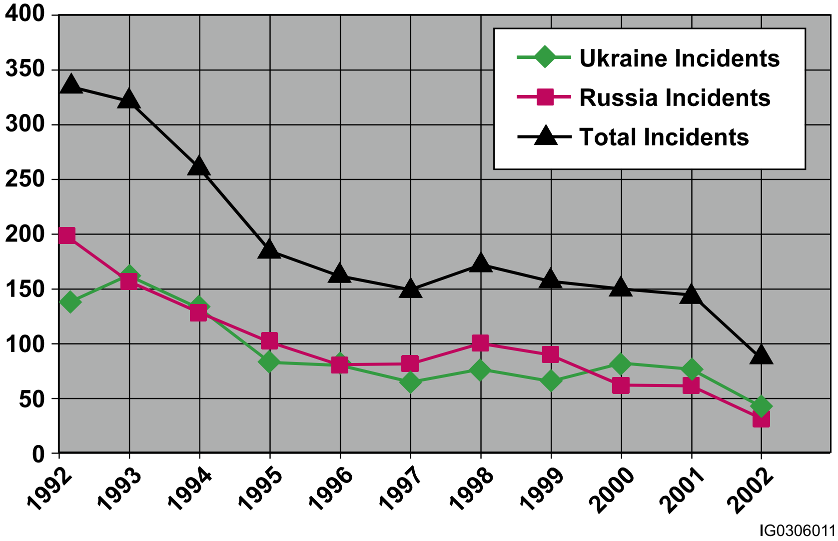

Figure 1. Number of minor safety events at Soviet-designed reactors in Russia and Ukraine

As the chart above shows, there was a significant decrease in the number of events reported during the first few years of our assistance activities. When you factor in the improvements made in the reporting standards (reporting on incidents that were previously not reported), the decrease in the number of events is even more impressive.

In summary, it is clear that the efforts by the host countries, with the assistance from the U.S. and other donor countries, have improved the safety of the Soviet-designed reactors significantly. It is also clear that our assistance has helped the host countries develop the necessary infrastructure and safety culture to sustain the improvements made at their plants.

NUCLEAR ENERGY AND SOCIAL IMPACT

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Abstract Economic development and population increase are boosting a new process of energy demand all around the world which implies also a protection of the environment and, consequently, the reduction of emissions of CO_2, a challenge that has to be solved. Fossil fuels represent the cheapest costs in capital and have as common features that their exploitation is based on largely known technologies, having developed a big experience in construction, operation and maintenance. However they are big environment polluters. Nuclear energy fulfils three of the main objectives that should be pursued for a steady development: (1) It does not emit Greenhouse gases. (2) It is the cheapest produced energy. (3) It guarantees a security in its supply due to the fact, among others, that it is not conditioned by external factors. However, as any other energy source, nuclear power has its own drawbacks. Some are real and some are fictitious. For this reason it becomes necessary to improve the social image of this source of energy, so as to counteract the negative consequences of the antinuclear discourse, promoted late in the seventies that has permanently undermined public acceptance.

Keywords: energy demand, reduction of CO_2, advantages of nuclear fission, fictious drawbacks, nuclear language, sustainable development, nuclear fusion

Introduction

Energy demand in the world is growing increasingly, among other factors due to economic development. Every way of producing electricity has got drawbacks and has implicit environmental impact. Among all the energy sources, nuclear energy is the most polemic because of the way it is presented by antinuclear organisations, certain political parties and some mass media. This aspect provokes controversy to occidental societies which reject this kind of energy with arguments normally based on a wrong and insufficient knowledge of the matter.

Present economic development is boosting a new process of energy demand all around the world. This demand implies as well a protection of the environment and, consequently, the reduction of emissions of CO_2.

In the combustion of coal, oil and natural gas CO_2 is produced as well as, in a lesser degree, SO_2 and NOX. All these molecules that have got three of more atoms contribute to an increase of the Greenhouse Effect.

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A control of emissions of CO_2 becomes fundamental because it has an average life in the atmosphere of 100 years; being shorter the average life of SO_2 (weeks), and NOX (only days) and the duration of fossil fuel reserves depend on the limits established in the Kyoto Protocol.

Nuclear energy fulfils the main objectives that should be pursued for a steady development, being as well a non-pollutant source.

Advantages of nuclear fission

In 2008, 31 countries were operating 435 nuclear reactors with a capacity superior to 372 million kilowatts.

Among its most important advantages we can mention the following: (1) It does not produce Greenhouse emissions. (2) Nuclear power plants have an average lifespan of up to 60 years. (3) It is the cheapest produced energy: 80% of the energy produced in fossil fuel power plants and about the half of wind power plants. (4) It guarantees a security in its supply due, among others, to the fact that it is not conditioned by external factors. This last aspect is direct and strategically related to National Security and Defence.

The cost of uranium is a 5% of the cost of the electric energy produced, whereas the cost of coal and gas is about a 50% and a 70% of the costs of electric energy produced. With respect to uranium reserves, known and exploitable ones are presently 5.5 millions of tons, at a cost less than US$130/kg, being its distribution according to the following countries: Australia (25%); Kazakhstan (17%) Canada (9%), United States (7%), South Africa (7%), Namibia (6%); Brazil (6%) and, in a lesser degree, other countries.

According to the Red Book, data based on geological evidences consider that reserves of uranium are more than 35 million tons available for exploitation, that would provide uranium supply for 200 years at present consumption rate [1].

Factors associated to negative social response to nuclear energy history

Nuclear science is born with a first military use (Hiroshima and Nagasaki, 6 and 9 August 1945) and the antinuclear discourse takes advantage of it. It works with the psychology of social mass to make perceive that nuclear technology is influenced negatively by the "history" associated to the term "nuclear".

However this argument is counteracted with a powerful reality. Japan, the first and only country that regrettably suffered the nuclear bombings in 1945, is one of the nations that strongly rely on the use of nuclear energy for its industrial development. In 1966 Japan opened its first nuclear power plant in Ibaraki and by 2008 this country had installed 55 reactors, which account for about one third of the country's total electric power output.

With respect to its position towards nuclear proliferation, since 1968 Japan has adopted the following non-nuclear principles: it will not have nuclear weapons, it will not fabricate them and it will not allow nuclear weapons in its territory [2].

On the other hand, we cannot omit the fact that nuclear weapons shaped an international policy of containment and deterrence that during 50 years was the base of a global security status, based on the Assured Mutual Destruction (AMD) policy established early in the 1960s, that prevented a potential war in the worst years of tension between the powers during Cold War.

Nuclear language

Words have a meaning whose content corresponds to the abstract image that is represented in the information found in our brain. This is one of the reasons of why language plays such an important role in human perception.

Nuclear language in certain vocables contributes to create misperceptions, as in the case of the term reactor trip, which in Spanish is translated as "disparo" (shot), the same word used with weapons.

The term nuclear fuel is translated into Spanish as combustible nuclear, as if it underwent combustion process as coal and petrol.

Nuclear waste is stored in repositories. The translation of "nuclear repository" into Spanish is almacenamiento definitivo (definitive storing), but it has stuck the cryptic denomination "cementerio nuclear" (cemetery or graveyard for people).

In nuclear medicine, the radioisotope Cobalt-60 used in teletherapy is translated as "bomba de cobalto" (Cobalt bomb).

When we deal with nuclear terminology we have to underline that it involves two separated semantic fields. One is the field of nuclear engineering and the other is the very specific field of nuclear weapons, its production and philosophy.

The language of nuclear engineering involves a lexicology characterized by international, registered scientific terms accepted and integrated in the nuclear engineering practice. It is a precise and pragmatic field bound to express a series of facts, events, theories and new knowledge that did not exist previously. This precision and pragmatism was conveyed fundamentally by means of the use of neologisms and lexicalization [3].

However the language used in the nuclear weapons terminology is obviously intrinsically restricted to a limited community and would present a systematic use of euphemistical expressions and metaphors as the motive force of its development. The first nuclear bombs were named Little Boy (the Hiroshima bomb of uranium) and Fat Man (the Nagasaki bomb of plutonium), because of their nuclear fuel and size.

According to the definitions given in 1969 by the Nuclear Terms. A Brief Glossary, these two last weapons were included in the group of dirty bombs "a fission bomb or any other weapon which would distribute relatively large amounts or radioactivity upon explosion", versus clean bombs "a nuclear bomb that produces relatively little radioactivity fallout. A fusion bomb" [4].

Today, the definition of dirty bomb is rather restricted to a specific radiological weapon (radiological dispersion device), and clean bombs are directly associated to neutron bombs.

During the personal conversations I had with Dr. Edward Teller, he told me that when the hydrogen bomb was being fabricated at Lawrence Livermore National Laboratory, the device was known as Teller's baby [5].

We can also find terms such as strategic stability (peace) collateral damage (killing of people) and counter-value attacks (incinerating cities) [6].

As we can see, the language of nuclear weapons has got a conciliating role with a constant dissociation between thoughts and terms that finally becomes a group of abstract words that get sense in a very specific community, context and situation.

Nuclear terminology comes to Spain, as to many other countries, with the celebration in August 1955 of the First International Conference on The Peaceful Uses of Atomic Energy, sponsored by the United Nations in Geneva. This conference was held 2 years later of the launching by President Dwight Eisenhower of Operation Candor in 1953, whose main goal was to inform the American citizens of the dangers involved in a nuclear war. On 8 December 1953, President Eisenhower opened the door of the Program Atoms for Peace whose objective was to spread the use of nuclear energy for peaceful uses for the rest of the countries in the world [7].

Spanish nuclear language was adapted by experts of the former Spanish Atomic Energy Commission (JEN) which worked very hard during years with the avalanche of new concepts, magnitudes, devices and phenomena whose nomenclature had as main etymological source the English language that came out from the U.S. These experts not only had to translate the English terms but also had to provide them with their conceptual value in Spanish. The result was the text Nuclear Lexicology (Lexicología Nuclear) that was published in 1974.

Kyoto protocol

Kyoto Protocol to the United Nations Framework Convention on Climate Change was established on December 11, 1997 and entered into force on February 16, 2005. It was aimed at reducing the net emissions of Greenhouse gases, mainly carbon dioxide.

In Article 2 -iv) it is read: "Research on, and promotion, development and increased use of, new and renewable forms of energy, of carbon dioxide sequestration technologies and of advanced and innovative environmentally sound technologies" [8].

Nuclear energy was not mentioned as a good alternative free of Greenhouse gas emissions. This fact has been widely exploited by antinuclear sectors.

One of the conclusions of the Intergovernmental Panel on Climate Change (IPCC – 6 April 2007) says: "Climate change phenomena would cause extreme natural disasters, lead to serious food crises and increase health dangers".

This statement is another encouraging reason for the use of nuclear energy.

The antinuclear discourse

The antinuclear discourse promoted late in the seventies, has gone deeply into the collective social unconsciousness and has undermined public acceptance of nuclear energy due to three facts:

- Nuclear Proliferation
- Accident of Chernobyl
- Nuclear Waste

Nuclear proliferation

Nuclear weapons are to be related to nuclear energy in the same way that chemical or biological weapons are to be related to pharmaceutical chemistry or molecular biology, that is, they represent a completely different application of the same science. Not to say, nuclear, chemical or biological terrorism which could be considered as the evil side of these sciences that so many benefits and prosperity have brought to humankind. However in the case of nuclear weapons, the arguments have been exacerbated.

In First World War (1914–1917) some of the nations involved, used massively poison chemical gases in the battlefield. A decision that caused a number of estimated gas casualties that, although differing on the number according to sources, could be estimated between 530,000 and 1,300,000. If we take into account that the human losses of that conflict were an approximate number of 8,700,000 persons [9] among military and civils, the gas victims' proportion is both quantitative and qualitative high.

In Second World War (1939–1945) two nuclear bombs were dropped in Japan that, according to several sources, and taking into account the many difficulties to make the final accountancy, caused a number of casualties of about 300,000 [10]. Second World War, the most lethal conflict in the history of mankind, caused about 55,000,000 casualties among dead, injured and disappeared civil and military persons [11].

Accident of Chernobyl

Social opposition has seen in the highly manipulated Chernobyl accident (26 April 1986) a paradigm of potential nuclear accidents.

To combat this wrong perception, it would be necessary to explain the real circumstances of Chernobyl power plant that was provided with a reactor type RMBK, that since 1945 was considered as intrinsically unsafe. Indeed it was optimum for the production of plutonium but not for the production of electricity.

These light water graphite moderated reactors (RMBK) do not have containment building similar to the containment buildings found in West nuclear power plants, especially those of PWR and BWR. Another particularity of the RMBK reactors, considered since 1945 as intrinsically unsafe, is that the reactivity coefficient of temperature and void is positive: the higher the temperature, the higher the number of nuclear fissions and therefore the higher the energy produced that, in turn, leads to another increase of temperature.

The test carried out at Unit 4 of Chernobyl nuclear power plant was an extraordinarily dangerous experiment due to the intrinsic characteristics of the reactor. This experiment brought the reactor to its marginal limits of safety. Consequently, the violence of the accumulated energy made the cover of the reactor to jump up abruptly thus breaking the reactor's cavity. The combustion of the graphite converted the reactor in an immense furnace in which radioactive products were released to levels of several million of curies per day.

Anti-nuclear groups were joined by Cold War anti-Soviet propaganda and created a big international alarm that was not counteracted by Soviet authorities, which found themselves in the middle of an extreme complex situation in the context of a political instability that, only 5 years later, would lead to the dissolution of the State.

Solvent international organizations such as the United Nations, the International Atomic Energy Agency and the Nuclear Energy Agency Organisation for Economic Co-Operation and Development, among others, carried out several multidisciplinary high level researches and analyses of that tragic incident to establish, in an accurate and reliable manner, its real development and consequences:

- Chernobyl's Legacy: Health, Environmental and Socio-Economic Impacts and Recommendations to the Governments of Belarus, the Russian Federation and Ukraine. The Chernobyl Forum 2003–2005. Second revised edition: IAEA, WHO, UNDP, FAO, UNEP, UN-OCHNA, UNSCEAR, WORLD BANK GROUP. Belarus, The Russian Federation and Ukraine.
- The Human Consequences of the Chernobyl Nuclear Accident. A Strategy for Recovery. A Report Commissioned by UNDP and UNICEF with the support of UN-OCHNA and WHO. Chernobyl Report-Final-240102. 25 January 2002.
- Chernobyl Assessment of Radiological and Health Impacts. 2002 Update of Chernobyl: 10 Years On. Nuclear Energy Agency Organisation for Economic Co-Operation and Development.
- World Health Organisation. Chernobyl: The true scale of the accident. 5 September 2005.

Undoubtedly and apart from the acute health effects and late health effects, Chernobyl's accident caused social, psychogenic and psychological effects that have obviously intervened negatively in overcoming the difficulties and circumstances derived of that unforgettable event.

Nuclear waste

It is another factor presented as negative in the antinuclear discourse. Presently R and D is being carried out for the creation of a transmutator of long-life radioactive waste. It is a proton accelerator driven transmutation system which works against a lead target. Each proton induces 15 neutrons in the lead nuclei as a result of spallation and thus long life waste is converted into short life one The transmutator would have a 99% efficiency, and high density world nuclear waste would be reduced into 3,000 l.

Solution to the bad perception of nuclear fission energy in the society

To get a positive response from social stratums, it would be necessary:

- To adopt a realistic position by governments which should consider national energy policy as a state matter not a contingent question related to unfounded reasons or ideological criteria
- To clarify the real figures of the Chernobyl accident as reported by the United Nations, and to explain how Chernobyl was not a standard nuclear power plant for producing electricity
- To present a responsible, veracious and reliable advertising campaign in which nuclear science is presented as a main science for civil purposes in the fields of energy production, medicine, agriculture and industry

Contribution of nuclear techniques directed to basic human needs and to a sustainable development are not much known, and their uses in developing countries, either in Africa, as in Latin America and other parts of the world, have a broad scope of applications such as to assess the nutritional estate in children, their vitamin deficiency, bones diseases, etc. In countries were water is scarce, hydrological isotopic instruments help to know and organize better the existent supplies, etc.

In 1983, the International Atomic Energy Agency began the support of a program that allows developing countries to maintain their own tissue banks. In Lima in 2001 a fire that occurred in a market in the centre of the city took 400 people lives. However due that Peru belongs officially to this programme, its application saved the lives of 60 people that were severely injured during the fire. By 2002 the tissue banks had established 60 centres in Asia Pacific, 7 in Africa and more are being created [12].

Another important use of nuclear technology widely used as a form of insect birth control is the Sterile Insect Technique (SIT) and radiation to eradicate plagues producing fatal diseases. With respect to the tsetse fly, a model project was started by IAEA in Zanzibar in 1994 to eradicate both this pernicious fly and the Trypanosomiosis disease. The model project was applied afterwards in Sub-Saharan affected zones, being its final end to eradicate tsetse flies from 25,000 km^2. According to the IAEA report on this project “Trypanosomiosis cases in sentinel animals decrease to a negligible level of less than 0.1 per cent” [13].

Infections produced by malaria, Chagas disease, TB, hepatitis, etc are being also being approached by nuclear techniques [14].

With respect to the field of security and safety or nuclear power plants, it would be of public interest the information about the research that is being made on Generation IV nuclear reactors, that could represent the future of nuclear fission energy.

Conclusions

Distribution of energy resources is very irregular due to the fact that largest oil resources are mainly located in the Middle East (Saudi Arabia, UAE, Iran, Iraq, Kuwait and Qatar) and main gas resources are held by the Russian Federation followed by I.R. Iran, Qatar, Saudi Arabia, UAE, Nigeria, Venezuela, Algeria and Iraq [15].

Energy scenario in the twenty-first century appears as one of the most complex existing so far, since most countries in the world depend of external energy sources. Indeed, energy demand is gradually increasing in industrialized countries and it is also highly required by China and India, two countries in a quick industrialization via.

This economic growth could lead to an energy crisis if the increasing demand does not come in parallel with an increase in production, and the disadjusting of the balance between energy offer and demand would imply big increment and fluctuating prices.

Another factor to take into consideration is that it does not exist a supplying energy system that could be considered as completely reliable and safe for a long-term period of time, due to accidents, potential political crisis, technical failures, etc. that may affect directly to its supply.

Wariness in energy supplying systems grows in parallel also with the evolution of events derived of commercial disputes, such as the case of the gas delivery from the Russian Federation to Europe across Ukraine and Belarus (Litigious Moscow-Minsk [2006] and Moscow-Kiev [2006, 2008 and 2009]). This is one of the reasons of the new orientation of the energy policy of the European Union that is going to be directed under the principles of enhancing security in energy supply as well as competitiveness of European products, the cheaper the energy the cheaper the manufacturing products.

All the previous factors have led to a global growing interest in nuclear power that is being ratified at international levels by different organizations. EU countries are recommended to increase its share of nuclear power to a 40% by 2030 [16].

According to the Spanish expert, Professor Guillermo Velarde "New nuclear power stations should be constructed together with the implementation of R&D in the capture and storage of CO_2; nuclear waste transmutator; high-temperature thermal and new photovoltaic solar energy, and the production and use of hydrogen. However, the final solution to the long-term energy problem will be solved when nuclear fusion will be available. Nuclear fusion is the energy produced by the stars and, in particular, by our Sun, that we are looking for to produce on Earth" [17].

Indeed, nuclear fusion seems to be the best alternative for several reasons:

- Its fuel is deuterium which can be found in the water and therefore accessible to any country in the world.
- It would reduce or avoid the present dependence of primary energies based on fossil fuel sources.
- It does not emit Greenhouse gases.
- It would be available for every country in the world, thus benefiting the economy of developing nations.

On 29 May 2009 the NIF (National Ignition Facility) experimental reactor on fusion inertial confinement fusion will be inaugurated at Lawrence Livermore National Laboratory (United States) and within 2 years the LMJ Laser Megajoule, a similar reactor, will be operative in Bordeaux (France). The aim of these two experimental reactors is to achieve nuclear fusion with energy gains.

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THE ROLE OF NUCLEAR POWER IN THE REDUCTION OF GREENHOUSE GAS EMISSIONS

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Abstract Nuclear energy is a low greenhouse gas emitter and is capable of providing large amounts of power using proven technology. In the immediate future, it can contribute to greenhouse gas reduction but only on a modest scale, replacing a portion of the electricity produced by coal fired power plants. While it has the potential to do more, there are significant resource issues that must be addressed if nuclear power is to replace coal or natural gas as a source of electricity.

Introduction

Currently, nuclear power provides approximately 19% of the total electricity generated in the United States and approximately 15% of the world's electricity. In 2007, 439 nuclear reactors located in 31 countries generated over 2,698 TWh of electricity [1]. Of these, 104 nuclear power plants are located in the United States and generated a total of 806.5 TWh [2, 3] of electricity. Over the next 40 years, the number of reactors in the US and in the world is expected to grow as the world's demand for electricity becomes greater. The increase will be due to both population growth and the expanded use of electricity, with much of the growth associated with increases in electrical use in China, Asia and the developing economies. Figure 1 depicts the expected growth in electricity consumption worldwide.

Another factor influencing the growth of nuclear energy is the concern over carbon emissions. There is growing public interest as well as among decision makers on decreasing the emission of greenhouse gasses. The exact way in which these policies will be implemented has yet to be determined. What is clear is that those technologies that emit greenhouse gasses will be penalized in favor of those that are low emitters.

Because nuclear power does not burn fossil fuels to generate electricity, it is often cited as a currently available source of electricity that could contribute to the lowering of greenhouse gases. To do so, nuclear reactors must be built at a rate greater than ever before. Several impediments exist to achieving such a rate and include the availability of funding for construction, the lack of infrastructure for component manufacture, concerns over nuclear safety, the lack of a method to

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dispose of the spent fuel, and the lack of trained and experienced workers to build and operate these new facilities.

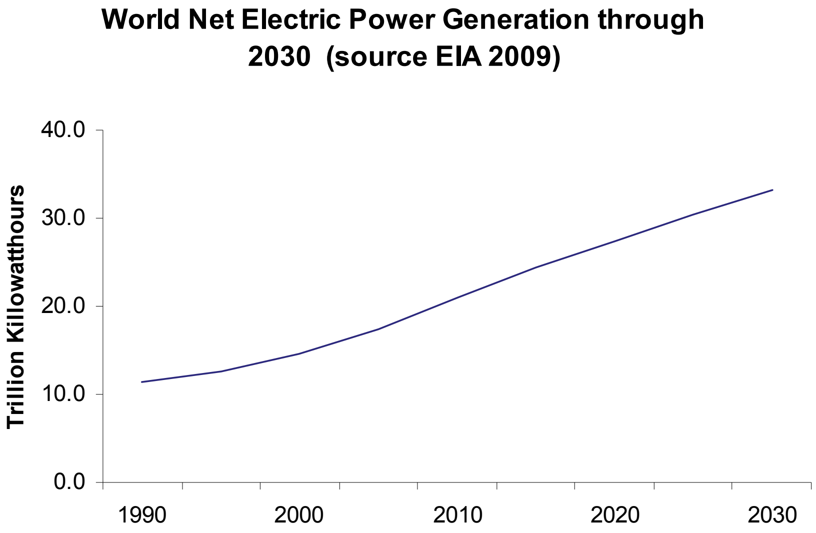

Figure 1. Actual and projected world net electrical energy production through 2030 (US EIA 2009)

Reactor safety

Since the fission process produces large amounts of highly radioactive material, the reactor must be designed, built, and operated to prevent the escape of the fission products to the environment. In western design reactors and newer reactors of Russian design, multiple barriers prevent the fission products from being released to the environment by in the event of an accident. The barriers are the fuel itself, the zirconium cladding, the reactor cooling system and the reactor containment building, which houses the reactor and associated systems.

Critics are concerned that a severe reactor accident much worse than occurred at Three Mile Island [4] could lead to failure of the containment building and widespread contamination of the surrounding area with fission products. Such an accident did occur at the Russian designed nuclear power plant at Chernobyl in the Ukraine. This reactor did not have a containment building and when the reactor failed catastrophically, it contaminated much of the surrounding area [5].

Waste disposal

Another concern that is frequently cited is what to do with the spent fuel that is generated. To optimize the burnup of the uranium 235, the reactor is shut down about every 18–24 months and some of the fuel replaced and the remaining fuel rearranged. A typical fuel assembly stays in the reactor a total of about 6 years before the uranium 235 content becomes too low for its continued use. It is then transferred to the spent fuel storage pool where the faster decaying fission products are allowed to decay and the assembly cools. It may remain there for many years before being transferred to a dry fuel storage cask. Even after removal from the spent fuel pool, the fuel assembly still contains very large amounts of highly radioactive material that must be kept from the environment. Under the National Waste Policy Act, the US Department of Energy is to take custody of the spent fuel and dispose of it through deep geological disposal.

After an extensive scientific assessment, the Department of Energy chose Yucca Mountain, located about 90 miles north of Las Vegas, Nevada, as the site for the repository. In June of 2008, the Department of Energy submitted a construction license application for the repository to the US Nuclear Regulatory Commission, the licensing authority [6]. The construction and operation of the proposed repository is highly controversial and is strongly opposed by many critics including Nevada's congressional delegation. Funding of the Yucca Mountain Project and activities at the site in Nevada were dramatically curtailed by the Obama Administration, which pronounced the project as dead. Thus at this time, the possibility of construction of the repository at Yucca Mountain is extremely unlikely. Even if the licensing and construction of the Yucca Mountain repository were to continue, it is not likely to be in operation until 2020 or later. Despite assurances that the spent fuel currently at reactor sites and anticipated to be produced in the future may be safely stored there for at least 20 years beyond the life of the reactor, critics are concerned that the nuclear industry has yet to develop and demonstrate a safe long term solution to the issue of spent fuel disposal and frequently cite this in opposition to future growth of the nuclear industry.

Outside the United States, the approach to the disposal of spent fuel is somewhat different. Through the use of reprocessing, the plutonium and unburned uranium are removed from the waste stream. Since plutonium is one of the materials in the fuel that remains radioactive the longest, its removal reduces the time the waste must be isolated from hundreds of thousands of years to a few thousand years. Although even safe storage of spent fuel for this amount of time has yet to be demonstrated, it is believed to pose much less of a technological challenge and has in fact been implemented at the Waste Isolation Pilot Plant or WIPP [7]. Waste from the US's nuclear weapons program is presently being disposed of at WIPP in salt domes. The waste consists only of the fission products and not the plutonium or uranium that would be in spent fuel sent directly for disposal without reprocessing.

Proliferation concerns

To operate a modern power reactor requires increasing the amount of the uranium 235 isotope from its natural value of 0.7% to between 3% and 5% using one of several enrichment technologies. These same enrichment technologies may also be used to increase the enrichment of uranium 235 to that needed for a nuclear weapon. Because of this, there is great concern an increase in the use of nuclear energy will lead to the spread of nuclear weapons. A classic example currently in the news is that of Iran.

Iran is currently completing the construction of a Russian designed commercial light water reactor. Although fuel for this reactor will initially be provided by Russia, Iran is also building a uranium enrichment facility. Some believe that this facility is not intended for commercial application but instead is intended for the production of highly enriched, weapons grade uranium. Iran has repeatedly denied this, asserting that the project is intended to provide a secure source of fuel for its civilian nuclear power program. Despite repeated requests for a complete and thorough disclosure of its plans, some believe that Iran has not fulfilled its obligations under the Nuclear Non-Proliferation Treaty to which it is a signatory. Its actions have prompted suspicion about Iran's motivations and led to sanctions being imposed by the United Nations.

The danger here is not the construction of the reactor or its operation. Rather it is the spread of enrichment technology and the construction of such facilities in countries that may divert the enriched uranium from peaceful uses to weapons. Efforts are underway by the United Nations and Russia, the United States and other countries to develop a fuel bank to ensure the supply of fuel for any country, eliminating the need for countries to develop their own nuclear enrichment capability.

Others have also expressed the concern that the plutonium that results from the absorption of a neutron by uranium 238 in the fuel of a commercial reactor could also be used to construct a weapon. The plutonium that is produced in a commercial reactor can be used for a weapon but it is far less suitable and also very difficult to extract from the fuel due to the tremendous amount of radiation emitted from used reactor fuel. To obtain plutonium from a reactor that is suitable for weapons requires fairly short times in the reactor, something difficult to achieve in most commercial reactors. Those countries that did produce plutonium for a weapon did so using research reactors or specifically designed production reactors.

To obtain commercial nuclear technology, a country must submit to monitoring by the International Atomic Energy Agency (IAEA) as required by the Nuclear Non-Proliferation Treaty. While this does not prevent a country from having a clandestine program such as some have suggested that Iran has, it makes it difficult to do so using commercial reactors. The fear of proliferation from commercial reactors is probably not well founded.

Factors favoring increased use of nuclear power

Given these concerns, what is driving the recent renewed interest in the construction and operation of new nuclear reactors? The current generation of reactors has demonstrated a very high capacity factor, upwards of 98% [8] and low generating costs compared to nearly all other forms of electricity generation. Typical generating costs for a nuclear station are about $0.018–0.02 per kWh [9], the lowest of any source. Further, since fuel costs are relatively stable and low compared to fossil fuels, there is some certainty that the cost of generation will increase much more slowly for nuclear fuel than for gas or coal fired power plants.

Finally nuclear is cited as extremely low in carbon footprint compared to nearly any other source of electricity. Studies performed in the US and abroad [10–13] show that while nuclear is not completely carbon free, its carbon emission is lower than any other technology currently available and some studies suggest that it is even comparable to renewables such as wind and solar. A detailed discussion of this topic is beyond the scope of this chapter. Table 1 compares the carbon emissions from a variety of sources including wind and solar.

Table 1. Comparison of carbon emissions from various sources

Technology	g/kWh
Coal	900–1,000
Combined cycle gas turbine	500
Solar voltaic	50–100
Wind	5–30
Nuclear	6–26
Hydro	3–11

Prospects for new nuclear power reactors

By 2030, electrical consumption worldwide is expected to increase by 70% [14]. To meet this demand, all sources of electricity will need to be increased. Currently in the US and abroad, there is significant interest in new nuclear power plants. As of this writing (June 2009), 17 applications for construction and operating licenses have been submitted to the US Nuclear Regulatory Commission for the construction of 26 new reactors. In addition, several reactors whose construction was stopped in the 1980s are now being considered for completion. Construction has already been restarted at one, Watts Bar Unit 2, and at least two other reactors are under review as possible candidates for completion [15]. In Japan, the number of reactors is expected to increase from 55 to 68 over the next few years. A recent study by the Office of Economic Cooperation and Development (OECD) predicts that by the year 2050, there will be between 600 and 1,400 nuclear reactors in operation worldwide. While the actual number will depend as much on economic factors and growth in electrical consumption as anything else, it is reasonable to expect the number of reactors to grow and possibly maintain the percentage of electricity generated worldwide by nuclear power. If such growth occurs, then nuclear may begin to reduce the greenhouse gas emissions contribution from electricity generation.

To assess the impact that new nuclear generation might have on greenhouse gas emissions from the electric generation sector in the US, a study was conducted by the author, using as its basis the EIA projections for electric generation by fuel source in 2030. Figure 2 shows actual and projected electricity generation in the US through 2030 broken down by source [16]. The projections assume that nine new nuclear power plants will be added by 2030 and there will be modest increases in the power produced by existing reactors through a process called power uprates. The EIA projects that overall electricity generation will increase about 25% by 2030 but that nuclear's share will decline from its current value of 19% to about 17.6%. To maintain nuclear's current percentage, given an overall growth in electricity generation, will require construction of an additional nine nuclear reactors for a total of 18 new nuclear reactors by 2030 [17]. An increase above the EIA's projections would increase nuclear's percentage share and at the same time decrease the amount of electricity generated by coal, reducing the amount of greenhouse gas emitted.

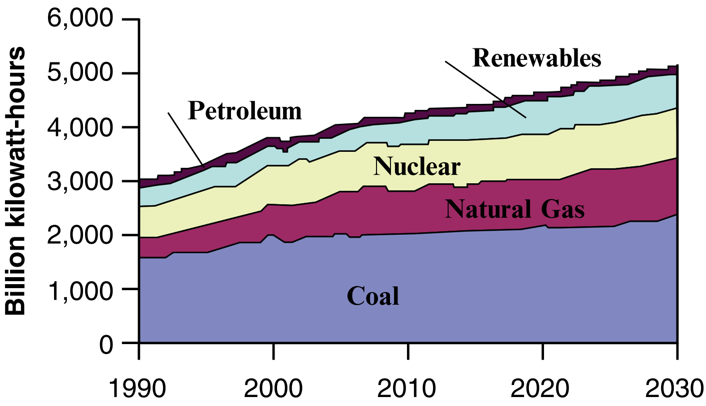

Figure 2. US electricity generation by source through 2030 (EIA 2008)

Table 2. Percentage of electricity generated in the United States in 2030 by coal and nuclear as a function of the number of new nuclear reactors built

	EIA study	EIA plus 9	EIA plus 18	EIA plus 27	EIA plus 36
Coal	46.7	45	43	40	38
Nuclear	17.6	19.6	22	24	26

Table 2 shows the effect on coal generation and hence greenhouse gas emissions of adding additional nuclear reactors above the nine in the EIA study. The table shows that one can achieve close to a 20% drop in the amount of electricity generated by coal producing a similar drop in greenhouse gas emissions by building a total of 36 additional nuclear reactors above the 9 in the original EIA study. Considering that there are currently a total of 17 applications for 26 reactors under review by the US Nuclear Regulatory Commission, it is reasonable to expect a majority of these will be built. These 26 reactors would correspond closely to the case labeled EIA plus 18, yielding nearly a 10% reduction in the amount of electricity generated by coal and a commensurate reduction in greenhouse gas emissions. If that number is doubled to 36 above the EIA study, then one could achieve a reduction in the percentage of coal fired electricity generation of nearly 20%.

Factors affecting the feasibility of increased nuclear generation

Currently, the US and other countries are considering major new nuclear building programs. There are currently 59 countries with nuclear power. An additional 21 others have indicated an interest in the construction of nuclear power plants. These programs feature a new generation of power reactors that are designed to be safer, cheaper to build, and are also expected to be easier to operate and maintain than the original designs now used. While for the most part these designs are based on the current technologies, they do represent some technological and cost risk since most of the design work has yet to be completed and only one of the new generation reactors has actually been built.

The new designs that are currently being considered for construction are Westinghouse's Advanced Passive 1000 (AP 1000), AREVA's Evolutionary Power Reactor (EPR), General Electric-Hitachi's Economic Simplified Boiling Water Reactor (ESBWR), General Electric's Advanced Boiling Water Reactor (ABWR), and Mitsubishi's Advanced Pressurized-Water reactor (APWR). Of these, only the ABWR has been built and is in operation, four in Japan and two in Taiwan. AREVA is in the early stages of construction of two EPR's, one in Finland and the other in France.

Each of these designs includes safety features that are intended to reduce the likelihood of an accident and to reduce the probability of a catastrophic release of radioactivity should an accident occur. The designs are also intended to be easier to build and less susceptible to construction delay through the use of modular construction techniques. Another advantage of the use of standardized design is building nearly identical reactors, reducing cost and construction time. Currently, the US has nearly 104 different reactor designs since each of the reactors built during the current generation are essentially one of a kind. By comparison, the French nuclear program has only three different designs in its 58 nuclear reactors. With this next generation of reactors, it is likely that no more than five designs will dominate the market.

Cost concerns

Even using labor saving construction methods, the cost of these new designs is expected be about $6 billion per reactor. At one time, it was thought that the cost of new nuclear power plants would be around $1,200 per kWe for an overall cost of between $1.5 billion to $2 billion. Unfortunately commodity price increases have forced these estimates up considerably to close to $5,000–6,000 per kWe or

$6 billion for a 1,000 MWe unit [18]. If the cost of project management, financing, and detailed design is included, some have suggested that the total cost of a new nuclear power plant would be upwards of $12 billion [19]. Such huge capital requirements in today's financial markets are likely to be difficult to fulfill without some forma of government intervention.

One possible way to reduce the risk and decrease the financing costs is through government loan guarantees. Under such a program, the cost to the guarantor is only the cost of administration of the program unless a default occurs. Use of the government guarantee would reduce the interest rate to a small margin above a long term US Treasury bill rate (or a small margin over LIBOR [20] plus the cost of an interest rate swap to "fix" the interest rate) which may not be available in today's market. It is likely that guarantees would only be needed for the first few plants of each type. Once experience is gained and there is some certainty as to cost and construction schedule, it is likely that private investment would be easier to obtain, obviating the need for guarantees.

Lack of an adequate supplier base

There are also a very limited number of suppliers for many of the major components that are needed to construct a nuclear power plant. Components such as the pressure vessel that houses the nuclear reactor, the pumps and valves used in the cooling system, and the steam generators must all be built to extremely high standards. Since very few nuclear power plants were constructed worldwide in the 1980s and 1990s, the number of suppliers of these components has dwindled significantly, particularly in the US. In fact, the US currently cannot manufacture these large components and must rely on other countries, mainly Japan and China, for them. Japan has continued building nuclear power plants and even it has only one supplier, Japan Steel Works, which can produce the large forgings needed to make a reactor vessel at a rate of eight to nine per year. The limited numbers of suppliers simply do not have the capacity to produce these components in the quantities needed to support such a major increase in reactor construction.

To overcome the limited number of suppliers, additional manufacturers are needed. Because of the current uncertainty, it is unlikely that such suppliers will enter the market without incentives. To increase the number of suppliers, it may be necessary for the government to devote some of the stimulus money to encourage alternative suppliers for these large components to enter into the nuclear component manufacturing business. These funds could be provided through tax incentives or direct grants to prospective suppliers to offset the cost of bringing additional capacity online in an uncertain market.

Uranium fuel supply

Once built, each reactor must be provided with fuel in the form of enriched uranium oxide. As discussed earlier, the isotopic content of uranium 235 must be increased from the naturally occurring value of 0.7–3–5%. To do so requires a large quantity of raw uranium ore. It takes about 10 metric tons of raw uranium to produce 1 metric ton of enriched uranium. To fuel all of the 400 plus reactors currently operating in the world requires about 65,000 metric tons of ore. The current estimate of proven reserves is 4.7 million tons. In addition it is estimated that about 10 million tons have yet to be discovered. This suggests that there is enough fuel to supply the existing reactors for over 200 years. In addition there are a number of non-traditional sources from which one could obtain uranium, albeit at a higher cost. These include the extraction of uranium from the ocean as well as from areas of very low concentration such as Chattanooga shale, which contains about 66 ppm of uranium [21]. Thus it is likely that current reactors, even considering a major expansion of such reactors, will have sufficient fuel for the foreseeable future.

Trained workforce

The last impediment to the large scale development of nuclear power is the availability of skilled, trained, and experienced workers and operators. As the French discovered with the construction of their first two EPR's, one must have trained workers who can produce the materials and components needed for a nuclear power plant and a construction workforce that can build the facilities to exacting standards. Every safety significant component or structure in a nuclear power plant is subject to extensive testing and inspection to ensure that each meets the required standards. The reinforcing bars and concrete used to make the reactor containment must be strong enough in the event of an accident that the containment building will not fail. Similarly, the welds used to connect the piping of the reactor coolant system must be defect-free to avoid a pipe failure and subsequent loss-of-coolant accident. To achieve these high standards requires a trained, skilled workforce. Training and qualification programs must be developed to create such a workforce.

US utilities that have plans to build are working with local technical schools to develop such a workforce. The US Nuclear Regulatory Commission and the US Department of Energy have both been tasked by the US Congress to aid in this effort through the use of seed grants to help schools develop the necessary curriculums, hire faculty and buy equipment to support the development of such programs. Such efforts are needed at all levels if the construction and manufacturing human capital needs are to be met.

Conclusion

While these challenges to the widespread deployment of new nuclear plants exist, they are not insurmountable, given the resources and will to succeed. As this paper points out, nuclear is a low greenhouse gas emitter. It is capable of providing large amounts of power using proven technology throughout the day and year regardless of wind or cloud conditions. In the immediate future, it can contribute to greenhouse gas reduction but only on a modest scale, replacing a portion of the electricity produced by coal fired power plants. While it has the potential to do more, there are significant resource issues that must be addressed.

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NUCLEAR ENERGY & ENERGY SECURITY

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Safety & security

Safety issues related to use of nuclear energy and secure operation of nuclear installations are mail stones of great importance. Although none of technologies producing energy are absolutely safe it is obvious that technology "extracting" the electricity from nuclear fuel needs to apply relatively higher level safety and security.

Risk of safety operation depends on many factors and varies country-by-country as well as technology-by-technology. The main principle of obtaining energy from the nuclear fuel is same for all nuclear power plants. In spite of this, safety level in modern technologies much higher. Past accidents and catastrophes on nuclear power plants served as a basis for improvement of nuclear technologies. Level of knowledge is also raised. First nuclear power plants were constructed by general engineers. Subsequently nuclear engineering established as a separate part with experience and knowledge oriented mainly on nuclear installations.

Decision of application of nuclear energy (as a source of electricity generation) should be based on routine investigation of risks, benefits and needs. It should be taken into consideration that nuclear energy technologies while decided to be applied may motivate the country to raise level of education, science, industry, state security. So nuclear energy may be considered as a locomotive for progress. But this needs to be applied right time and right place. Otherwise it may cause catastrophic consequences for economy and society.

Non-proliferation

This is not clear how the development of nuclear energy technologies related to country's will to obtain nuclear weapon. There is no need to spend so much time and resources such way. This is easier to acquire and possess illegally as for any case possession of nuclear weapon is illegal act according to agreement between Country (for example, Georgia) and IAEA on Non-proliferation of nuclear weapon.

In the other hand, possession of nuclear energy technologies obliges country to enforce internal procedures in order to guarantee limitation of use of nuclear energy only for peaceful purposes.

Nevertheless everything depends on country's will. You can use the brick for constructing the house. But you may kill the man with same brick.

S.A. Apikyan and D.J. Diamond (eds.), *Nuclear Power and Energy Security*,

Terrorism

There is no example of terrorist act with nuclear or radioactive material involved. Terrorists generally do not express their interest to use such materials as they need momentous effect as a result of terrorist act. For such reasons explosives are most appropriate. Even other parts of WMD (Weapons of Mass Destruction) as Biological and Chemical agents are not popular. There are just several cases of use – anthrax and salmonella in US, botulinum and Sarin in Japan, defoliants in Eastern-Southern Asia etc. Nevertheless increasing of global terrorism may make some "corrections". The consideration that air plane crash may destroy nuclear power plant alarms. Such consideration urges technology makers to raise safety level of new generation power plants but currently such plants are only on paper. For existed power plants security improvement is essential even by use of anti-aircraft systems.

So if you decide to bay luxury car you have to obtain modern security system to avoid theft.

Climate change

Nuclear energy is energy with nearly zero green-house gases emission. For this reason it well fitted in current environment with serious threat of climate change. As for data of the year 1993 nuclear energy replaced 2,100 million tonnes of carbon dioxide emission per year. Nevertheless nuclear energy can not prevent all emissions. Currently carbon dioxide emission is app. 7 billion tonnes annually which is envised to be double in 2050. For nuclear energy to offset only one billion of carbon dioxide means that 1,000 MeW installation should be connected to grid in every 2 weeks from today till 2050.

For such reason conjugation of reasonably available nuclear energy with renewable energy sources plus energy efficiency and energy conservation measures may help human society to achieve considerable results.

Cheap energy

Cost of energy installation divides on capital and operational costs. For nuclear energy capital cost is quite higher than operational. The one reason is that construction cost is high than fuel price is low. In the other hand fuel price change reflected very smoothly. For example, even doubling of fuel price causes electricity production cost raise only by 3–5%. So the statement that nuclear energy is "cheap" needs clearance. This is also important that in case of nuclear fuel this is possible to make stockpiling long time ahead and thus, avoid rough change of electricity production cost caused by permanent fluctuation of carbohydrates prices on the Global market.

Nuclear power plant needs high capital investments while licensing, constructing and commissioning. After stages as above it operates for long time with low maintenance and fuel prices. Taken into account the current tendencies of global market in price changes for goods, materials etc. this is reasonable to state that investment made in industry (nuclear power plant) facility may have benefit in future by itself.

It should be considered also that states expressing their will to construct nuclear power plants strongly recommended to extend their industry possibilities so to cover construction capacity needs (in materials and sub-constructional elements) by up to 60%. It means that even wholly subsided by Government, the monetary resources will realized inside the country by up to 60% – the perfect example of "locomotive" for other part of industry in the State.

Besides other findings should be discussed. Broadly known that launching the nuclear program does not mean starting of plant construction from the beginning – long time preparatory work should be fulfilled before. Due to different calculations 10–15 years needed before plant commissioning. This period of time is crucial in capital cost formation as any delay cause rising of capital investments. In this the Parkinson's law, which is well known in administrative management, should be taken into account. According to this "work expands so to fill the time available for its completion". The time needed for preparatory work thus should be optimised in order to avoid economical loses caused by excessive prolongation of this time.

Another challenge is how the final electricity price change related to the energy production/energy consumption levels change. Reduction of final electricity price may cause increase of electricity consumption. This means energy demand also will be increased which by itself demands more energy production installation to be in place. Thus, introduction of cheap energy source may cause increase in demand of new energy production facilities installation.

Peaceful and non-peaceful use

There are few examples of use of nuclear weapon during history. But no guarantee that such facts will not take place in future. In the other hand the nuclear weapon is a mean of retaining by itself – this is also the fact. This is generally recognized that presence of nuclear weapon avoided conflicts between countries possessed such weapon.

War-time targets

In case of nuclear power plant the issue is more complicated. Power plants may become targets for terrorist but also they may be damaged during potential war campaigns. Nevertheless the resent case in former Yugoslavia while tensions rose between Slovenian and Croatian troops shown that Krsko nuclear power plant located in Slovenia very close to border with Croatia acted as a "pigeon of peace" and conflict finished in hours – both sides avoided to destroy nuclear power plant with catastrophic results for their countries. But other reason why this conflict stopped quickly may be more important. The Krsko nuclear power plant was built by cooperation of Slovenia and Croatia by investment sharing 50/50. The 50% produced electricity exported to Croatia without payment. So they avoided not only ecological but also extremely negative economic consequences. This example shows feasibility and sustainability of multi-national nuclear projects. Especially if such project is shared between neighboring countries – this may be strong guarantee of peaceful development of whole regions.

Conflicts vs economy

The other factor is also should be taken into account. The tendency of nuclear power reactor modification includes rising of reactor capacity – economically this is better to construct big nuclear reactor and thus to decrease electricity production price. In the other hand nuclear power reactor with high capacity (1,000 MW and more) is an unpleasant “bargain” for electricity grid. In case of nuclear reactor emergency switch-off the whole system may be collapsed. Generally known that ideal capacity for each power installation inside the country should nor exceed 10% of whole current capacity in order to avoid abovementioned instabilities in electricity grid. Therefore, application of one “big” common nuclear power plant for several countries in one region may help to achieve double aim – to provide with cheap, stabile energy and to guarantee the peace.

Fusion

Even fusion remaining as a “fantasy” up to now this is considered as one among future sources of energy. Investigations in this sphere shown deployment of fusion reactors may be anticipated after 50–80 years. Even everything unclear this is evident that fusion technology is an extension of nuclear. Such technology needs same (or even higher) level of safety and security, infrastructure development etc.

Do Georgia needs nuclear energy?

Nuclear energy is high technology and application of such technology needs definite level of industry, science and society development. Nuclear energy is not only source of electricity production – application of nuclear energy increases year-by-year for medical, science and industrial use.

As an energy source Georgia has priority to extend hydro-power capacity by reasonable use of all available water resources. In parallel regime the application of energy efficiency and energy conservation measures should be considered but currently this is not prioritized by Government. Meanwhile this should be taken into consideration that attempts to reduce energy consumption by increasing energy efficiency would simply raise demand for energy in the economy as a whole.

The Nuclear energy application needs routine calculation and investigation. For this reason Government Commission is already established. But it seems in advance that regional nuclear power plant for South-Caucasus region would be much more attractive for future.

OVERVIEW OF THE ELECTRICITY MARKET OF ESTONIA AND THE PLAUSIBILITY OF NUCLEAR ENERGY PRODUCTION

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Abstract The Republic of Estonia is a small country in Northern Europe, with electrical energy production dependent mostly on oil shale. The local supply of oil shale has given Estonia its energetic independence but it also presents great challenges: it is waste-intensive and causes massive emission of greenhouse gases into the atmosphere. It also causes damage to the landscape and to the health of the population living near the mining and energy producing area. Due to the above mentioned problems the use of nuclear power has been taken into consideration, but the debate is at its beginning and the need for further analyses is great.

Basic facts about Estonia

The Republic of Estonia is situated in Northern Europe on the coast of the Baltic Sea. Its neighbors include Finland, Sweden, Latvia and the Russian Federation. It is also a very small country, with an area of 45,227 km^2. The population of Estonia is close to 1.34 million.[1] The republic of Estonia is a member of the United Nations since 17 September 1991, a member of NATO since 29 March 2004, and a member of the European Union since 1 May 2004.

In 2008 Estonia's gross domestic product (GDP) at current prices was about 248 million kroons[2] which is approximately 23.2 million USD in total or 17,300 USD per capita.[3] The worldwide financial crisis in recent months has led to an estimation that Estonia's GDP will fall about 13% in 2009.[4]

[1] Statistics Estonia
[2] Ibid
[3] International Monetary Fund
[4] Ibid

Current situation in the energy market

It should be mentioned that the market being considered in this paper is the market for electrical energy, not the market for energy in its broader sense.

Electrical network

Estonia's electrical network was mostly constructed during the Soviet period and is thus well connected to and also synchronized with Latvia's, Lithuania's, Belarus' and Russia's electrical networks.[5] The Baltic States are the only region in the European Union (EU) where there is no lack of transfer capacity or, in other words, there are no electricity bottlenecks. Yet, Estonia is still developing links to the Nordic countries. Since 2006 there is also a sea cable called Estlink between Estonia and Finland with a transmission capacity of about 350 MW.[6] The construction of a second cable named Estlink 2 will start in the near future. Its planned transmission capacity is nearly twice the previous, at 635 MW. The construction of the second cable received considerable support from European Commission at the beginning of May 2009 (100 million euros of estimated total cost of 250 euros).[7, 8] Another cable is also planned to connect Latvia and Lithuania with Sweden. Establishing those connections will make it possible for the Baltic States to become a part of the North-European electricity market.

Electricity production

Until now Estonia has always been able to meet its own demand in electricity production. The key to its energy independence lies in oil shale, which is the most important natural resource in Estonia. There are about 4,500 million tons of oil shale in Estonia, 14 million of which are currently extracted per year.[9] The gross production of electrical energy in 2007 was 12,188 GWh which includes production for own use.[10] The gross consumption of electrical energy in 2007 was 8,534 GWh (1,354 of which was transmission losses). The rest of the energy was exported to Finland and Latvia (2,765 GWh).[11]

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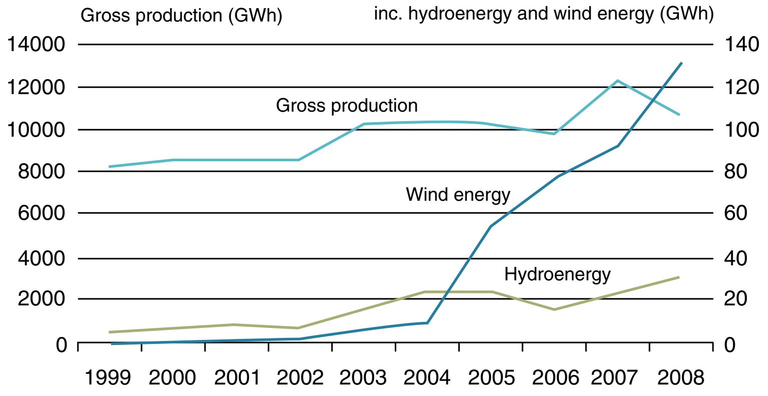
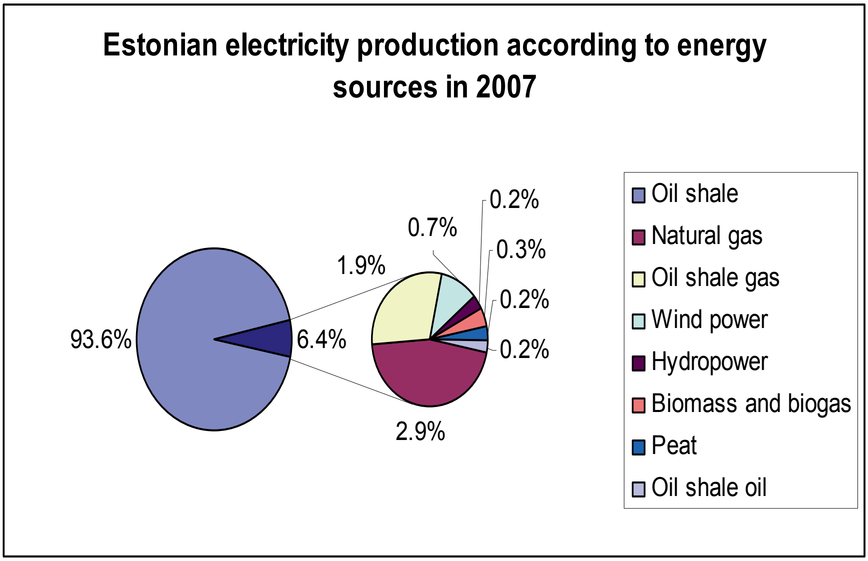
[5] Eesti elektrimajanduse arengukava aastani 2018, p. 47
[6] Nordic Energy Link
[7] "Euroopa Parlament kinnitas Estlink 2 rahastamise"
[8] Permanent Representation of Estonia to the EU
[9] Minifacts about Estonia 2009, p. 6
[10] Eesti elektrimajanduse arengukava aastani 2018, p. 11
[11] Ibid, p. 11

Energy production, 1999-2008[a]



[a] The data on 2008 are preliminary

Energy production, 1999–2008[12]

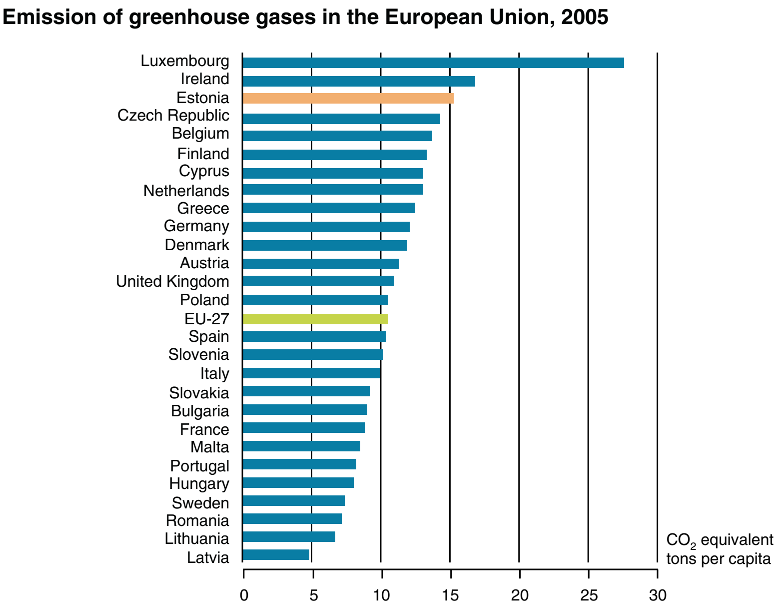


[12] Minifacts about Estonia 2009, p. 45

As indicated on the diagram above, almost all of Estonia's electricity is produced from oil shale (93.6%). Adding oil shale gas and oil shale oil raises oil shale dependent electricity production to 95.7%.[13]

Problems with the current system

The dependence of Estonia's electricity production on oil shale poses one of its greatest challenges. Oil shale energy is waste-intensive and causes massive emission of greenhouse gases into the atmosphere. The share of carbon dioxide emitted from oil shale incineration was 71% of total greenhouse gas emissions in 2006 in Estonia,[14] lifting Estonia into the top ten greatest per capita emitters of greenhouse gases in the world.



Emission of greenhouse gases in EU, 2005.[15]

Estonia signed the Kyoto Protocol in 1998, taking greenhouse gas (CO_2, CH_4, N_2O, HFC, PFC, SF_6) emission reduction commitments of 8% by the year 2012 compared to the base year 1990.[16] During the past years, Estonia has already fulfilled its Kyoto Protocol requirements. In fact, greenhouse gas emissions in

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[13] Statistics Estonia
[14] Minifacts about Estonia 2009, p. 53
[15] Ibid, p. 53
[16] Ibid, p. 53

2006 were only 42% of 1990 levels.[17] This was due to the closure of many Soviet era manufacturing plants and a shift within the economy towards the service sector. Still, there are incentives and directives provided by the EU to lower the CO_2 intensity in production. The EU has launched its own Emissions Trading Scheme (ETS). In 1 January 2008 ETS reached its second phase, which includes the emission volume cut of 6.5% compared to 2005.[18] This step was taken to ensure real cut in emissions. Estonia's energy company was not satisfied with the cut and the matter was taken to European Court. Regardless of outcome, it is clear that the cost of oil shale electricity will increase significantly due to diminishing quotas.

In addition to greenhouse gases emissions, oil shale extraction also causes local environmental and health effects for the mining and producing area. Oil shale lies in a relatively thin layer in the ground. One square meter of ground provides only about 3.5 t of oil shale, and consequently oil shale mining upsets large areas.[19] Due to mining, the ground water in North-East Estonia is below health standards right now and the health of inhabitants of mentioned region is below average.[20] Also about two thirds of Estonia's total waste is produced by oil shale power plants.[21]

There is also a problem with the oil shale technology used. It is estimated that the demand for electricity will rise about 2% annually until 2025.[22] By joining the EU, Estonia has also taken a duty to lower the SO_2 emissions from the Narva power plant in years 2012 and 2016.[23] Under this agreement, some blocks of currently used Narva power stations must be closed in 2016, diminishing the electrical output capability considerably.[24] This change will be a dramatic reversal for Estonia, which would stop being an electricity exporter and need to import about 1,600 MW. Also most current power plants are well advanced in their lifecycle and in need of considerable investments.

Import of electricity is, however, complicated. As the demand for electricity in the region is expected to grow significantly, there is lack of capacity in the entire region. Although Russia has been willing to export electricity into the EU, it will not be able to produce enough to meet export needs during peak demand.[25] Also, import from Russia is not the preferred option considering Russia's security of supply. As a matter of fact, Estonia would prefer to retain energy independence and remain an energy exporter. The situation is exasperated by Estonia's running of a current account deficit, meaning that its imports exceed exports.

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[17] Ibid, p. 53
[18] The EU Emission Trading Scheme, p. 8
[19] Vilu
[20] Ibid
[21] Eesti elektrimajanduse arengukava aastani 2018, p. 47
[22] OÜ Põhivõrk
[23] Eesti elektrimajanduse arengukava aastani 2018, p. 23
[24] Ibid, p. 13
[25] Ibid, p. 29

Debate over nuclear power

Public discussion about nuclear power use in Estonia has stemmed from a threefold problem of environmental regulations, energy security and rising demand for electricity. While alternative energy sources have also been considered, on the 27 February 2006, at a meeting in Trakai, Lithuania the Prime Ministers of Lithuania, Latvia and Estonia signed a communiqué which invited state-owned energy companies in each Baltic country to invest in the design and construction of a new nuclear power plant in Lithuania.[26] Due to various reasons this project has currently been called to a halt. The main cause lies in the amount of investments needed. For the moment Lithuania has not made a decision whether to invest in a nuclear power plant or to buy electricity from Russia.[27] The Estonian Government has also discussed a possibility of acquiring a share in new Olkiluoto power plant block in Finland, but the completion of the block is also delayed at the moment. Estonia has been the more interested party in the project because Finland is already facing a shortage of electricity production capacity.

As the projects in Lithuania and Finland remain frozen, the idea of Estonia's own power plant took hold. Although most of the discussion in the media has not yet reached the level of deep analysis and unbiased commentary, some preliminary analyzes have been made. Estonia's Development plan for electricity until 2018 takes into consideration two possible scenarios including nuclear power, one of which would include building a nuclear power plant in Estonia. The nuclear scenario proposes building new oil shale blocks with capacity of 400 MW, nuclear power plant with capacity of 1,200 MW and windmills with capacity 250 MW.[28] (The other nuclear scenario includes nuclear power for 400 MW.[29]) As the cap between demand and supply will surface already in 2016, it is clear that in first decade or more the energy must be imported. Below are listed some basic estimations for this scenario. The investments and prices of fuels are estimated at the 2007 level.

Price for electricity (CO_2 price 25 euros/t)	0.064 euros/kWh
Price for electricity (CO_2 price 50 euros/t)	0.070 euros/kWh
Need for investments	4.3 billion euros
CO_2 content in electricity produced	0.17 t/MWh[30]

The strengths of the scenario are low emission of CO_2 and low electricity price. On the other hand there would be considerable dependence of electricity import until the completion of Estonia's own nuclear power plant. Building the plant will need great investments and also will create a need to invest in reserve capacity. As Estonia's experience with nuclear power is extremely limited, there is currently a

[26] "Three Baltic states say "yes" to nuclear energy"
[27] "Ignalina tuumajaama ehitamine on kahtluse all"
[28] Eesti elektrimajanduse arengukava aastani 2018, p. 23
[29] Ibid, p. 25
[30] Ibid, p. 23

lack of specialists and also the legislation needs updating to meet the requirements presented by nuclear energy.[31]

Some of problems presented above have already been tackled. The University of Tartu and Tallinn University of Technology are working together to establish a new joint nuclear master's program, in cooperation with international partners. The aim of the program is to train the workforce capable of working in a nuclear power plant or in other nuclear-related institutions.[32] Estonia's Development plan for electricity until 2018 also includes goals such as updating the legislative base and founding an institution to deal with nuclear safety by 2012. Still a lot remains unsure and there is a great need for further analysis. Not only do the economical, environmental and technological aspect need more attention, but also social and public relations aspects are still mostly left unstudied. As one of Estonia's scientists has said "The worst course of action in the current situation would be not to educate ourselves about nuclear power but to spread emotional opinions powered by a lack of knowledge. The answer to the question of whether Estonia ought to use nuclear power lies in knowledge, skills, visions and economic calculations.[33]"

It is the author's estimate that the earliest date for nuclear power plant in Estonia can be around 2020 if not later.

Conclusions

- The future is uncertain because demand for energy is on the rise and production is limited by underinvestment and environmental concerns.
- To avoid running an energy (and current account) deficit, the government is seriously considering domestic or international projects to harness nuclear energy.
- A great deal of analysis is required before a plan entailing the construction of a nuclear power plant can be implemented.

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THE ROLE OF SMALL AND MEDIUM REACTORS IN THE ENERGY SECURITY OF A COUNTRY, IRIS EXAMPLE

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Abstract Nuclear options for electricity generations are assessed in this paper. Probabilistic (stochastic) method is used for economic comparison of nuclear power plants, wind plants and natural gas fired plants. Optimal nuclear power plant size is also discussed. IRIS is presented as a representative of small and medium reactors.

Keywords: Nuclear energy, comparison of energy options, small and medium nuclear reactors (SMRs)

Introduction

The main criteria for selection of electrical power generating technologies capable to meet the demand are economy of power generation, security of fuel supply and environmental impact.

An opportunity to implement nuclear energy is seen through the electricity price, Kyoto obligations (unrealistic to fulfill without nuclear energy), and security of supply and energy diversification.

Probabilistic method is useful for comparing economics (discounted net cash flow) of power supply system's consisting of natural gas plants, wind plants and nuclear power plant, because it allows inclusion of uncertainties in future generating cost prediction, particularly with respect to future fuel cost changes.

Analysis of competitiveness of power options

The aim of the analysis is to compare potential option for electricity generation. Nuclear plants, wind plants and gas plants are considered.

In the model for economic comparison of wind and gas fired plants it is assumed that both plants have equal total installed power 1,200 MW. The electricity generation in gas fired plant is reduced by the amount corresponding to electricity generated by wind plants. The applied cost model of combined gas and wind

S.A. Apikyan and D.J. Diamond (eds.), *Nuclear Power and Energy Security*,

plants is highly simplified because it does not consider additional costs of power transmission and control.

Probabilistic analysis is performed by calculating probabilistic distribution of levelized life time bus bar electricity generating costs of selected power generating technologies. Calculation of discounted net cash flow is based on current money cost and gives the average cost for which discounted overall costs of electricity generation would equal to total discounted utility income for selling produced electricity. Advantage of probabilistic approach is in possibility to define input within estimated ranges instead of using single values. Large number of net cash flow calculations (1,500–2,000), by using random data within estimated ranges, are performed by using STATS computer code.

Estimated values of input data are as follows: NPP investment cost in the range US$2,100–2,300/kW, annual operational and maintenance costs in the range US$110–130/kW, for wind and gas plants used investment cost are US$900–1,100/kW and US$500–600/kW and operational and respective operations and maintenance costs US$14–18/kW and US$8–12/kW. Wind plant capacity factor 16–20%. Uranium cost US$200–220/kgU and gas cost US$8–12/GJ with both fuel annual increase rate 4–6%.

A pessimistic assumption is used for the uranium future cost increase, while on the contrary the estimated rate of future long term gas price increase is probably on optimistic side.

The financing of plant construction is assumed as follows: bank loans with 6.5–7.5% interest with repayment period 20 years for investment in more intensive projects (hydro, nuclear) and 15 years for less investment intensive projects (gas, renewable). Loan repayment starts at beginning of plant commercial operation. The owner capital (equity) is assumed on the level 15–25% with 10 years return and 12% interest. The levelized cost calculation is performed with discount rates of 7–9%.

External costs used in probabilistic analysis are probably underestimated because they are based on constant CO_2 cost of US$20/t. This is lower than the cost of foreseen environmental damage caused by CO_2 emissions. In addition, external costs caused by other pollutants created during natural gas combustion have been neglected.

Net cash flow is the difference between the plant investor's income and expenses. Income is value of electricity sold at plant bus bars (no transmission cost included). Cost of electricity at plant bus bar in the period of plant start up is foreseen in the range US$4–6 cents/kWh and its average yearly rate of increase in the range 3–4%. The electricity cost is an indicator to the investor of relative potential profitability of the investment. Since the purpose of this analysis is to compare relative economics of two power options cost of electricity could not affect ranking of considered options. The selling cost of electricity shall depend upon demand and offer in open market and also on degree of government restrictions. In principle it should be compatible with marginal production costs of electrical power generating plants.

Discounted cash flow has been calculated for two intervals. First is the interval of first 10 years of operation corresponding to the period of most intensive capital repayment and second for total plant life time (assumed 40 years).

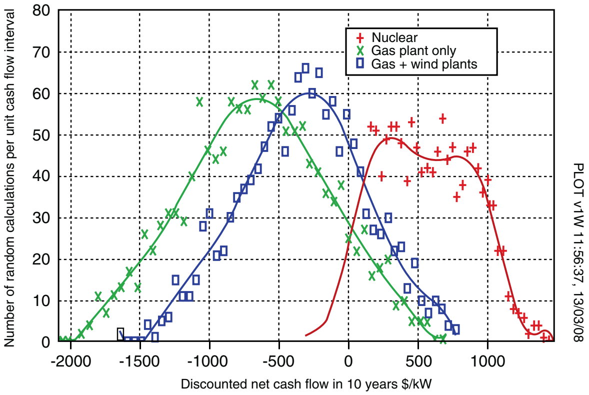

Figure 1. Discounted net cash flow for first 10 years of operation for nuclear power plant, combined cycle gas fired plant with wind plant and combined cycle gas fired plant only

Figures 1 and 2 show that the economic advantage of nuclear plants respective to gas and wind plants in both considered periods is very pronounced. In 10 years period only nuclear plants have more than 80% probability to achieve positive net cash flow while other considered options have probability of only 20–30%. Discounted net cash flow in plant life time (40 years) for all options is more favorable, as shown in Figure 2. It remains however with more than 50% probability negative for the option containing gas plants only. It has to be noticed that the option containing wind plants is more competitive than the option containing gas plants only. The economic advantage of gas-wind option over option with gas plants only is increasing with gas cost and with wind plant capacity factor.

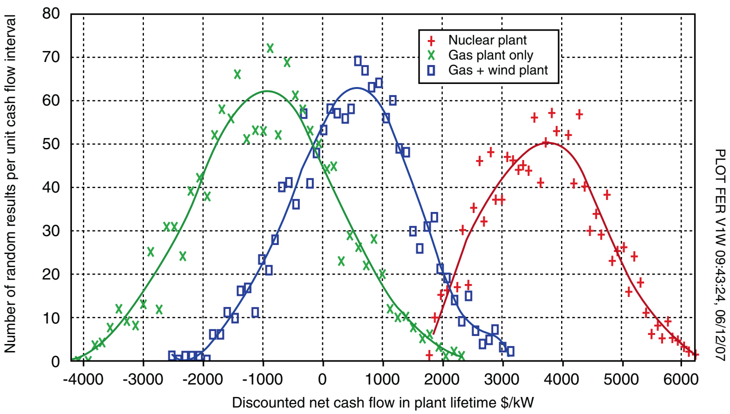

Figure 2. Discounted net cash flow in plant lifetime for nuclear power plant, combined cycle gas fired plant with wind plant and combined cycle gas fired plant only

Economics of SMRs

Due to the postulated economy of scale, it is frequently assumed that small and medium power reactors (SMRs) could be a preferred solution primarily in the cases when specific site conditions prevent efficient use of large plant installed capacity. These are sites in remote or isolate areas, in countries with weak and non interconnected grids, and in cases when not only electrical energy is needed (desalinization, cogeneration). In such circumstances potential competitors to SMRs are not large nuclear units but fossil plants of comparable size.

However, utilities in countries with strong grid interconnection could also in some cases be attracted by small reactors due to possibility of easier handling some issues as follows: smaller investment risk, shorter construction period, lower cash flow, possibly of slightly easier political and public acceptance, and easier solution of technical site restrictions. In such cases construction of a single large nuclear plant could be replaced by sequential construction of smaller units 0.

A paper prepared by Westinghouse for IAEA 0 has analyzed the investments of subsequent nuclear units build in series.

Figure 3 illustrates the effect of the six variables in determining the capital cost of SMRs: economy of scale, multiple unit economies, learning economies, construction schedules, unit timing, and plant design.

As can be seen from Figure 3, the effect of scale is to significantly raise the cost per kilowatts electric as one follows the solid black curve from 1,200–300 MW(e). However, this gives the cost of a scaled large reactor (SLR), the cost that would be obtained if a large reactor were scaled down to ¼ of its original size with no other design changes. The SMR cost is then obtained from the SLR cost by including the other five factors and following the arrow vertically downward.

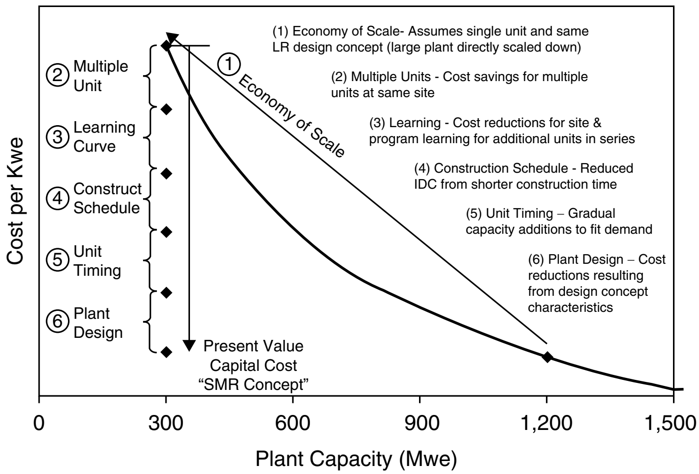

Figure 3. Potential SMR cost factor advantages

To demonstrate economic competitiveness of SMRs in comparison to large reactors, the methodology illustrated in Figure 3 was applied to a test case. SMR based power station consisting of four 300 MW(e) units was compared to a single large reactor of 1,200 MW(e).

The results of the calculations are given in Table 1. As it can be seen the specific capital cost of the SMR due to the economies of scale is 1.74. However, when the other factors are combined, the specific PVCC is only 1.04.

Table 1.

	Capital cost factor ratio (Four SMRs vs. Single LR)		
Capital cost factor	Overnight capital cost	Total capital investment cost	Present value capital cost
1. Economy of scale	1.74	1.74	1.74
2. Multiple units & 3. Learning	0.78	0.78	0.78
4. Construction schedule	N/A	0.94	0.94
5. Unit timing	N/A	N/A	0.95
6. Design specific	0.85	0.85	0.85
Cumulative total	1.16	1.09	1.04

IRIS reactor

The International Reactor Innovative and Secure (IRIS) is an advanced, integral, light-water cooled, pressurized reactor of smaller generating capacity (1,000 MWt, or about 335 MWe). It is being developed through a strong international partnership by a team lead by Westinghouse and including about 20 organizations from 10 countries. The IRIS integral layout is shown in Figure 4.

The integral configuration offers intrinsic design improvements as briefly discussed below:

- Steam generators With the primary coolant outside, tubes are in compression, and tensile stress corrosion cracking is eliminated.
- Primary coolant pumps The axial fully immersed pumps result in no seal leak concerns, no possibility for shaft breaks, and no required maintenance.
- Internal CRDMs This solution eliminates head penetrations and possibility of seal failures, as well as any future head replacements.
- Pressurizer Much larger volume/power ratio gives much better control of pressure transients. Additionally, no sprays are required.
- Thick downcomer The 1.7 m thick downcomer reduces the fast neutron flux on reactor vessel by five orders of magnitude. This leads to “cold” (i.e., not activated) vessel, almost no outside dose, no vessel embrittlement, and no need

for surveillance. The vessel is essentially “eternal”, and decommissioning is simplified.

- Fuel assembly Almost the same assembly as in standard Westinghouse PWRs is used, but it can provide an extended cycle up to 48 months.
- Maintenance Intervals between maintenance outage can also be extended to 48 months, thus enabling uninterrupted operation for up to 4 years.

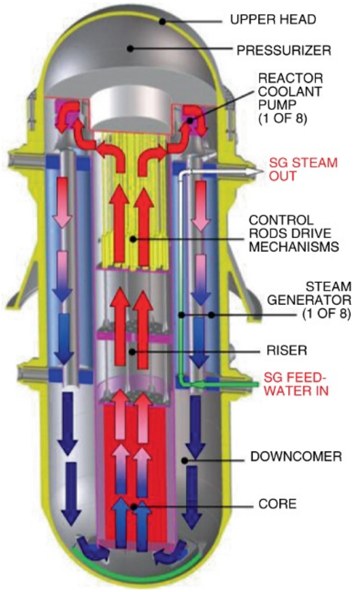

Figure 4. IRIS integral primary system

While leading to a larger reactor vessel, the integral layout results in a smaller containment (as illustrated in Figure 5) and overall a more compact site, with positive impact on safety and economics.

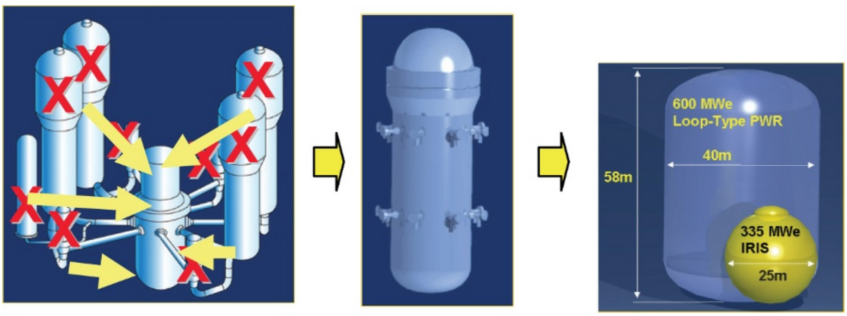

Figure 5. IRIS compact integral layout

In addition to the design improvements, the integral configuration also offers very significant intrinsic safety advantages, which have led to the unique IRIS safety approach. This approach is represented by three tiers.

1. The first tier is safety-by-design™ which aims at eliminating by design the possibility for an accident to occur, rather than dealing with its consequences. By eliminating some accidents, the corresponding safety systems (passive or active) become unnecessary as well.
2. The second tier is provided by simplified passive safety systems, which protect against the still remaining potential accidents and mitigate their consequences.
3. The third tier is provided by active systems, which are not required to perform safety functions (i.e., are not safety grade) and are not considered in deterministic safety analyses, but may contribute to reducing the core damage frequency (CDF).

IRIS development started in October 1999, the whole project schedule is presented in Table 2.

Table 2. IRIS project schedule

Program started	End 1999
Assessed key technical and economic feasibility	End 2000
Performed conceptual design, preliminary cost estimate	End 2001
Initiated NRC pre-application licensing for design certification	End 2002
Completed NSSS preliminary design	Mid 2005
Initiate necessary testing for NRC design certification	Spring 2006
Completed design of integral test facility testing	Mid 2008
Complete testing	2012
Submit design certification application	Early 2013
Obtain final design approval from NRC	2015–2017

IRIS economics

IRIS is complementary to larger reactor units. Specifically, it meets the requirements of smaller countries, markets or utilities with limited grid size (typically several gigawatts electric) that cannot install large units. To mitigate grid stability concerns, these markets typically limit any single plant to several hundred megawatts electric. Additionally, IRIS offers co-generation options (desalination for hot/dry climates, district heating for cold regions), already resulting in a significant interest in several countries to address regional needs.

IRIS further supports these markets by enabling a gradual increase in generating capacity to match future growth needs. Financial risk and needed investment capital are largely reduced since the staggered construction of modules deployed several years apart enables income to be generated from previous unit(s) while the next unit is being built.

Conclusions

Probabilistic analysis of economics has been performed for power generating systems consisting of combined cycle gas fired plant jointly with wind plants and nuclear power plant.

The obtained results demonstrated pronounced advantage of nuclear plants (in spite of the assumption of most unfavorable prognosis of uranium cost increase in next decades). The advantage consists in higher discounted net cash flow to plant investor and in reduced carbon dioxide emissions.

SMRs can significantly enhance the country's energy supply security. Additionally, local market conditions in combination with economic comparisons can make SMRs the competitive choice.

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CHAPTER III

APPLICABLE TECHNOLOGY

STATUS REPORT ON THE SAFETY OF OPERATING US NUCLEAR POWER PLANTS (WHY EXPERTS BELIEVE THAT TODAY'S OPERATING NUCLEAR POWER REACTORS ARE MUCH SAFER THAN THEY WERE 20 YEARS AGO)

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Abstract The main emphasis of this presentation and paper is to address why experts believe that today's operating nuclear power reactors are much safer than they were 10 or 20 years ago. There is strong evidence to support this belief for the power reactors now operating in all of the advanced countries, and in many of the less developed countries too, although in a few of these latter countries there are continuing safety concerns. The paper will present recent and historical data from the U.S., a discussion of what the data mean and why, and a perspective about what events and trends have been the causes for the major safety improvements that have occurred. The extension of the conclusion to other countries will also be discussed. Finally, the reasons why safety-improvement programs must continue in some of the less-developed countries are described.

Introduction

The issue addressed in this paper is why experts believe that today's operating nuclear power reactors are much safer than they were a decade or two ago. The evidence for this, based on operating experience in the United States, will be presented and discussed. The evidence will be shown mostly in the form of figures that can be studied visually, with accompanying discussion contained here in the text itself.

There are 104 operating nuclear power plants in the U.S. (Figure 1), and these represent about one-quarter of the number (about 430) of operating power plant units worldwide.

S.A. Apikyan and D.J. Diamond (eds.), *Nuclear Power and Energy Security*,

We will start by asking three questions about nuclear plant safety: How is "safety" achieved? How is "safety" analyzed and measured? And why do we believe that safety has improved significantly in the last decade or two?

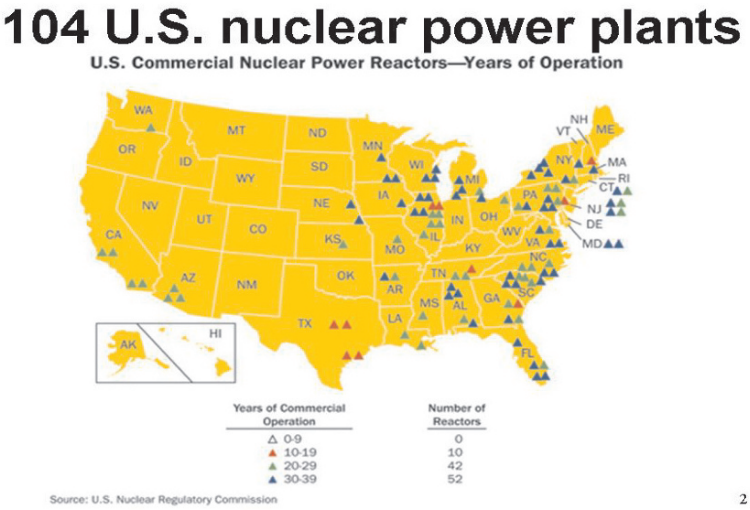

Figure 1. Map of the 104 operating U.S. nuclear power plants

What characterizes a "safe" nuclear power plant?

These three questions, of course, cannot be answered unless we can address a deeper question, namely what characterizes a "safe" nuclear power plant? The answer requires understanding that "safety" relates to the absence of a major nuclear accident – an accident that would release large amounts of radioactivity beyond the plant itself into the environment, causing property damage, environmental contamination, radioactive exposures to individuals leading possibly to latent cancers, and in rare cases even death from doses beyond what a human can tolerate in a short time.

So we can say that a "safe" plant is one whose probability of enduring a major accident, in say a given year, is "acceptably low." This itself raises yet a deeper question, which is how low an annual probability is considered acceptable. In different countries, there are different answers to this question provided by the different safety authorities, but they do not differ very much in their operational significance. In the United States, the U.S. Nuclear Regulatory Commission has provided an answer in the form of a safety-goal policy statement [1]. This establishes certain risk goals for the broad population, which translate approximately, for the purposes of NRC's regulations, into striving to assure that the annual probability per reactor of a large early radioactive release is less than about 1 in 1,000,000 per year, and that the probability per reactor of an accident that seriously damages the reactor core is less than about 1 in 100,000 per year. The

NRC considers its own regulatory programs to be effective based in a major way on whether these approximate targets are achieved for the entire fleet of 104 operating U.S. power reactors.

How does one analyze for safety?

All of the above then raises a still deeper question, which is how do experts analyze plant performance to ascertain what the core damage frequency and large early release frequency are for a given power reactor? The answer is that this requires a quantitative safety assessment, which intrinsically must be probabilistic in character, a so-called “probabilistic safety analysis” or “PSA.”

In the first 2 decades of nuclear power, until the mid-1970s, no techniques existed for performing such a PSA analysis. The development of PSA methods was first accomplished by a team under the guidance of N. Rasmussen of MIT and S. Levine of NRC with NRC sponsorship [2], and it has completely changed – the word “revolutionized” might be a better word – the way experts understand reactor accidents and reactor safety. Now, 3 decades later, these PSA methods have spread around the world, and almost every power reactor has been subjected to a PSA study to understand not only what is the probability of large accidents, but crucially to understand what types of initiating events, equipment failures, configurations, operator errors, internal and external hazards, and the like are the principal contributors to the risk.

To do such a PSA analysis, the analyst must postulate every “accident initiator” that might occur, determine its frequency, work out the probability contingent on the initiator of a serious core-damage accident, and finally work out what the radiological and other consequences would be. Each scenario being studied must be evaluated separately, a massive undertaking that before Rasmussen’s and Levine’s pioneering work was thought to be too complex to be feasible, but is now routinely done. In fact, there is now a methodology standard for performing PSA, developed by ASME and ANS [3].

Of course, a major “problem” for the PSA analysts is that there have been almost no accidents to use for benchmarking the bottom-line core-damage and risk numbers from a PSA analysis. This is, of course, a triumph for engineering, but a “problem” for the PSA analyst charged with figuring out what the very low accident frequencies might be, because essentially none of the accidents being analyzed have ever occurred, or in fact will ever occur (probabilistically). However, other benchmarking methods exist that lend confidence to the results, for example by studying partial precursor sequences that have occurred, and by evaluating failures of systems, subsystems, and components.

Understanding “safety” using methods besides PSA analysis

In the end, it is very helpful to use several different ways of understanding “safety” besides using PSA to reach any overall conclusion, either about an individual reactor or about the safety achievements of the entire fleet. Besides the overall

PSA analysis of each entire reactor, there is system-specific analysis, analysis of precursors, the use of certain safety "indicators" to follow trends, and crucially there are methods for assessing the "safety culture", which culture is central to enabling an enduring excellent safety record.

In practice, to achieve safety and maintain it over the years, it requires a combination of the overall *design*, the quality of *construction*, the quality of *operations* and *maintenance*, the *safety culture*, and the application of *continuous-improvement* programs. All of this would not be sufficient without a *safety philosophy* that underpins everything. This philosophy uses defense-in-depth, redundant systems, lots of "engineering margin" in each facet of the plant, a well-trained operating crew, and diligent learning-from-experience worldwide, with no-fault reporting, in order that the entire industry can maintain and enhance safety.

What underpins the general conclusion of safety experts that the nuclear-power industry is generally achieving better safety performance overall than was the case 10 or 20 years ago is that in essentially every area just cited, the indications are that things are better – much better, in fact.

The data will speak to this point, and next we will present some of it. All of the figures in this paper are from open-source public information available from the U.S. Nuclear Regulatory Commission.

The data that support conclusions about safety

The discussion here will be centered on introducing and explaining a series of U.S. industry-wide compilations found in Figures 2–6. These figures provide major support for the conclusion that safety is improving in the U.S. fleet. They are extracted from various NRC and nuclear-industry sources.

Figure 2, "Significant Events at U.S. Nuclear Plants", shows that the number of these events has declined by a factor of 10 or more in the last 2 decades. (A "significant event" is defined in the figure itself.) This is a major roll-up figure that combines a large number of effects from a large number of causes and initiatives. It is difficult to pin down just which of the many improvements, taken together, have produced this huge decrease, but the data speak compellingly.

Figure 3 shows "Automatic Scrams while Critical", another major safety indicator. One needs to understand that there are a large number of set-points for various conditions in any nuclear power plant, such that if any single condition departs from its "normal" setting beyond a pre-assigned threshold, then the plant automatically initiates a "scram" or shutdown – the control rods are inserted and the reactor shuts down. The types of off-normal deviations that cause a scram serve as the "initiating events" for most of the potential large accidents that we are concerned with. The decrease is dramatic: In 1980 there were 7.3 scrams per plant, in 1990 1.57, in 2000 0.52, and in 2006 there were 0.32. This is a huge and significant change.

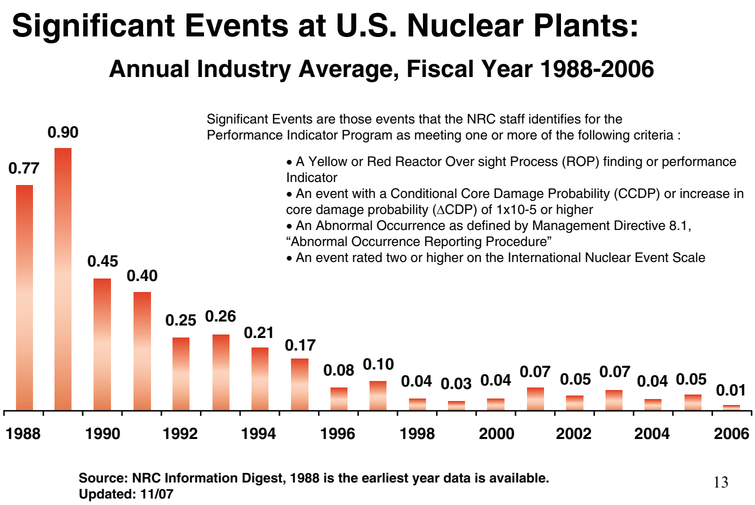

Figure 2. Significant events at U.S. nuclear plants

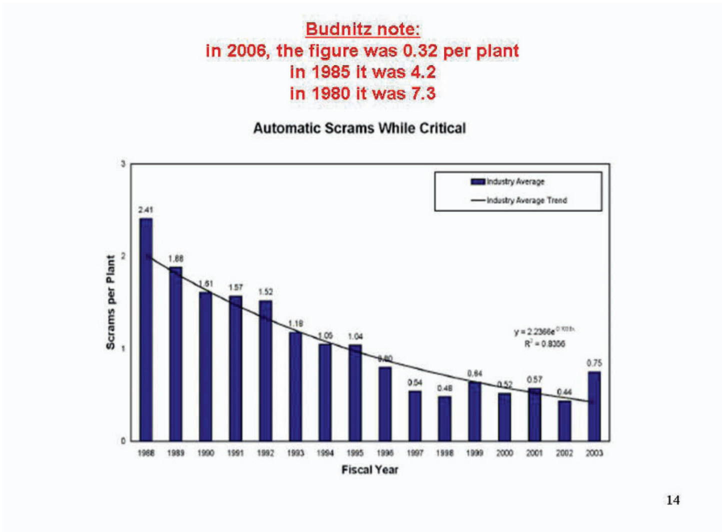

Figure 3. Automatic scrams while critical

Figure 4 shows "Safety System Failures", for safety systems that normally operate. Again there is a big decrease, a factor of 5 decrease in the 10-year period 1998–2007. Figure 5, "Safety System Actuations", involves safety systems that are in stand-by, awaiting being called into service if an off-normal event were to occur. There has been a factor of 5 decrease in the number of actuations, industry wide, over the 15-year period on the figure.

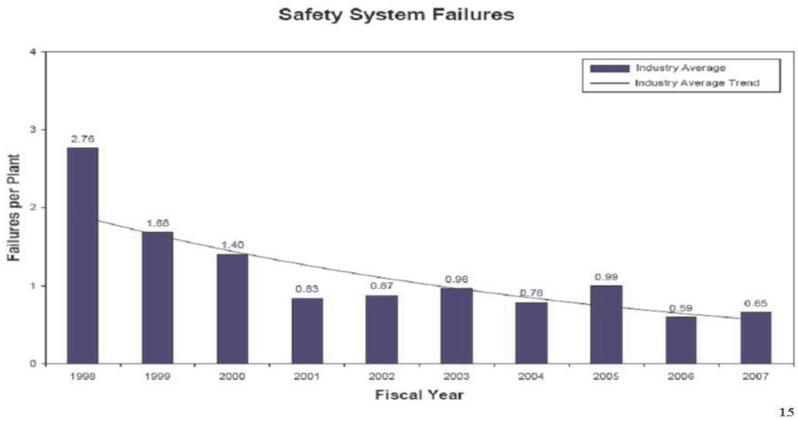

Figure 4. Safety system failures

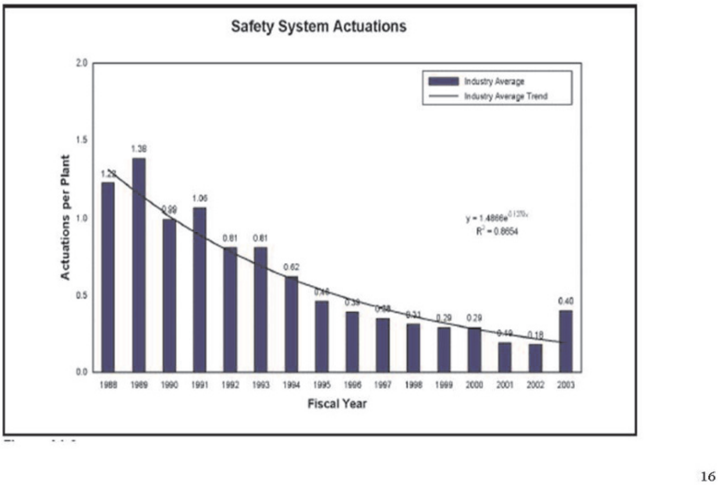

Figure 5. Safety system actuations

Finally, Figure 6 shows “Forced Outage Rate”, in percentage terms, meaning the fraction of the time that a power plant is forced out by various events, so that it cannot produce electricity. This measures something different than the earlier indicators, because a forced outage that lasts twice as long contributes double to this indicator. Again, a factor of about 6 or 7 decrease is revealed over the last decade.

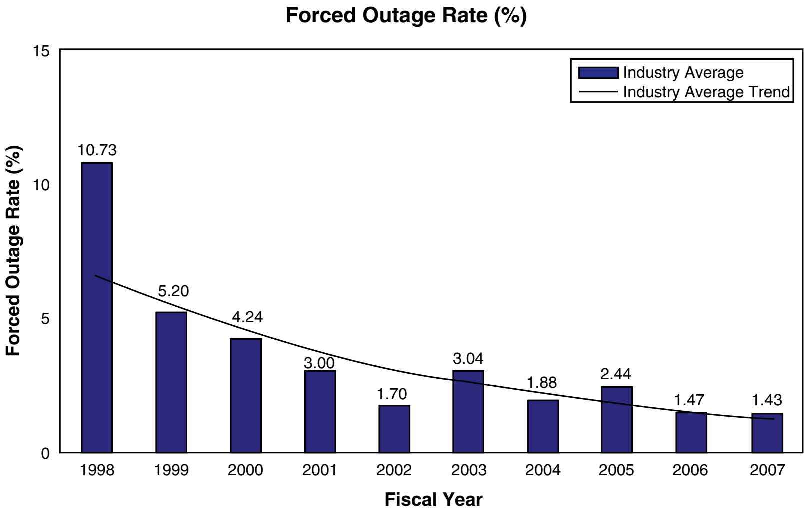

Figure 6. Forced outage rate (percentage)

These are, of course, U.S. industry-wide averages. It is important not to be deceived into thinking that each and every nuclear unit has achieved these decreases uniformly. Some units are better, some not a good in terms of their performance. But unless a given unit is very much worse than the average, then in terms of asking what the likelihood is of a nuclear accident anywhere in the U.S., these industry averages are a reasonable indicator. And in fact the spectrum of performance across the industry is not so skewed as to invalidate using these broad indicators as useful markers of the trends!

It is also crucial to keep I mind that *safety performance is intrinsically probabilistic*. Even if the likelihood of an accident is small, *probabilistically an accident could occur any time*. Only the foolish would forget this, and this sobering thought serves as an admonition that the industry must continually work to maintain its record.

What accounts for these trends?

There are several underlying reasons that account for these trends. To discuss each of the factors below could each require its own full paper in this meeting, so here they will only be mentioned without elaboration:

- Learning from experience: There is an industry-wide reporting system. Involving reporting everything to everybody, in a no fault mode.
- Analysis: There is a major effort to analyze each significant event for its causes and its implications.

- Maintenance: There is an effort to concentrate maintenance on the important things, and to design for easier maintenance.
- Operator errors: There is a huge effort to drive down operator errors, through universal simulator training, and by careful attention to developing high-quality procedures.
- Industry-wide peer-to-peer inspection visits and task forces are used to share experiences and upgrade the weaker performers. These usually do not involve the NRC, but are done by the industry itself.
- Design changes: There are major efforts to eliminate design flaws, and to achieve a “forgiving” design.
- NRC: The NRC uses “risk-informed” methods to prioritize its enforcement actions (so as to give much less weight to minor events), and to revise its regulations and guides using risk insights. This has taken hold especially in the last few years.

Taken together, all of these provide an environment in which continuous improvement is sought, backsliding is not tolerated and is identified and fixed, and the industry’s culture is one of constant comparisons of each power plant with its peers.

This environment, by the way, did not come about overnight, and in fact it did not exist back in the 1970s or even into the middle 1980s. But its existence is a credit to the hard work of thousands of individuals trying to assure that the culture of the industry puts safety first at all times. The results are clearly visible in the data.

Is this a trend only in the U.S.?

Although this paper does not contain the evidence, the fact is that the evidence presented here for the U.S. seems to be generally true for power reactors in all of the developed countries. In a few countries, whose economies are not yet as strong as in the most advanced countries, or whose *technological sophistication* has not yet advanced as much as it needs to, some older reactors have safety features that are of concern. And in a few countries, concerns remain that *safety culture* has not yet become advanced enough.

However, there is a worldwide recognition of the problem areas, and *international cooperative programs* now in place [4] have been addressing these issues for many years. The remaining major safety issues should be addressed over the next decade or so. (At least, everybody hopes so.) This means that, while nobody can say for sure that a nuclear power plant accident will not happen anywhere, *the trends are in the right direction everywhere*.

Industrial safety and costs

Figures 7 through 9 demonstrate similar trends in industrial safety (worker accident rates *and* worker radiation doses) and in cost reductions (declines in outage durations). The figures speak for themselves.

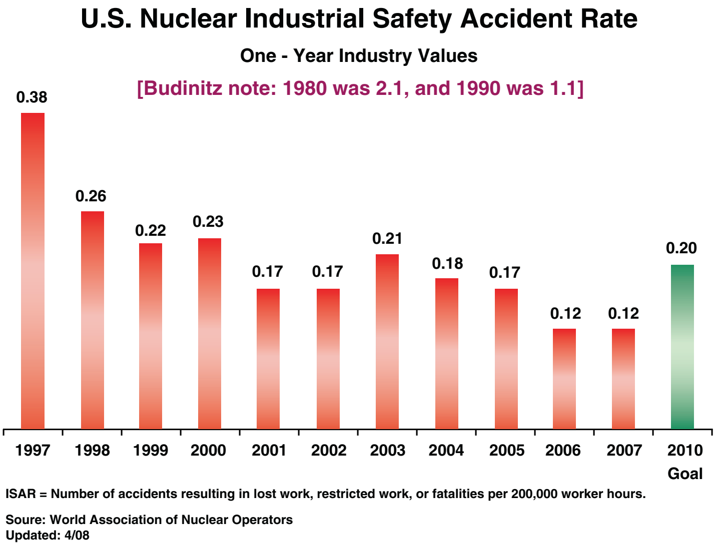

Figure 7. U.S. nuclear industry safety accident rate

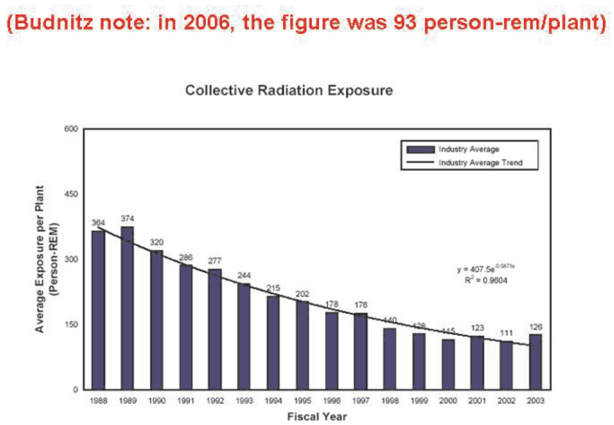

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Figure 8. Collective radiation exposure

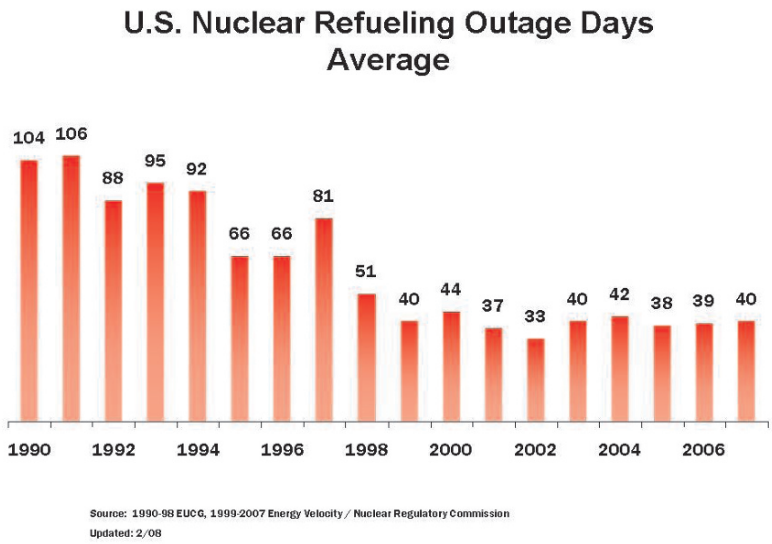

Figure 9. U.S. nuclear refueling outage days average

Summary

In summary, the overall trends are improving significantly for all of the indicators presented here. There is no doubt, none whatsoever, that overall safety of the worldwide fleet of nuclear power plants is significantly better than it was 10 years ago, and better still compared to 20 years ago. And there is reason to believe that this trend will continue.

What are the major factors? In this author's opinion, there are three crucial underlying factors, most importantly an improvement in *safety culture*, and continually striving for a *"forgiving" design*. These, plus effective *regulatory oversight*, provide the major reasons for these trends.

Again, this does not mean that there will not be a nuclear plant accident. The possibility is always there, and the probabilities, although low, are not zero. Which leads to the final thought, which is that *eternal vigilance is crucial*.

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4. The International Atomic Energy Agency and the Nuclear Energy Agency Both Have Extensive Programs, and Numerous Publications (Too Numerous to List), on the Cooperative Assistance Programs that Have Assisted Many Less Developed Countries to Enhance the Safety of Their Operating Nuclear Power Plants.

NATO-ASTEC-MATRIX – RESEARCH ENVIRONMENT, INFORMATION SHARING AND MC&A

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Introduction

The weapons of mass destruction (WMD) threats facing the world are constantly evolving and have grown more complex since the end of the Cold War. After the breakup of the Soviet Union in 1991, the former soviet republics inherited the world's largest arsenal of chemical, biological, radiological and nuclear (CBRN) materials. The republics also inherited the technologies needed to create weapons of mass destruction. The absence of security systems, accounting systems and controls for export of technology, materials and missile programs poses one of the most serious threats to international security because the possibility of diversion of CBRN materials and technologies to rogue nations and terrorist organizations has increased.

The collapse of the USSR initiated dissolution of the infrastructure, which was the underlying cause for the further chaos and collapse of the economy. Many civilian and military oriented organizations lost strong government control, and the level of the supervision, and management were broken. In the Soviet period, Armenia had a strong scientific and technology infrastructure. Today the Armenian nation still has several localized research centers and laboratories for chemistry, biology, physics and electronics, which have been involved in the civilian and military oriented research and development. An essential part of the research and development of these centers and laboratories was used to address various Russian projects.

The 1991 economic problems caused numerous disruptions at Armenia's research centers and laboratories. In particular, over the past 15 years these laboratories have done little monitoring, auditing and accounting of the CBRN materials and technologies. As a consequence of this, it has been impossible to implement international or national inspections and control. In recent years, Armenia like other civilized nations of the world community, has given important attention to CBRN materials nonproliferation by safeguarding sensitive materials,

S.A. Apikyan and D.J. Diamond (eds.), *Nuclear Power and Energy Security*,

equipment and technology. We have worked to improve our system of inspections and safety standards in order to prevent terrorists from acquiring or using dangerous WMD materials. However, much work remains to be done to meet international standards.

Formation of Research Environment and Infrastructure (REI) in Armenia

Progress toward countering WMD threats in Armenia will require the formation of international science and technology teams that combine multiple scientific disciplines and span from basic research to systems engineering and manufacturing. Given this need for broad research and technology teams, it is important to explore opportunities to improve the coupling between international academic, industrial research and development communities. The highly collaborative research facilities could provide a fertile environment for nucleating these new research teams and associated collaborative science and technology projects.

The goal of the project is to break across institutional barriers and based on NATO-MATRIX create REI in order to facilitate communication and collaboration for users. In support of that goal, a successful Research Environment should:

- Operate within a “need to share” culture
- Build on MC&A and other existing systems, where appropriate; and allow users to share information among laboratories and institutions
- Ensure direct and continuous online electronic access to information
- Implement security and access control by adequate identity management, authentication and authorization mechanisms
- Insure the accessibility of data by users in framework rather than through centralized information control
- Incorporate strong mechanisms to enhance accountability and facilitate control, including audits, authentication and access controls
- Include technical framework and standards, business processes and policies enabling integration and collaboration

It will be important that the research and technology teams involved in the NATO-ASTECMATRIX are able to take full advantage of the spectrum of capabilities available at regional and international institutions, laboratories and university-based programs.

- The development of the NATO-ASTECMATRIX can help to stimulate the formation of the expert teams capable of identifying the needed resources for, cross-disciplinary and multi-institutional international and regional collaborations focused on critical needs for countering terrorism inside Armenia and in the regional countries.
- To implement the needs identified by the NATO-ASTECMATRIX, to strengthen advance fundamental research, online collaborative efforts and

virtual conferencing to facilitate productive interaction among geographically diverse team members.

International and Regional Information Sharing System (IRIS) in Armenia

The activity on development of information systems for nonproliferation purposes in Armenia is focusing on projects related to the development of centralized information databases and information management tools for use by government agencies.

The IRIS must provide capabilities that allow research information to be integrated to the NATO-ASTECMATRIX, so users across all the communities can better detect threats relevant to their missions. Information Sharing provides multiple institution capabilities working together across all levels of security. At the same time, the NATO-ASTECMATRIX policies, procedures and technologies must fully support the specific functions that each community uses to achieve its mission, particularly

- Security and Privacy Safeguards
- Information Discovery and Search
- Knowledge Extraction
- Collaboration

In this project we attempt to propose systematic methodology for information sharing between collaborating entities in a secure manner ensuring information assurance requirements and business continuity, preserving entities privacy preferences, and incorporating new security constraints/policies raised by emerging technologies.

- In response to the increased need for timely information sharing and exchange of MC&A related information among members of the International and Regional law enforcement community
- Leverage and integrate existing and proven technology to provide a new capability to assist law enforcement in identifying and analyzing terrorist and other criminal activity, and appropriately disseminating it to law enforcement agencies nationwide in a secure, efficient, and timely manner

The information-processing regional network, will provide the scientists, engineers and policy-makers in the region and worldwide with high-performance information sources and extensive databases.

Monitoring, accounting and control (MC&A) systems for CBRN materials in Armenia

MC&A systems were developed to provide the first line of defense against CBRN materials smuggling that could lead to CBRN materials proliferation or CBRN terrorism. MC&A system has achieved a reasonable balance between system optimization, a system that is understood, accepted, and efficiently used by security and site personnel. Computerized system for the monitoring, accounting and control of CBRN materials (MC&A) was installed at many Armenian laboratories and institutes.

Install comprehensive, technology-based MC&A systems that are consistent with international standards and Guidelines, which are appropriate for the unique conditions at each site and effective for securing CBRN materials against insider and outsider threats.

Through the MC&A program, we have built a legacy of trust, solid working relationships and cooperation with government agencies, institutes and scientists, facilitating our efforts to improve the security for CBRN materials at highest risk.

- To allow the centralized computer aided accounting of CBRN materials and facilities in Armenia
- To establish a fast and effective control and supervision system for accountting of consumption and migration of CBRN materials and facilities into and out of Armenian borders, allowed easily located and identified components
- To provide computerized work places for the personnel performing administrative, supervising and other functions relating to CBRN materials and facilities accounting and control inside Armenia
- To ensure the accountability of CBRN materials and facilities to the industry, administration and central information system of the government of Armenia
- To create methodological and organizational basis for the inspection of national and regional control programs of the CBRN materials
- To create the configuration control and easy maintenance system
- To create the contingency plan in the event of partial or complete system failure
- To provide adequate information exchange between the MC&A and other systems, to easily integrated with other site functions

The NATO-ASTECMATRIX infrastructure

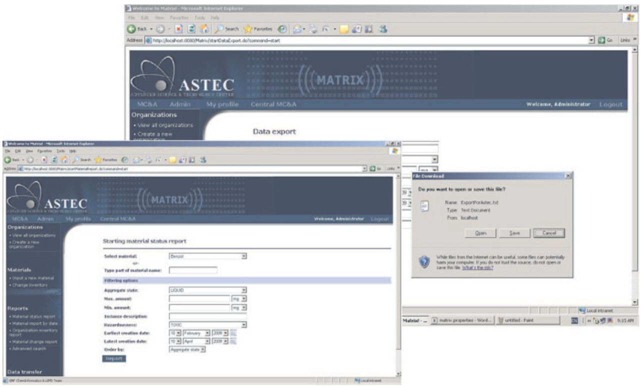
The major technological task of the project is to accomplish effective information sharing and creating research infrastructure among all levels of users. Most useful are the decisions based on the Internet technologies. WEB Content Management offers a flexible, robust and scalable solution that allows partners to collaborate, contribute and access to research environment from anywhere. The web-based model of deployment allows the software programming effort to focus on development instead of distribution. The Centralized Information Repository, based on “Advanced Science & Technology Center” (ASTEC), where centralization of technical and scientific resources for development and technical infrastructure is supposed.

The security claims must ensure the limited access among all levels of authorized subscribers and provide protected delivery of information over the network. The issue of authorization is solved by creating a digital certificate based on infrastructure to the MATRIX resources and that is managed and controlled by authorization server.

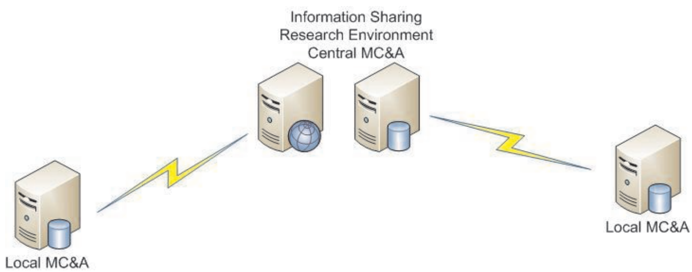
During the project is establishment of structures in local laboratories directed to creation local MC&A system for the personnel performing administrative, supervising and other functions relating NRBC material accounting and control. The creation of system of automatic and manual input of the information is supposed also. The local information continuously will be uploading to the Central repository.

The network infrastructure ensures the requirements of maximum security, optimal reliability, and redundancy. Depending on the organizations' geographical location, a landline, a wireless connection or Internet Service Provider (ISP) connection will be used.

Use of the high-speed protected communication lines with cryptography will enable realizations all information transferred between organizations by IPSec encrypted technology. Data centers are also fully protected behind an advanced system of firewalls and network security software. They are monitored to protect against hacking, fraud, theft, and denial of service attacks.



IRIS includes alert, notification, collaboration, decision support and action coordination features across the Matrix. User access will include Graphical User Interface that supports both free-text and structured search and consists of standard form elements. Participating institutions and laboratories will provide varying levels MC&A information depending on the network security domain.



Finally the MATRIX consist from

- Information Sharing (IS) Server, which provides the standards-based security infrastructure for encryption and digital signing of transactions and information.
- Administrator Tool – a web-based server application for managing the IS System.
- Matrix Agent is the authorization enforcement point for all resources, i.e., Files, or Web Applications, according to the access level defined by the Authority Center.
- Matrix is assure the availability of information in the MC&A form and manner conducive to its use in analysis, investigations and operations.
- End-users get a set of unobtrusive WEB browser-based tools to help them discover, filter and sort information and, as a part of a community of interest, annotate these web resources with valuable commentary.

Conclusion

The successful implementations of the NATO-ASTECMATRIX project in Armenia are essential contribution into security, stability and solidarity among regional nations, by applying the best technical expertise to problem solving. Collaboration, networking and capacity-building are means used to accomplish these goals. A further aim is to promote the co-operation with new partners and the ASTEC are creating links between scientists and organizations in formerly separated communities, developing new strategy concentrating support on security related collaborative projects and finding answers to critical questions and a way of connecting nations.

The NATO-ASTECMATRIX within Armenia leads to a network of high standards laboratories that will drastically improve the overview and the technical infrastructure for monitoring, accounting and control of CBRN materials in the Armenia. This new infrastructure will enhance the exchange of information on this vital issue via the IRIS. In follow-up phases, it will also help to better define the needs and requirements for a policy to enhance legal tools for the management of these materials, and for the creation of one or several agencies aiming at dealing with wastes or no longer useful materials containing CBRN components in Armenia.

ESTABLISHING CONTROL OVER NUCLEAR MATERIALS AND RADIATION SOURCES IN GEORGIA

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Abstract Regulatory control over radiation sources in Georgia was lost after disintegration of the Soviet Union. A number of radiation accidents and illegal events occurred in Georgia. From 1999 Nuclear and Radiation Safety Service of the Ministry of Environmental Protection and Natural Resources is responsible for regulatory control over radiation sources in Georgia. US NRC Regulatory Assistance Program in Georgia Assist the Service in establishing long term regulatory control over sources. Main focuses of US NRC program are country-wide inventory, create National Registry of sources, safe storage of disused sources, upgrade legislation and regulation, implementation licensing and inspection activities.

Regulatory control over radiation sources in Georgia was lost after disintegration of the Soviet Union due to many changes in the government and economy. Georgia faced significant problems in dealing with orphan sources that resulted from departure of the Soviet military and from privatization of industries previously engaged in activities with radiation sources.

As a result a number of radiation accidents and illegal events occurred in Georgia in the past years and caused concern both in Georgia and abroad.

Main Incidents:

Disused Co^{60} sources from the gamma therapy devices were discovered by railway workers at railroad storage yard in 1997 in Kutaisi. This incident caused four fatalities.

Eleven border patrol guards received serious injuries from radiation exposure in Lilo (near Tbilisi) in 1997. More than ten Cs^{137} sources (ten Ci each) with no protective container were discovered at that site.

Six Sr^{90} radiation sources with total activity around ^{210}KCi, which were removed from the RTG device, were discovered in Svaneti region in 1998–2001. These sources caused injury and death of several individuals (Figure 1)

S.A. Apikyan and D.J. Diamond (eds.), *Nuclear Power and Energy Security*,

Figure 1. Injuries from radiation incidents in Georgia

In this period increased number of illicit trafficking events in Georgia with nuclear and radioactive materials:

- 20 September 1999: workers of Ministry of State Security have detained persons that possessed 219 capsules containing 16% enrichment U^{235}, total weight 1,000.7 g.
- 21 April 2001: 920 g 3% enrichment U^{235} were intercepted.
- 18 July 2001 1,581 g 5% enrichment U^{235} were intercepted.
- 16 July 1998 – Pu-Be source $5*10^6$ n/s
- 1 February 2006 – 110 g 89.5% enrichment U^{235}.
- 17 July 2006 – some package of Cs^{137}.
- 9 June 2007 14 g low enrichment Uranium.

For locating, aggregating and securing storage of radiation sources, at first searching operation for orphan sources were held in 2002–2006 with support of IAEA, US, France, Germany, Turkey and India Government. During this period more than 270 orphan sources were recovered. All these orphan and unused sources were congregate into four temporary storages, where they were keep without international norms and compliance safety and security.

According Georgia's needs for construction of a new Central Storage Facility of Radiation Waste (CSFRW), US DoE helps us to design and build it on the area of old Reactor site of Institute of Physics. Construction of CSFRW was finished in September of 2006 and licensee for its activity was issued at March of 2007. All high activity sources will be relocated in CSFRW by DoE project in 2009. Congregation of all disused three to five categories sources at CSFRW was began from 2008 and was finished in May 2009 by support of US NRC.

Relocation process (Figure 2) assessment was based on Radiation Sources Database (RASOD) software created by Armenia NRSC, TSO of Armenia Nuclear Regulatory body: It provides for geography of sources temporary storing, sources current activity, possibility transportation of some containers at same time (photo), planning of additional technical resources in difficult events, Contact information of temporary storing responsible persons. Today in CSFRW are stored around 400 containers with more then 700 sealed and 50 unsealed sources, with total current activity ≈30 TBq.

Figure 2. Relocation process of unused sources into CSFRW

Nuclear and Radiation Safety Service (Service) of the Ministry of Environmental Protection and Natural Resources is responsible for regulatory control over radiation sources in Georgia. It was established in 1999, when Law of Nuclear and Radiation Safety of Georgia was issued. Today Service has ten specialists and six expert-consultants on non-permanent basis. Main functions of Service are establishing a long term regulatory control over radioactive sources, in order to prevent in the future a repeat of a current situation and to participate with other Georgian agencies in combating illicit trafficking and responding to emergencies, to prevent proliferation of radiation sources, their illegal use and harm to the population.

US NRC Regulatory Assistance Program in Georgia Assist the Service in establishing long term regulatory control over sources (since 2004). Main focuses of US NRC program are country-wide inventory, create National Registry of sources, safe storage of disused sources, upgrade legislation and regulation, implementation licensing and inspection activities.

Purpose of inventory was to establish and document current disposition of all types (sealed, unsealed, x-ray generator, asso) of radiation sources in Georgia and create according this information National Registry of sources. Inventory process consists Administrative search (Collection and analysis of historical and user provided data), creation of user and source preliminary list, on-site verification visits to physically inspect all of the organizations in Georgia last known to possess radiation sources, to enter inventory information into RAdiation SOurces Database (RASOD). Inventory results:

- 480 user-organizations (sealed, unsealed, x-ray generator)
- 780 – sealed sources
- 74 – unsealed sources
- more then 1,000 x-ray generators for medical, industrial, scientific activities

Very important step for establishing regulatory control are update/create of legislation and regulation in nuclear and radiation safety field. Old law of regulating nuclear and radiation activity in Georgia needs fundamental changes. By support US NRC Service creates new Amendment to the Law on Nuclear and Radiation Safety. Amendment gone expert analyze by IAEA, EU specialists. Law will be signed in 2009. Service creates drafts of Law on Transport of Radioactive materials and Law on Radioactive Waste Management Facilities, also Update of Basic Radiation Safety Requirements for handling of radiation sources, which will be signed after issue of framework law.

Service planed to create requirements: Physical protection of radiation sources, Decree on categorisation and registry of radiation materials, National emergency plan, etc.

One of the main problems of Service was unimplementation of requirements of existing law, especially in the field of licenzee and inspection activity. Until 2008 only 44 licenzee were issued. For increasing above mentioned activity by support US NRC experts Service prepared user guidance for potentially licensing organisations. On the base of information about facilities from RASOD software Service conducted 75 user seminars throughout Georgia with 280 participants in all parts of Georgia.

After seminars Service had significant progress in licensing process. At May 2009 were licensed 115 facilities. By Georgian laws, before giving licenzee to facilities, pre-licenzation process must be held. Because of that, service had implemented inspections in service. Both process increased competence of our staff in these fields.

Important progress was reached in field of Physical protection of radiation sources. New modern equipment was installed/upgraded in facilities with sources of I–II category, CSFRW. In near future Service will begin to create documents about Physical protection system requirements in Georgia, based on IAEA, GRS, US NRC experience.

Service has a lot of principle problems and tasks. For example, establishment of regional office in western Georgia, provision of training and equipment for HQ and regional offices, transport; Provision of portal radiation monitors for main border crossing points, provision of training for the personnel – SLD program (for Customs and Patrol Police); Issuing of a formal protocol for interaction between agencies responsible for combating illicit trafficking and responding to emergencies; Final stage of upgrading of physical protection for facilities with category I–III sources.

NUCLEAR ENERGY IN ARMENIA HISTORY, PROBLEMS, POSSIBILITIES AND OUTLOOK

Gera Sevikyan[1], Movses Vardanyan[1], Samuel Apikyan[2]

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The structure of the Armenian electric energy system is presently well balanced. The production capacity mix consists of about H42% nuclear, of about H40% gas, and H18% hydropower capacities. Before 2012, almost exclusively, new gas fired power plants are expected to be constructed, and some old gas fired ones are predicted to be closed down. A significant change in the structure of energy-production would occur after 2016, if the ANPP unit was shut down with the expiry of its operational license limited recently by the design lifetime.

For Armenia which is taking place in a rather complex geopolitical situation, and at absence of own natural power resources, ANPP today is sole guarantor of power and general independence and safety of our country.

We have realized it fully when our plant was shut down after the 1988 destructive earthquake and when the entrance of fuel for thermal power plants became impossible.

This hardest energy crisis 1991–1995 has forced us to accept the decision on renewal of ANPP operation. Naturally, in order to prevent recurrence of a similar situation, we are aimed on continuation of operation of our unit down to creation of compensative capacities.

Based on the present tendencies and market conditions, the industry is either predicted to cover the lack of electricity and the growth of demand with gas fired power plants that produce energy more expensively compared to the nuclear power plants, or would import the electric energy itself increasing the import-dependency. This way between 2012 and 2019 the import gas consumption of electric energy production, as well as its carbon-dioxide emission would grow dramatically compared to its present values (even in case of an intensive utilization of renewable energy sources). The electric energy import would, in the long run, be an expensive and obviously import-dependence-increasing solution. For the compensation of the production of ANPP it is rather difficult to find a green alternative.

In view of this situation the decision on construction of the new NPP made by the Government of Armenia is accepted by public (around 70%).

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We clearly understand that features of a political situation in and around Armenia, general watchful-negative and not always impartial attention to the questions connected with nuclear energy, deprives us the right on mistake – any light malfunctions (which are natural and acceptable for another NPP) at our plant will be equal to failure and, practically, will mean end of history of nuclear energy in Armenia. Moreover, similar event will be inevitably identified and widespread to all branch, that, the further ways and rates of development of so unpopular and so necessary atomic engineering will appear unpredictable.

Essential feature of nuclear energy objects is the unconditional priority of safety during its operation. This priority should be observed under any conditions, quite often to the detriment of economic, financial and/or political aspects.

In the described situation the realization of the Governmental decision on construction of the new NPP becomes especially important, responsible and laborious problem.

The new NPP should completely correspond to current international safety requirements and reliability, both during construction of NPP, and at the moment of its commissioning.

In principle, maintenance of an appropriate technical condition and increase of a level of safety of object of nuclear power is the permanent process beginning at a stage of decision-making on construction and proceeding up to formation of «green lawn» on a place of NPP.

All activity in this direction is being triggered by following major factors:

- Changes in safety requirements (IAEA, Regulatory Body)
- Modernizations of projects (changes of configuration, separation of systems, adding of new supports, restrictors)
- The Newest design researches (improvement of efficiency and reliability of separate elements of systems)
- Introduction of new materials (more resistant steels and alloys, effective additives in the working medium)
- Development of new techniques and procedures (monitoring, repair, information)
- Moral and physical ageing of separate components (modernization, replacement)
- Administrative changes (creation of new services, departments, laboratories, redistribution and addition of duties, functions)
- Operational experience (results of analysis of the revealed defects, refusals, results of the executed compensative measures, a self-estimation)
- The Information from the international cooperation (WANO, IAEA)

For the new NPPs it is especially important to provide a starting high level of safety that will allow maintaining in the further its technical conformity to constantly varying safety requirements using the rather small means and efforts.

Chronologically the first step in this direction is the work with offered General Projects of NPP to be constructed.

Only the scrupulous comparative analysis of these projects, taking into account of each trifle for estimation of their full conformity to requirements of standards and rules, currently in force, can guarantee the optimum choice excluding in the further the occurrence of serious and occasionally insoluble problems of operation.

In this direction the FNPP experts have got the richest experience, during almost 40 years deal with problems of increase of plants design safety.

The brief review of this experience can be offered on a background of the general information of our NPP.

As you, most likely, know, our plant consists from two Units with reactors ℜℜ⇑∠-440, first generation of the Russian projects.

The commissioning of Unit 1 was accomplished in the December 1976 and of Unit 2 – in January 1980.

After the Chernobyl accident and destructive Spitak earthquake both Units have been stopped under the public pressure:

The Unit 1 in February 1989 and the Unit 2 – in March 1989.

In 1993 by the Governmental decision have been begun repair-and-renewal works on the Unit 2, and on November 5, 1995 the ANPP Unit 2 has been connected to a power supply system of Armenia.

Main outcome of ANPP UNIT 2 operation after restoration:

Power generation (Total 1995–2008) – 29,735 billion kilowatt hours

Power consumption for auxiliaries – 7.95%

Number of safety related events in NPP operation (according to INES) – 9 «Level 1 (anomaly)»

Number of scrums – 7 (from them 5 by the external reasons)

The average annual value of collective dose of radiation – 1.24 Man*SV

Comparing these outcomes with the average parameters of 68 Units of Moscow Center BAO NPPs and of 249 Units PWR/VVER of the world it can be noted that in some cases, comparison appears in favour of ANPP. We are inclined to consider such worthy estimation as result of long-term, purposeful work on enhancement of our plant's reliability and safety.

Really, to return our plant in operation, besides unprecedented volume of repair-and-renewal works, it became necessary to execute also the whole spectrum of the special actions directed on elimination of deficiencies of safety, revealed by new requirements and rules.

Thus, the second Unit of ANPP, putted into operation on November 5, 1995 actually can be considered as the new object, with higher level of safety, than it had in March, 1989, at the moment of shutdown.

The following years of reanimated Units operation were found even more intense from the point of view of design safety as target IAEA missions have revealed essential deficiencies (TECDOC-640).

In total, for all period from 1995 up to present time 180 technical actions and 1,364 modernizations on increase of safety are executed.

More than 30 technical actions are included in the current plan of safety increasing and are to be executed the near future. Naturally, process on it does not come to an end – new actions, up to a final shutdown of Unit will be constantly developed and executed.

In addition to the planned actions on safety increasing, a lot of means and efforts became necessary for elimination of the discovered design mistakes and manufacturing defects of separate units of equipment.

Some of most significant examples are presented below

1. Corrosion damage of RPV main flange cladding surface (revealed during 1996 outage)

Before repair

After repair and 12 years operation

Radical cause of this damage	–	The design error (the monitoring channel drilled into the RPV flange cladding was inaccessible for inspection and for sediment cleaning)
The direct reason	–	Origination and propagation of corrosion cracks was caused by violation of the RPV preservation condition during 6 years after Units shutdown

The damaged part of cladding was carved and restored by local welding and machining.

The monitoring system of RPV tightness was modernized (the system's several components were displaced – from reactor flange to reactor cover).

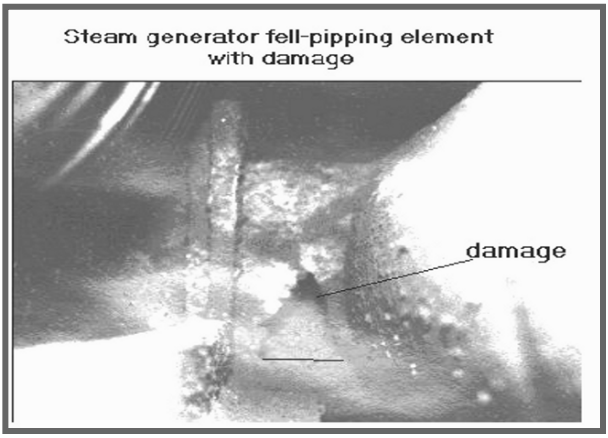
The analysis and elimination of this defect were executed together with Izhora and Gidropress.

This modernization now is being applied for designs of all new RPV

Probable consequences

- Damage of sealing surfaces of the reactor's density control unit – shut-down of reactor during 24–72 h
- Development of defects up to damage of the reactor's main seal unit's surfaces
- Output of the primary circuit's radioactive water
- Significant damage of reactor's flange under influence of an expiring jet of primary water
- Actuation of systems of emergency protection for Immediately shutdown of reactor operation

2. Corroding damage of SG feed-water inner collectors (revealed during 2000 outage)



Radical causes of this damage	–	The design error – an untrue select of material (carbon steel)
The direct reason	–	Violations of required conditions of preservation (during 6 years after shut-down)

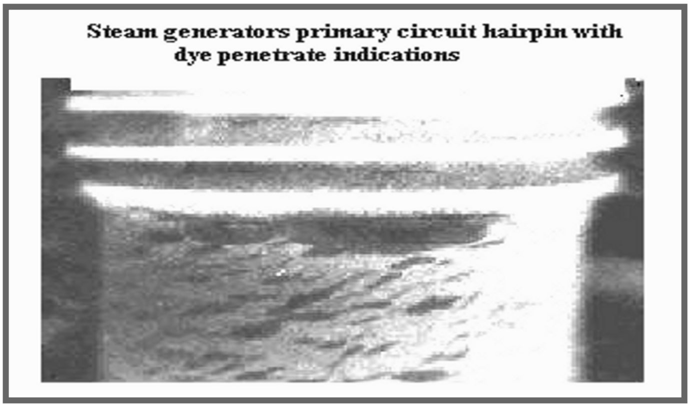
The complete sets of feed-water inner collectors for all six SG were replaced by new (stainless steel) in 2002–2006.

The design and manufacturing of new set of inner collectors was fulfilled by Gidropress, replacement – by our personnel.

Probable consequences

- Infringements of designed thermal and hydrodynamic characteristics in a steam generator
- Destruction of the damaged parts of collector, free moving of broken particles in inter-tubes space of steam generator
- Damage (up to through-the-wall crack) of heat-exchange tubes in consequence of temperature stress, dynamic vibration and impacts of the destroyed elements
- Leaks from primary circuit to secondary circuit
- Actuation of emergency protection system and shutdown of reactor operation

3. Fatigue damage of steam generators primary circuit collector's stud bolts



Radical cause of this damage	–	The design error in calculation of stud bolts safety margin and SG hydraulic tests' conditions
The direct reason	–	Casual (fluctuation of strain value) overexertion of double-end bolts during assemblage of primary circuit collector's seal

All stud bolts with such defects were replaced by new ones.

The value of pressure for hydraulic testing of primary circuit (including SG collectors) was reduced from 195 to 175 kg/sq.sm

The analysis and elimination of this defect, decision making were executed together with VNIIAES and Gidropress.

For exception of similar defects in the future the modernization of unit with replacement of nickel-based gaskets by the graphite gaskets was offered.

The application of such gaskets allows lowering a strain in bolts on 30%.

Accordingly, the safety factor of bolts is increased, and the probability of their damage will be decreased.

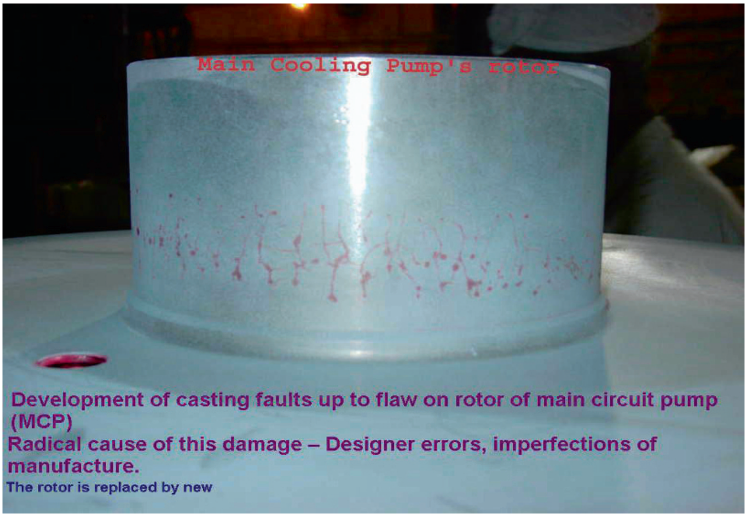
This modernization was performed at our plant in past year within our direct contract with Nuclear Research Institute (NRI Rez, Czechia).

Probable consequences

- Growth of defects up to destruction of M48 stud bolt
- Ejection of broken stud bolts under action of elastic forces
- Provoking jump of tensile stress on the near studs and their consecutive destruction

- Leaks from primary circuit to secondary circuit (LOCA Dn > 120)
- Actuation of emergency protection systems and emergency shutdown of reactor operation

4. Microcracks on the surface of Main Cooling Pump's Rotor



Radical cause of this damage –	The design error in option of rotor's configuration and its manufacturing procedure (casting)
The direct reason –	Growth of interior (latent) defects of casting with their outlet on the surface

The damaged parts of surface were carved (up to full disappearance of defects) and restored by local welding and machining.

The analysis and elimination of this defect, decision making were executed together with Designer (CKBM, St. Petersburg) and Manufacturer (Kirov Plant, St. Petersburg).

Given event was the reason for development of new design of impeller.

Presently it is being manufactured by welding of machine forged parts.

Probable consequences

- Growth of microcracks and their concentration up to unstable size
- Superficial fragmental damage of the driving wheel, the inflow of splinters into reactor's core and probable damage of nuclear fuel
- Dynamic unbalance of impeller (rotor) and its fatigue failure
- Non-recoverable damage of the Main Cooling Pump

- Actuation of emergency protection systems and emergency shutdown of reactor operation

These examples convincingly enough prove that during consideration and estimation of offers on the new NPP the rapt attention should be given not only to the general project, but also to each separate component.

The present-day understanding of complexity, responsibility and potential danger of nuclear power practically excludes isolation of any activity in the given area.

Not only the official international organizations, but also each separate owner of nuclear power object actively participates in processes of information interchange, technical cooperation and mutual assistance.

From the period of repair-and-renewal works at our Unit and till present time we constantly feel this friendly support and understanding. The material, scientific and technical aid of practically all countries to our small NPP totally amounts more than 100 million dollars, morally it is invaluable inasmuch as only owing to such support we managed to reanimate our Unit and already the 14th year we are operating it without infringements and incidents.

We very much hope that this remarkable tendency will be continued and widespread to our activity connected with construction of the new Nuclear Power Plant. Apropos, already there is a first acknowledgement of our hopes – the International Consortium “Worley Parson” had won the tender declared by the Government of Armenia on the subject: “The Managing Company of the new NPP”.

It means that the respective activity already should be begun in different directions from which the most important and urgent we think the following:

1. Development (option and adaptation) of package of Guideline and the Rules for nuclear engineering with giving of the State status
2. Formation of “Management of projected Nuclear Power Plant” and selection of the competent, responsible and skilled personnel
3. Development of the Performance Specification for the new NPP’s design and of the Terms of Reference (ToR) for Bidders of the tender for designing of the new NPP
4. Development of general Quality Assurance Programme and providing of its implementation
5. Calling for tender on the new NPP’s design and the Bids evaluation
6. Making (signing) the Contract with the Winner of the tender and taking control of its exact, timely and qualitative performance
7. Development of the general schedule of new NPP construction and of the working schedules for each of stages
8. Development of the summary specification of the necessary core equipment, option of manufacturers (suppliers) on the basis of estimation of conformity of these plants’ production to new requirements

9. Development of the general Aging Maintenance Programme (AMP) and origination of first files for Database of this Programme
10. Development of general Programme of personnel professional education and training with clear criteria of estimation of its knowledge and skills

Naturally, given list cannot pretend to completeness and accuracy (a similar problem is not for short article), but gives the general representation about the major directions of activity at the initial stage of new NPP construction.

DEVELOPMENT OF NUCLEAR ENERGY IN ARMENIA

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Abstract This paper presents an attempt to depict the situation in the Armenian Nuclear Energy Sector with the particular focusing on its further development. Basing on the energy independence and national security strategy principles, the Government of Armenia made a decision to construct a new nuclear unit in the Republic to replace Unit 2 of the Armenian NPP after its decommissioning. The paper shows that the only acceptable way of electricity generation in Armenia is the combined operation of thermal power plants and new nuclear unit, with the use of domestic renewable energy sources. This will allow to cover the Republic's energy demand and to export the excess electricity to the neighboring countries.

Armenia is one of 32 countries in the world operating nuclear power plants and is a country with about 30 years experience in the field of nuclear energy development. Nuclear energy is the most important part of the Armenian Energy Sector – Armenian NPP (ANPP) provides the country with about 45% of all the electrical energy produced in the Republic.

After the 1988 earthquake, both units of Armenian NPP, though had not been destroyed, were shut down, and Armenia lost minimal reasonable level of its energy independence. Therefore, after gaining its independence at the beginning of 1990s of the past century, the Republic of Armenia has got into the severe energy crisis. In 1993, the Government of Armenia made a decision to restart the operation of the ANPP, and in 1995, Unit 2 of the ANPP was put into operation. Armenia has come again to the minimal reasonable level of its energy independence which enabled it to overcome the energy crisis. Today, we can definitely declare that we have success in maintaining the power system that fully covers the electricity demand in internal market, reserves significant potential to export the electricity, and is one of the best among the CIS countries due to the implemented measures towards market reforms.

The issues of securing the necessary safety level of Unit 2 of the ANPP always have been and are still under the special attention of the Government of Armenia and Ministry of Energy and Natural Resources. Several countries (USA, Russian Federation, EU, Czech Republic and Great Britain) and international organizations, such as the IAEA, WANO, have been providing the ANPP with the technical

S.A. Apikyan and D.J. Diamond (eds.), *Nuclear Power and Energy Security*,

assistance for its safety upgrading. The Ministry of Energy and Natural Resources has always made the allocations from the internal resources for the ANPP safety upgrading since Unit 2 re-commissioning, and will continue to do this until the last day of the operation of the ANPP.

The realization of the required measures for the ANPP decommissioning is under way. The Decommissioning plan for nuclear units is under elaboration on the basis of the ANPP Decommissioning Strategy, which was approved by the Government of Armenia in December 2007. According to the appropriate normative documents, this plan must be ready and submitted to the Regulatory Body for its approval at least 5 years before the decommissioning of the ANPP. The ANPP Decommissioning Fund is functioning properly. Under the framework of Action Plan of EU Neighbourhood Policy, the negotiations are under way on the matter of providing the technical assistance for development of Strategy for Radioactive Waste Management.

The Nuclear Energy Sector of Armenia is rich with the human resources, many high-skill nuclear specialists and professional workers are involved into this field of activity. Armenia has a developed educational system for preparation of new nuclear specialists – two Universities of Armenia have Nuclear Energy Chairs.

The experience obtained during the years of energy crisis is teaching to conduct such an energy policy that would be able to provide the country with the reasonable level of energy independence. Taking into account the continuous rise of gas prices and issues of ecology requiring to restrict the emissions of CO_2, there are no other alternatives, but the further development of nuclear energy in Armenia, and it is a necessity to construct a new nuclear unit to replace the old one when Unit 2 of the ANPP will be decommissioned.

The strong legislative base existing in Armenia serves as a legal support to the maintaining and further development of nuclear energy. A number of Laws of the Republic of Armenia, relevant to this field, regulate all the issues related with the existing nuclear power plant operation, its decommissioning and new nuclear unit construction. Some new laws and regulations are needed. A new Law on Construction in Armenia of a New Nuclear Unit has been developed, and recently approved by the Armenian National Assembly in the second reading.

Being guided by applicable international principles for ensuring the necessary energy security the following structure for electricity generation is possible in Armenia:

- The priority should be given to renewable energy domestic sources and maximal utilization of its potential during the nearest 20 years, including hydro, wind, geothermal and solar. It is necessary to consider that all the mentioned sources have seasonal character.
- The rest of the requested electricity should be generated by the new nuclear unit of the ANPP and thermal power units, including combined cycle units.

All this has been reflected in the Armenian Ministry of Energy and Natural Resources Action Program which was developed on the base of the National Security Strategy principles and adopted under the Government Decision.

For the realization of provisions of that Action Program, the Minister of Energy of RA and the Ambassador of the USA signed in 2007 the Statement of Cooperation for development of planning studies for a preliminary Environmental Impact Assessment and Feasibility Study for a new nuclear power unit in Armenia that will be the core component of the Armenian Energy Sector development strategy. According to the results of those studies we can make the following conclusions:

- The following currently available prototypes of reactors were selected as candidates to be used in a new NPP project: AP-1000 (USA), WWER-1000 (RF) and CANDU-6 (Canada). They all are similar in cost.
- The export of excess capacity from the new nuclear unit to neighbor countries is technically and economically feasible.
- The current infrastructure in Armenia allows assuming that two new nuclear units can be constructed on the existing ANPP site.
- The finance for the construction of a new nuclear unit could come from the state budget of the Republic of Armenia, private investors, or mixed investments. Another potential source of funds can be investments from neighboring countries.
- A comparison analysis of the total cost of a 1,000 MW nuclear unit project versus thermal power plant with the same capacity was conducted. It shows that there is no economic alternative to the nuclear generation expansion plan for Armenia.
- The 1,000 MW(e) NPP will also reduce CO_2 emissions by about 3.2 million tons per year as compared to the TPP generation.

A chapter of the Feasibility Study has been developed, with the IAEA assistance, on the required training for personnel that will be involved in construction and operation of new unit. It was completed in November 2008. The human resources needs for the construction of a new nuclear unit have been determined.

A chapter of the Feasibility Study related to the seismic re-assessment of the NPP site is being developed with the Armenian financial support. TOR for seismic exploration of the NPP site was elaborated and submitted to IAEA's approval. Now, the seismic re-assessment works are ongoing. It is envisaged to complete the works by October 2009.

A package of tender documentation to select a Management Company for implementation of a project on construction of new nuclear unit (s) was approved by the Government of RA, and the tender was announced. The tender winner was selected – a "WorlyParsons" company and a contract was signed with the company on the realization of a project on construction of new nuclear unit (s) in Armenia.

According to the Terms of Reference, the activity of the Management Company is divided into the four phases:

- Phase I – Development of Bankable Feasibility Study (BFS) as a basis for the implementation of the project and selection of the Strategic Investor(s)
- Phase II – Selection of Strategic Investor(s)
- Phase III – Contractor(s) (EPC) Selection
- Phase IV – NNU Construction Project Execution

Armenia is ready to cooperate with the neighboring countries and to construct the new nuclear unit of regional significance. In our opinion, this approach will be more appropriate for the covering of the regional electricity base demand. For Armenia, it is obligatory to be involved in the regional power market which is currently in a process of formation and foresees the establishment of a circular power system of Black Sea countries, as well as creation of North–South parallel operation relations (Russia–Georgia–Armenia–Iran, and others).

So, in future, the leading role in competition for providing services to regional power market will be given to a country which is able to produce base-load electricity at the nuclear unit with the minimal green-house emissions. We are confident that Armenia meets this requirement and is ready to undertake this role in the region.

The following information is about the recent events of international cooperation in the field of nuclear energy:

- In 2007, the Government of Armenia made a Decision on the Republic of Armenia joining to the Agreement between the Governments of the Republic of Kazakhstan and Russian Federation on establishment in Angarsk of International Uranium Enrichment Center.
- In July 2008, the Russian–Armenian joint venture was established for uranium geological exploring, mining and processing.
- Armenia has been invited to join the GNEP. On 01.10.2008, the agreement was signed, and Armenia has become a member of the GNEP, the participation in which would provide the Republic of Armenia with the significant benefits in the field of nuclear energy.

SOME NEUTRON ABSORBING ELEMENTS AND DEVICES FOR FAST NUCLEAR REACTORS REGULATION SYSTEMS

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Abstract It is shown that performed technological, physical-mechanical and radiation tests clearly indicate the prospects of using Neutron Absorbing Elements (NAE) based on B-10 and some rare-earth compounds during the creation of highly effective Control and Safety System (CSS) rods for fast neutron nuclear energetic reactors. Particular attention was paid to the development of new and upgrading of existing computing and real technologies for designing and preparing the optimizing NAE items characterized by all physical and strength properties for obtaining desirable operational parameters of CSS rods on their base.

Keywords: neutron, fast reactor, control and safety rod, absorbing element

Introduction

The solution of problem linked with the creation of energetic nuclear reactors operating in prolonged life time conditions in many respects depends on the reliability of control and safety systems (CSS). In this regard, the role of the main and basic parts of the nuclear reactors' CSS rods – neutron-absorbing elements (NAE) is being increased more and more, as well as their quality characteristics, which meet new, strict requirements [1, 2].

The more hard operating needs are to be satisfied by rods of CSS for nuclear reactors on fast neutrons, the capacity of which directly depends on CSS [3].

For the practical applications to control systems in power reactors far from all these elements fit this task. Among neutron absorbing elements the most preferable are based on the isotope B-10 absorbers in terms of efficiency in neutrons' intermediate and fast power spectra. They are distinguished by an optimal absorbing capability and heat-physical and physical-mechanical characteristics from the standpoint of their usability as NAE [4, 5].

The importance of the utilization of boron-containing NAE as well of based on NAE rods of CSS for intermediate and fast neutron power reactors causes a great interest in the technologies of rods' fabrication and investigation of their properties.

Many monographs, articles and inventions are dedicated to nuclear power stations management and control facilities based on boron containing CSS. Alongside with that, it is necessary to be mentioned that at present many issues linked with the principles of technologies for their production as well as with the physics of relevant processes still are to be clarified.

The experience gained since 1970s in the USSR, USA, France and other countries has shown that the development of highly effective CSS requires the realization of complex investigations in the fields of thermo physics and technology, as well as of radiation influence and reactor technology [6].

Of a highest significance is the definition of materials and mechanical structures for the utilization of energetic fast nuclear rectors, as well as the improvement of existing technologies for obtaining items with desired properties (structure, density of the thermal flows, thermo-physical properties).

Some characteristics of boron-based neutron-absorbing elements (NAEs)

At present, it is well known that the initial properties (phase composition, structure, heat-physical characteristics, etc.) of neutron-absorbing materials and items on their base have a governing influence on the effectiveness of fast reactors' CSS different rods and NAEs.

There was studied the corrosion resistance of items made from B4C in sodium and its compatibility with stainless steel (NAEs housings' material). It was found out that the boron carbide and stainless steel components actively do not form chemical compounds with the pure sodium below temperature around 9,500°C. At the same time, it was shown that the interaction takes place by the materials solving in a liquid metal with their consequent sedimentation upon the stainless steel surface and by diffusion through this surface. As a result, there is observed the boronizing and carbonization of NAEs housings' materials with all subsequent consequences. On the base of computation analysis it also must be mentioned that the corrosive resistance in sodium is strongly influenced by oxygen impurities in the liquid-metallic heat-carrier that rather negatively affects the operational stability of NAEs and CSS rods in total.

The behavior and durability of boron-containing elements in high parameters water (increased temperature and impurities concentration) also strongly depend on initial properties of reacting materials, temperatures and time parameters of their operation. In total, the corrosion resistance of high dense items made from the boron carbide enriched by the isotope B-10 up to 90% is very satisfactory in terms of their utilization in CCS rods' NAEs.

Structures of neutron-absorbing elements (NAEs) of CSS rods for reactors-breeders basically consist of metallic housings and compact items made from boron-contained materials enriched by the isotope B-10 (Figure 1).

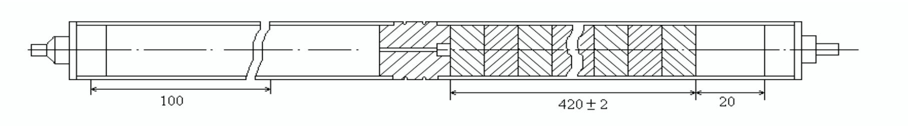

Figure 1. The simple model of neutron absorbing element for fast nuclear reactor regulating rod

NAEs the number of which in most of rods is seven are gathered in a cluster inside the housing's pipe and fixed in upper and lower parts of the CSS rod. In most of cases AEs are hermetically sealed and their structurally consist of the proper absorbing part and the gas collector where the accumulation of helium takes place. The formation of helium in the absorbing material during its exploitation in the neutron irradiation field is caused by the n, α nuclear reaction.

At present, the role of NAEs basically is performed by made from enriched B4C compacted items of two configurations: cylindrical and annular. NAEs structures and sizes depend on configuration and parameters of the reactor-breeder's active zone. Main problems in terms of NAEs working capacity occur basically because of the temperature field's nonuniformity and also due to gas swelling of their components [7].

Because of high temperature and mechanical loading the NAEs are being regularly surveyed during their exploitation as well as thoroughly studied in special so called "hot chambers" after "campaign" is over. Main damages typical of NAEs during their exploitation are form-changing and NAEs housing's deformation caused by the radial loading. It is worth mentioning that during a long exploitation and in presence of curved neutron fields very often the disturbance of NAEs housings' hermiticity takes place. It causes the gas accumulation in rod's hollows and thus the sharp impairment of its working capacity's parameters. In this regard, frequently are used the so called untaught NAEs while in the rods structure there is provided a possibility removing gases formed as a result of nuclear reactions.

One of positive factors of the utilization of neutron-absorbing items made from the boron carbide is their gas swelling's linearity that allows to maintain the structural stability of AE, and hence – of the rod, even in cases of their fast burn-out and heating to high temperature when the emergency stoppage of the nuclear reactor i.e. the rapid insertion of rods into the active zone of the fast reactor take place.

Some types and structures of CSS rods for reactors-breeders

In fast reactors there are used three types of controlling rods. They are rods of fine control, coarse control and emergency rods. Functions of each of them are either the control of nuclear reactivity or stoppage of reactor's operation. Controlling rods serve for reactivity's compensation during the run, temperature increase, burning out and external effects. In particular, from the standpoint of fine adjustment controlling rods' function – reactor's control, the most important parameter of these rods is the control's rapidity. Emergency rods serve specially for emergency stoppage of the nuclear reactor as rapidly as possible.

Rods for compensating the reactivity of the reactor-breeder usually have a structure consisting of seven absorbing elements (NAE) gathered in a cluster inside the housing tube (Figure 2). In the lower part of the rod NAEs are rigidly fixed (usually welded), while in the upper part they move freely in axed direction. NAEs are hermetic and structurally consist of neutron-absorbing part and gas collector. Basically, they are made from cylindrical modules B4C enriched by the isotope B-10. During exploitation such a compensation rod (CR) is located in the central cell of the active zone and as the uranium-plutonium fuel is being burnt out the CR moves upward.

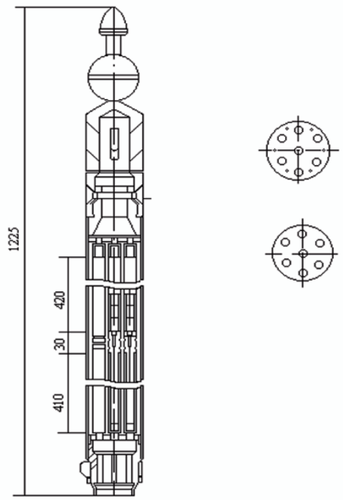

Figure 2. Reactivity compensation rod design

Among the CCS rods intended for the emergency stoppage of the reactor-breeder the most optimal is the structure of the emergency guard rod (EG) worked out for the energetic nuclear reactor "BN-600" (Figure 3). It consists of the head, upper extension section, two neutron-absorbing sections and lower extension section.

NAEs of such a rod usually are made from B4C enriched by the isotope B-10 up to 80%. The rod is not hermetic, in its upper end component are two inter-perpendicular apertures. The internal volume, through the groove seal between the upper end component and the jacket as well as through special apertures is linked with the heat-carrier. There takes place the initial filling of gaps by the liquid-metallic heat-carrier – sodium as well as the exit of a heat generated during the exploitation.

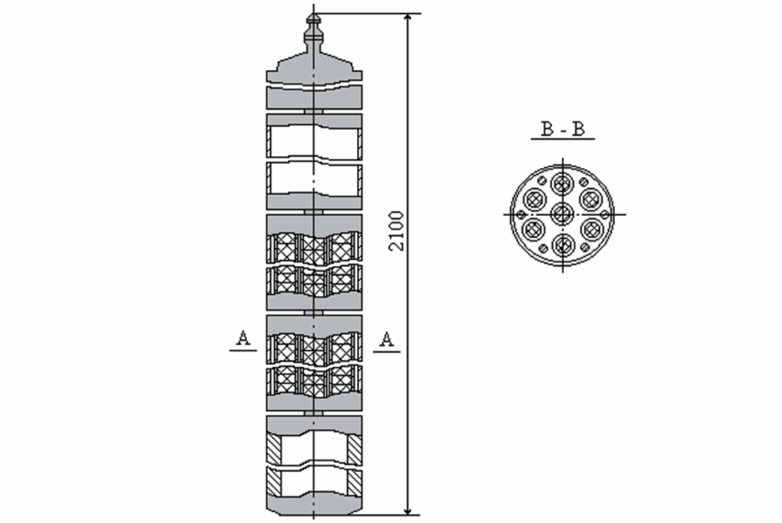

Figure 3. Emergency protection rod design

Last years, according to active zones' parameters of reactors-breeders there are used CCS rods of other structures.

The temperature compensation rod (TC) of nuclear reactor's active zone (Figure 4) basically is made from NAEs where the composition of europium oxide and metallic molybdenum (Eu_2O_3 + Mo) serves as a neutron-absorbing material. In this rod, inside the absorbing working section there are located 48 absorbing elements. AEs are encapsulated by end components and welding. They can be of an assorted type (consisting of modules or cylinders) and of a filled type. Rods with filled NAEs are approximately two times cheaper due to the high capacity and an absence of waste of Eu_2O_3 during the fabrication of their tablets the hot compacting method.

The rods-traps are among the most prospective reactors-breeders' CCS rods. In these rods (their structure is shown in Figure 5) the role of neutron-absorbing element was performed by tablets made from europium oxide (Eu_2O_3) or ring items from boron carbide (B4C) enriched by boron-10 up to 92%.

Experiments carried out for determining comparative effectiveness of rods-traps on the critical assemblages with plutonium fuel have shown that such CCS' rods structures provide the increase of the neutrons absorption effectiveness (working capacity) by up to 10–20% according to characteristics of neutron field and other parameters of the nuclear reactor's active zone [8].

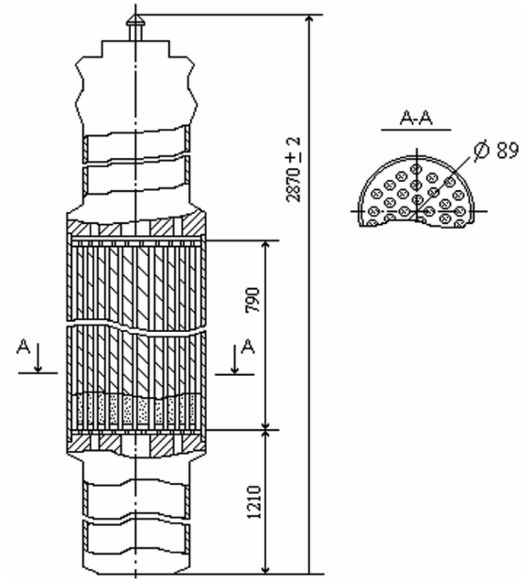

Figure 4. Temperature compensation rod design

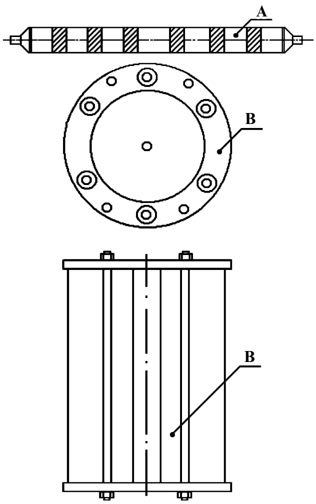

Figure 5. The scheme of the neutron absorbing element-A and trap-type regulating rod

In order to increase the effectiveness of CCS rods operating in the high energy neutrons field as well as to improve their reliability some interesting structures were worked out.

For ameliorating NAEs cooling conditions there is developed the rod in which absorbing elements have a form of a disk with central aperture and are bordered from top and bottom by conic surfaces (Figure 6). The angle of a slope of the absorbing elements' lower surface is larger than that of the upper one and between them capillary gaps for the heat-carrier moving.

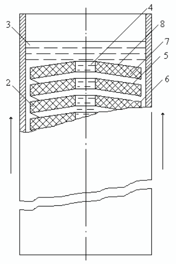

Figure 6. The scheme of advance regulating rod with better cooling conditions

While the rod operates within the nuclear reactor's active zone there actively circulates in the internal space of rod the liquid-metallic heat-carrier the more cold part of which flows downward and the warmer one – upward. Alongside with that the heat-carrier moves in broadside direction from periphery to centre. Finally, it provides the substantial improvement of the heat transfer from neutron-absorbing NAEs [9].

For ameliorating the evenness of the burning-out process of a neutron-absorbing material there is developed the CCS rod's structure including the container for powder-absorber with permeable walls (Figure 7). While the rod operates within the reactor-breeder's active zone the engendered by the nuclear reaction process of heat liberation continuously takes place in the bulk of the powder-absorber. At the same time, there appear temperature conditions sufficient for organizing the liquid-metallic heat-carrier's boiling process. The liquid-metallic heat-carrier of relatively low temperature penetrates into container trough external walls moving trough and cooling the absorbing material. During this process it gets warmed itself, turns into the gas-liquid mixture and enters the rod's central channel. The container's volume and powder-absorber's amount is selected with regard for providing powder's continuous, slow agitation. Having the mean circulation directivity, the migration results in powder's displacement upward in the central zone. In such agitation conditions the whole neutron-absorbing material will be burnt-out evenly. Such structure of the controlling rod is attractive because of the fact that the absorber's agitation process, hence its even burn-out, runs without using any drive mechanisms, external motor means and engines. All this has a positive effect on the effectiveness and reliability of the nuclear reactor's whole controlling and security system [10].

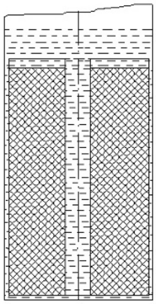

Figure 7. The scheme of the regulating rod with the good burn up properties

Last years there is intensively going on an activity focused on creating new highly effective and reliable CCS rods for fast nuclear reactors. Structural particularities of modern rods are determined by new optimizing neutron-absorbing elements as well as by the necessity of providing optimal heat and thermo-mechanical conditions for their exploitation [11, 12].

It is also necessary to underline that the development of novel nanotechnology methods for NAE and NAM preparation as well as new technologies of computing and modeling and simulation experiments and elaborations create a possibilities to develop of new high effective NAM, NAE, and relevant devices with new much more effective parameters [13].

Conclusions

Investigations focused on the development of CSS rods for fast energetic reactors carried out for last 2 decades in countries possessing nuclear technologies showed the expediency and possibility of building their various structures providing effective and reliable operation. At the same time, it is sufficiently fixed that the most appropriate absorbing elements are isotope-enriched boron compounds as well as compositions of rare-earth metals.

The performed technological, physical-mechanical and radiation tests clearly indicate the prospects of using B-10 containing NAEs during the creation of highly effective CSS rods on their base.

In this respect, particular attention is to be paid to the development of new and upgrading of existing computing models as well as effective molecular nano and microtechnologies for producing the novel generation of items characterized by all physical and strength properties necessary for obtaining desirable operational parameters of CSS rods on their base.

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DEVELOPMENT OF DESIGN OF A RADIOISOTOPE SWITCHABLE NEUTRON SOURCE AND NEW PORTABLE DETECTOR OF SMUGGLING

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Abstract Development of simple and cheap radioisotope switchable neutron source for application in the portable device of detecting of smuggling is presented. Detailed calculations (Monte-Carlo modeling) for the purpose of optimization of a design of the source and the detector module are carried out. The sufficient an yield of neutrons, about $2 \cdot 10^5$ n/s provides the source with the sizes of approx $25 \times 25 \times 60$ mm^3. Results of simulation of scanning smuggling areas (polyethylene $10 \times 10 \times 5$ cm^3) behind the thick steel wall (1.2 cm) gave the relation of signal/background 7–8.

Despite development of hi-tech radiation complex monitoring systems of cargoes and luggage, the requirement for portable radio isotope search devices remains, for detecting of explosives, the drugs, highly enriched uranium, etc. Such contraband is often placed in the hidden cavities, behind thick metal walls of vehicles – sea courts, cars, cargo containers, etc.

For example, in Figure 1 steel structures of the hidden cavities of the sea container are shown. Thickness of steel walls varies from 2.0 up to 4.0 mm. The volume of the hidden, tightly welded empty cavities in containers exceeds 200 l where without special efforts can be hidden illegal enclosure.

Among compact radio isotope devices of search appointment it is possible to name BUSTER K 910B (CSECO – Campbell Security Equipment Co) (Figure 2). In the device the gamma-albedo method with application of a radioisotope Barium-133 is used [1]. It examines cars, trucks, walls of containers, fuel tanks, automobile tyres, boats and ships etc., for detection of the hidden drugs, explosive material and other contraband. The successful design, good ergonomics and the provided radiating safety have caused the big popularity of these devices among customs officers and frontier guards of more than 50 countries of the world. The basic lack of this device is a small thickness of barriers, not more 2.5 mm of a steel.

S.A. Apikyan and D.J. Diamond (eds.), *Nuclear Power and Energy Security*,

Figure 1. Steel structures of the hidden cavities of the sea container

Figure 2. Photo of BUSTER K 910B device

The neutron technique allows finding out confidently the explosive and narcotic substances hidden behind metal barriers in the thickness of 30 mm and more. Prominent features of interaction of neutrons with substance make neutron methods and devices NDT exclusive and often irreplaceable. Especially when it is necessary to find out light substances behind thick-walled metal barriers.

In devices of neutron nondestructive testing traditional isotope sources of the neutrons including a radioactive isotope – a source of α-radiation (^{238}Pu, ^{239}Pu, ^{241}Am) and a target (Li, Be, F) continuously generating neutrons, are used basically [2–5]. In the equipment where sources of neutrons are used, it is desirable to have source which can "be switched off" for the time when the device does not work. It is especially important to have such source in the portable device as for safe storage and transportation of an isotope source of neutrons with an output 105–106 n/s, it should be placed in the shielding container weight of which can amount tens kilogram.

Detector "CINDI" (Compact Integrated Narcotics Detection Instrument) developed by the American enterprise "NOVA R&D, Inc." 2001) is the characteristic representative of the portable neutron devices intended for detection of illicit hidden places behind barrier. It contains a source of fast neutrons of Californium – 252 having activity about 50 μCi.

Developed by us in the beginning of 90 for customs and boundary service of Georgia the neutron portable search device with ^{252}Cf source is a prototype of the presented device [6]. It contained ^{252}Cf having activity not more than 50 μCi and ^{3}He counters were used as the detector of the backscattering slow neutrons (Figure 3).

Figure 3. Developed by us the neutron portable search device with ^{252}Cf source

Figure 4. Smuggling detect modification

Figure 5. Level-meter modification

Device operating experience has shown, that it reliably controls metal thick-walled (15–20 mm and more) eaves, doors, wheels, the chassis cargo and cars, deaf eaves and edges of rigidity of containers used as hidden places for illegal materials – explosives, drugs etc. having minimal weight 10–20 g, located on depth about 250 mm. It could be effectively used for detection and control of whatever hidden places by relevant services.

A working surface of a sensor control of the device made 60 × 100 mm, and the weight did not exceed 350 g. Application of the telescopic handle of the device provided radiating safety of the operator (Figure 4).

Our enterprise made simpler updating of this development, level indicator [7], and successfully sold it to the different petrochemical enterprises of the former Soviet Union, had preliminary orders on hundreds of neutron level gauges (Figure 5).

However the certain inconveniences and complexities at storage and transportation of neutron sources because of high weight of containers, as well as radio phobia, push away consumers. The real prospect for safe, wide consumption of our as well as of many other neutron development represents transition on quailtatively new, radiation safe radioisotope sources of neutrons with an regulated output.

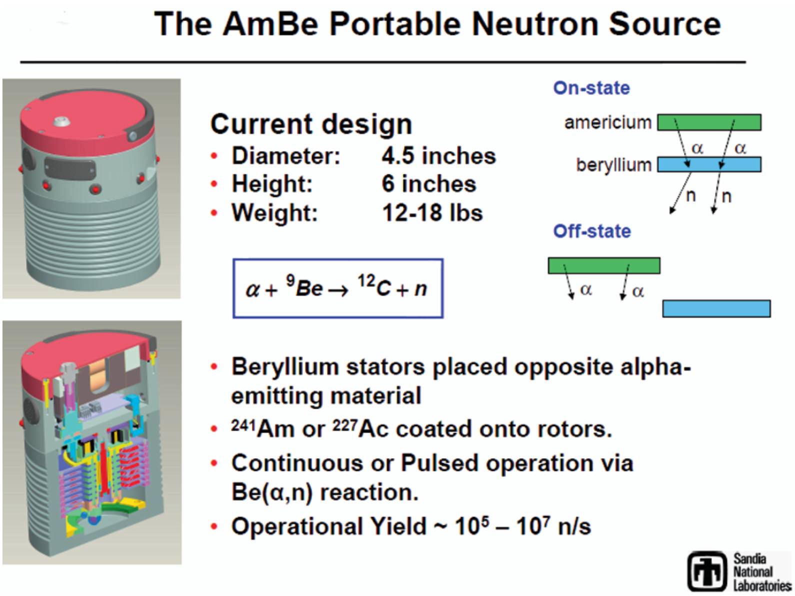

Figure 6. Principle of operation of switchable radioisotope sources and operating unit (Sandia National Laboratories [11, 12])

In the scientific literature the sources of this kind are named differently – radioisotope generators of the neutrons, adjustable sources of neutrons, Switchable Neutron Sources (SNS), “ON-OFF”, etc. [8]. As a matter of fact they are included and switched off mechanically and are radiation safe at storage and transportation.

Development of manufacture and duplicating of such sources of neutron radiation will give a new pulse for perfection of neutron methods of not destroying testing.

For last 2 decades there has been an essential progress in workings out of switched off sources of neutrons – radioisotope Switchable Neutron Source – RSNS and portable D-D neutron generators [9, 10]. On Figure 6 the illustration of a physical principle of a switched off neutron source and realised in Sandia National Laboratories (Kristin Hertz) pulse SNS is presented [11, 12].

In a switched off isotope source it is necessary to bring in working position in contact an alpha a radiator and a target so that at deenergizing, they could be separated again, not having polluted one another. This requirement is fundamental for creation of a pure and reliable switched off neutron source.

Application SNS in portable search devices will provide radiating safety in a non-working condition – during transportation and storage. Creation of such sources can stimulate development of new generation NDT and multipurpose search-devices [13, 14].

The output of neutrons of such sources basically depends on the area of a target and an α-emitter and dimensions (volume) of SNS will definitely depend on the set activity (output) of neutron radiation. Except for that specific activity of α-emitters and their nuclear characteristics, the different probability of (α, n) reactions on targets accordingly influence size of the necessary area of choose pairs – targets and an α-emitter.

SNS developed in SNL generates a pulse stream of neutrons that is extremely important for synchronous detecting. But for this reason the source has turned out complex enough and, probably, too expensive. In our project design SNS is as much as possible simplified (it is not required pulsed a stream of neutrons), switching on and off of source is carried out by a hand simple turn of the lever.

For maintenance of a yield of neutrons $2 \cdot 10^5$ n/s, the contact area of an injector and a target should be 120 cm^2 for Am-Be pairs and 40 cm^2 for Pu–Be pairs. The thickness an alpha of a radiating layer is sufficient 0.1–0.2 μm. Such thickness of a layer of a radiator makes approximately 10% from size of the maximum range of α-particles in them. It means, that about half of neutrons are used.

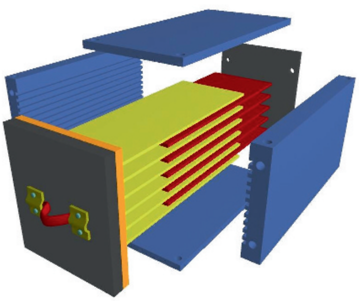

Figure 7. Box-form design switchable source

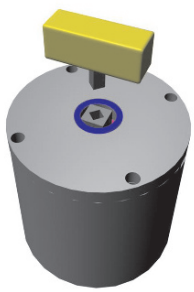

Figure 8. Cylinder-form design switchable source

Possibility to collect on layers the necessary contact area allows creating optimum geometry of a source box (Figure 7) or the cylindrical form (Figure 8). In the first case switch on-off occurs displacement of a lateral wall to targets, and in the second – rotation of a package of disks on 180°. In all cases biological protection against accompanying soft gamma-rays radiation is provided.

Figure 9. Component of cylinder-form source

On Figure 9 are shown a set of disks static and rotating. Half of area of a disk covered two sides by an injector material, and other half – a target material. On Figures 10 and 11 is shown position of disks in the switched on and switched off state.

The sufficient yield of neutrons, about 2 10^5 n/s, provides a source with dimensional in the sizes of the case approx 25 × 25 × 60 mm^3.

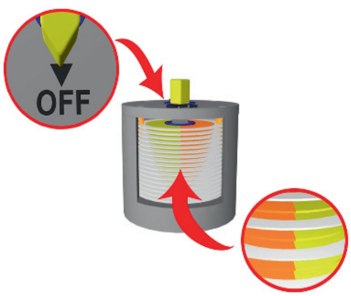

Figure 10. Switch off state

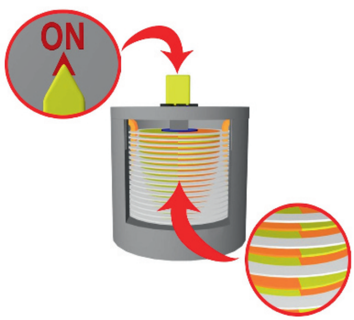

Figure 11. Switch on state

It is natural, that all previous neutron developments of small-sized devices have been optimized on application point-like, small-sized traditional sources of neutron. By development of detecting module of the new device it will be necessary to investigate and optimize its new geometry (architecture), taking into account real dimensions (volume) of SNS.

As a rule, when for contraband concealment their hidden metal cavities are used fill completely, i.e. the geometrical sizes of smuggling big enough. Therefore, rather big sizes SNS practically are not worsened sensitivity of the device. On Figure 12 results of scanning (Monte-Carlo simulation) smuggling areas (polyethylene 10 × 10 × 5 cm^3) for thick (1.2 cm) a steel wall the device with pointlike (box-point) and with volume sources (a switchable source) are shown. From Figure 12 it is visible, that results of scanning practically coincide, and, main result, the relation of signal/background is equal to 7–8.

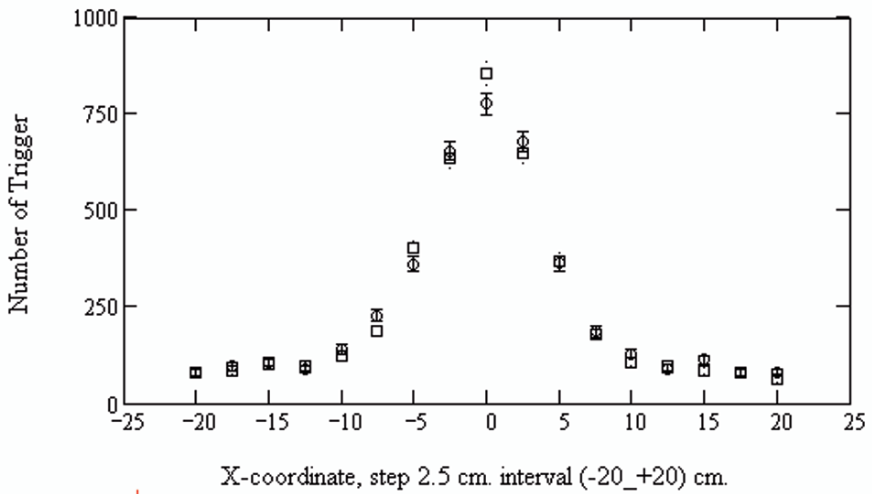

Figure 12. Results of scanning (Monte-Carlo simulation) smuggling areas:circle-switchable source, box-pointlike source

Our experience gained in development, production and marketing of this equipment confirms that radiation safety is the main characteristic among others, determining demand for this equipment.

We also have developed of design of apparatus for detection of highly enriched uranium (HEU) hidden in luggage [13–16]. As a source of neutrons the switchable radioisotope source is used.

The active method is used: slow neutron-induced fission Uranium-235 and accounts of coincidence of fission neutrons. Confidence level of detection HEU is calculated by means of Monte-Carlo simulation. Quite comprehensible results are obtained: in volume of the control of hand luggage 60 × 50 × 60 cm^3, with the Pu-LiF switchable source of neutrons activity not more than 5 × E5 n/s, 10 g of

Uranium of 90% of enrichment is found out for 1 s with more 98% confidence level.

This device can be used as an additional, new link as a part of conveyor system of existing x-ray scanners or as more flexible, in block design version, for the mobile control in non-standard situations. The obtained results represent a good basis for practical realization of this product.

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NEW DESIGNS OF MEDIUM POWER VVER REACTOR PLANTS

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OKB, Gidropress, Russia

Introduction

The task of constructing NPPs as the objects of regional power industry is included into the Federal Target Program on nuclear power technologies of new generation for the period till 2020. Such NPPs are considered as perspective sources of energy for solution of the problems concerning provision of electric energy, household and industrial heat to the regions with limited capabilities of the power grid.

OKB "GIDROPRESS" present the conceptual study of RP design for the Unit of 600 MW (el.) power, taking into account their long-term experience in the field of development and operation of VVER reactor plants.

Approaches to designing

1. Evolution and improvement of equipment and systems of the operating RPs, including usage of the existing equipment
2. Safety characteristics at the level of international requirements for NPP of generation 3+
3. Orientation towards requirements for NPP of the fourth generation
4. Confinement of the core melt inside the reactor vessel under severe accident owing to vessel cooling from the outside

Design concept

1. Cutting down the scope and time of construction, as well as the mounting work and operational expenses
2. Unit operation mode – load following mode, base mode
3. Design service life of the main equipment is at least 60 years
4. Maximum use of service capabilities for R&M of RP equipment, for transportation of fresh and spent fuel

S.A. Apikyan and D.J. Diamond (eds.), *Nuclear Power and Energy Security*,

VVER-600 reactor plants

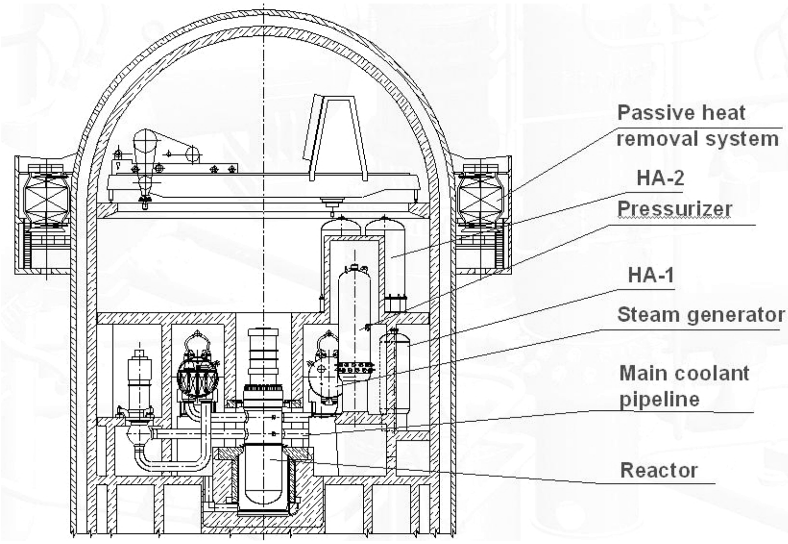
Technical data

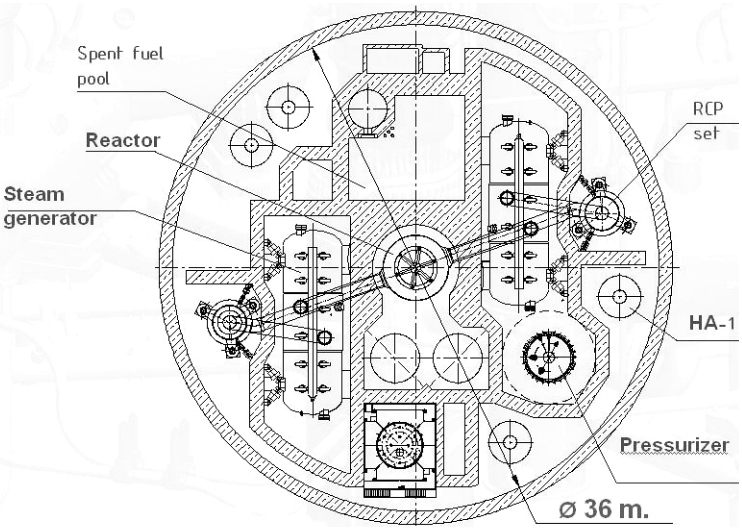
Parameter	Value
Thermal power, MW	1,600
Coolant pressure at the reactor outlet, MPa	16.2
Coolant temperature at the reactor outlet, °C	327
Coolant temperature at the reactor inlet, °C	299
Coolant flow rate through the reactor, m^3/h	47,140
Number of circulation loops (RCP sets), pcs.	2
Steam pressure at the outlet of steam generator steam header, MPa	7.0
Fuel burnup fraction, MW day/kgU	to 70
Neutron fluence to the vessel wall during 60 years, not more than, neutr/cm^2 (E > 0.5 MeV)	$4 \cdot 10^{19}$
Reactor plant service life, years	60
Load factor	>0.9
Operation mode	Load following, base

Main equipment

RP equipment unit	Characteristic
Reactor	New design based on VVER-1200
Steam generator	PGV-1000MKP (2 pcs.)
RCP set	GCNA-1391 (2 pcs.)
Main coolant pipeline	“Hot” and “Cold” legs – Dnom 850
Pressurizer, relief tank	VVER-1200
Equipment for reactor maintenance	VVER-1200
ECCS hydroaccumulator (HA-1)	VVER-1200 (4 pcs.)
SCPF hydroaccumulator (HA-2)	Similar to that at VVER-1200 (4 pcs.)

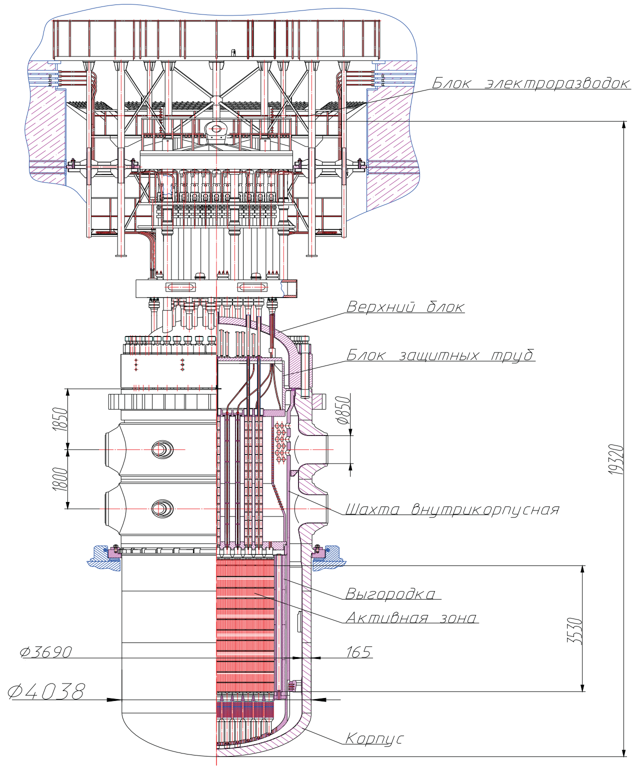
Layout solutions





Reactor with the core arranged of 109 FAs

Reactor design solution



Technical characteristic

Reactor thermal power, MW	1,600
Pressure at the reactor outlet, MPa	16.2
Coolant temperature, °C: – At the reactor inlet – At the reactor outlet	 299 327
Coolant flow rate through the reactor, m³/h	47,140

VVER-600 RP safety systems

Targets of optimization of safety systems design bases:

1. Simplification of layout solutions for active and passive channels, reduction of equipment units
2. Keeping the acceptable safety level
3. Reference character of technical solutions

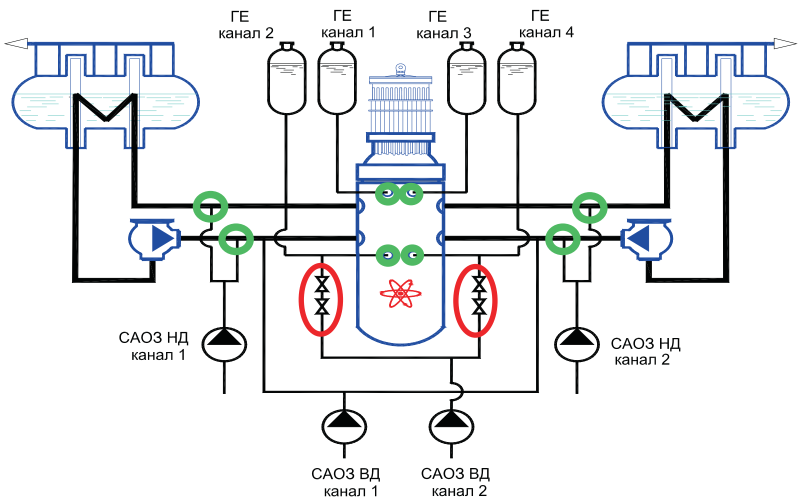
Results of design bases optimization:

1. Layout solutions exclude the following failures dependent on the initiating events:
   - Simultaneous failures of passive and active system channels
   - Simultaneous failures of active safety systems within the boundaries of one channel (HP ECCS and LP ECCS)
2. Demand for diversity of safety systems is assured.
3. Redundancy of emergency power supply is provided for two-channel system when one channel is brought into repair (station diesel-generator).

Basis solutions of SS structure optimization

Layout solutions excluding the simultaneous failures of passive and active system channels dependent on the initiating event:

1. Connection of HA and HP ECCS to different points of the primary circuit (reactor and MCP, respectively)
2. Possibility of operator's isolation of HP ECCS channel from supply into leak during management of the accident with break of HA pipeline

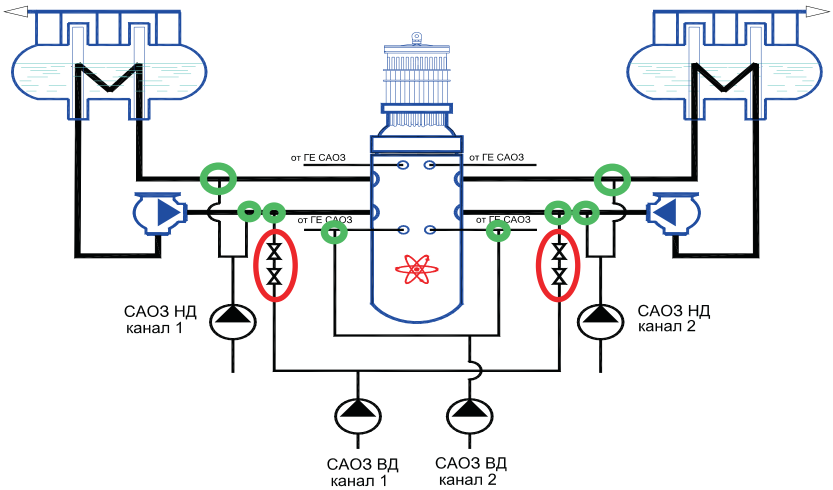


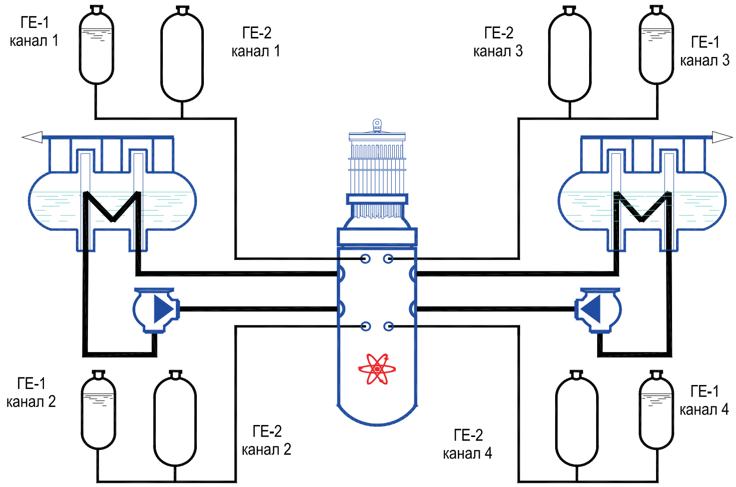
Layout solutions excluding the simultaneous failures of HP ECCS and LP ECCS channels dependent on the initiating event:

1. Connection of HP ECCS and LP ECCS to different points of the primary circuit
2. Possibility of operator's isolation of HP ECCS channel from supply into leak during management of the accident with MCP break

Layout solutions on connection of passive SS to the primary circuit:

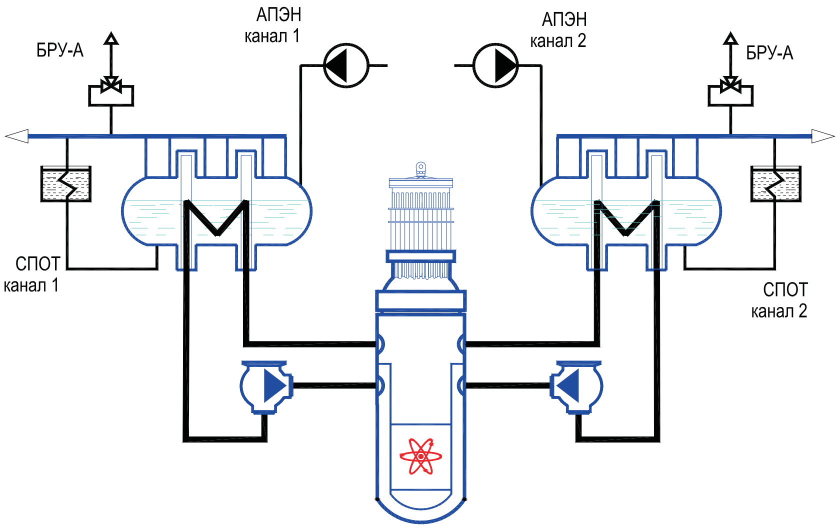
1. First stage HA – four channels
2. Second stage HA – four channels





Cross-redundancy of systems for heat removal from the secondary circuit:

1. EFWP + BRU-A – two channels
2. PHRS – two channels



Results of solution of SS structure optimization problems:

1. Optimization of characteristics of active and passive safety systems towards reducing their flow rate characteristics
2. Twice decrease in the number of equipment of active safety systems
3. Cutting down the scope and duration of construction and mounting activities
4. Reduction of capital costs and operating costs (maintenance, inspection, repair)

R&D for VVER-600 RP:

1. Basis – R&D on AES-2006 design
2. Additional R&D – for justification of transition from four-loop to two-loop reactor plant
3. CFD simulation is proposed (numerical experiment) for solution of the following problems:
   – Assuring the uniform character of coolant flow at the core inlet
   – Prevention of pressure pulsations in the coolant flow path
   – Prevention of occurrence of stagnant regions
   – Assuring the acceptable characteristics for a short-term operation with one loop

Stages of design development:

1 STAGE
Elaboration of the basic design documentation within the scope sufficient for preparing the documents for licensing – 12 months from the beginning of activities

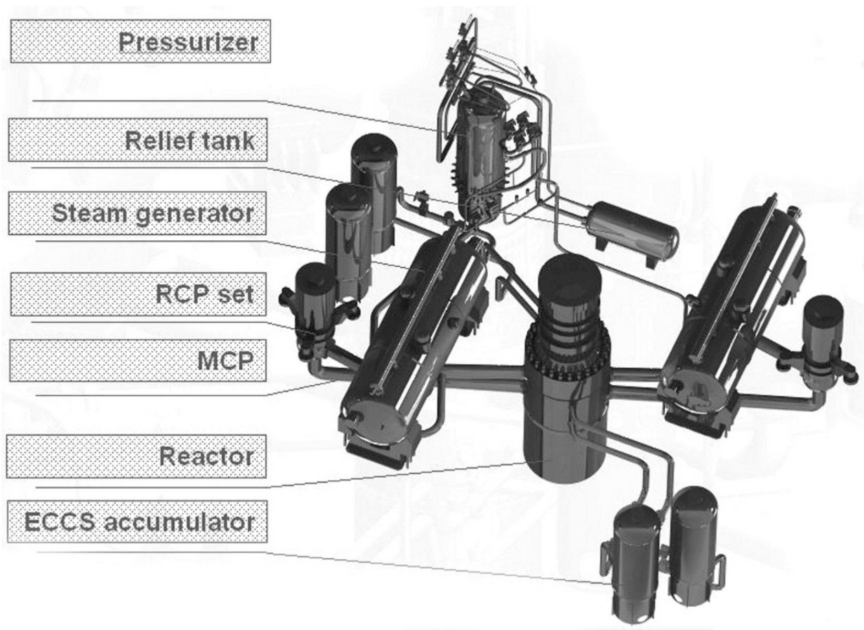
2 STAGE
Elaboration of documentation within the scope required for putting into production the equipment with long run manufacturing cycle – 18 months from the beginning of activities

3 STAGE
Elaboration of complete detailed project report – 24 months from the beginning of activities

VVER-300 reactor plant

Analysis of the existing demand for NPPs of small and medium power (to 300 MW el.) showed that nowadays the consumer market for such NPPs is available (remote regions of Russia with limited capabilities of the power grid).

OKB "Gidropress" present the conceptual study of RP design for the Unit of 300 MW (el.) power based on equipment of VVER-640 reactor plant, taking into account their long-term experience in the field of development and operation of VVER reactor plants.



Main technical data on VVER-300

Parameter	Value
Nominal reactor power, thermal, MW	850
Electric power of NPP Unit, MW	300
Number of circulation loops, pcs.	2
Steam capacity under nominal conditions, t/h	1,700
Coolant flow rate through the reactor under nominal conditions, m^3/h	20,500–23,000
Nominal pressure of steady state conditions at the reactor outlet (absolute), MPa	15.7
Average coolant temperature in the core under nominal conditions, °C: – At the inlet – At the outlet	 294.0 322.0
Pressure of generated saturated steam at SG outlet at nominal load (absolute), MPa	7.0 ± 0.1
Feed water temperature (under nominal conditions), °C	225
Fuel burnup fraction, average (under load-follow mode), MW day/kgU	60

Basic design solution

Layout:
– Inside diameter of RP arrangement in the containment – 34 m
– Number of circulation loops – 2

Reactor vessel:

- Maximum inside diameter of the vessel in the beltline region – 3,145 mm, vessel outside diameter – 3,445 mm.
- Two-row area of nozzles Dnom 620.
- Central part of the vessel is made of steel 15Х2НМФА class 1 + corrosion-resistant cladding.
- RPV assigned service life is 60 years.

Reactor internals:
Design of the reactor internals is similar to that in VVER-1000.

Reactor core:

- FA type – TVS-2, TVS-2M
- Number of FAs in the core – 85 pcs

CPS drive:

- CPS drive SHEM-3
- Number of CPS drives – 34 pcs

Steam generator:
Horizontal SG based on PGV-1000МКП

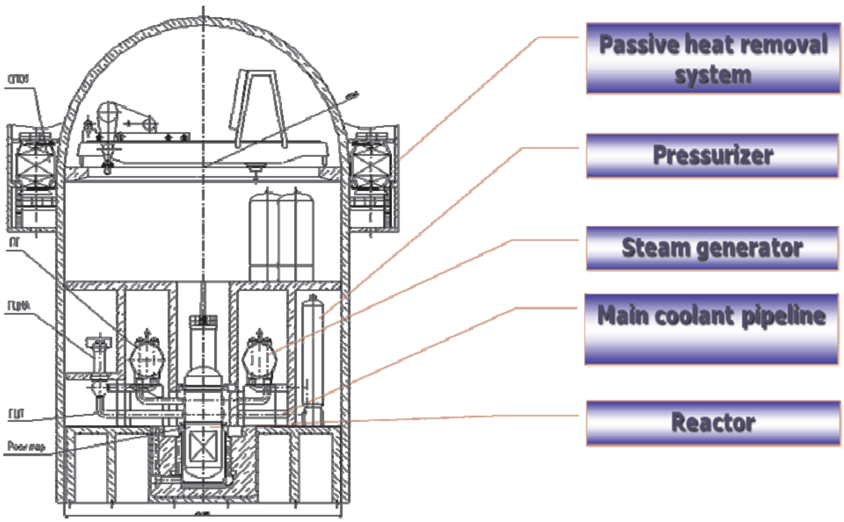
Reactor coolant pump set:
Design of CKBM based on GCNA-1455 (design of VVER-640 reactor plant)

Main coolant pipeline:
MCP with inside diameter of 620 mm (material 10ГН2МФА+ corrosion-resistant cladding or 08X18H10T)

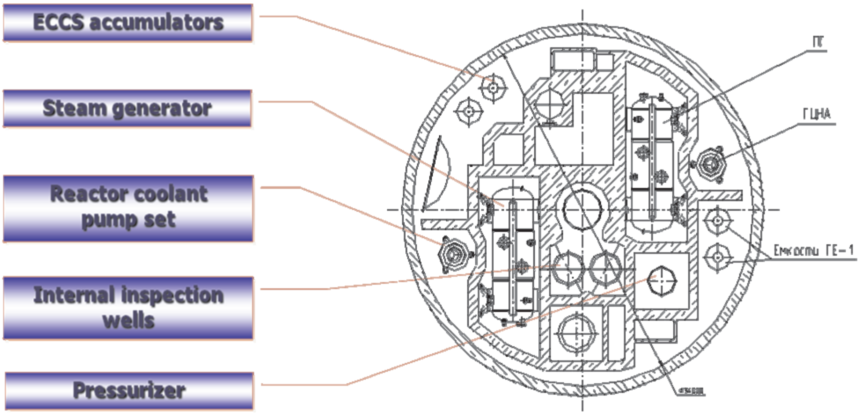
Pressurizer:
PRZ design is similar to the design of PRZ of VVER-1000 reactor plant. Total volume of PRZ is 30 m^3.

Relief tank:
Design of the relief tank is similar to the design of relief tank of VVER-440 reactor plant (model V-213).

RP layout



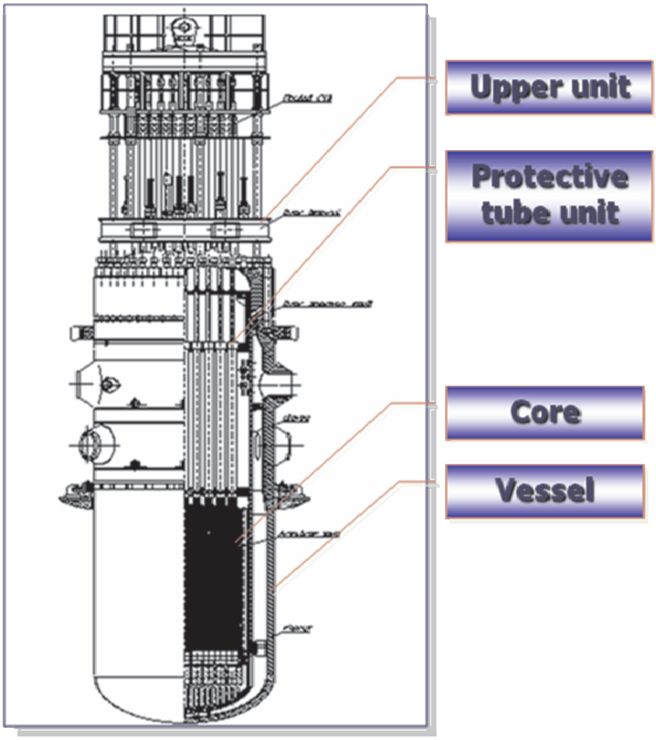
RP layout (plan)



Reactor
Technical characteristic

Parameter	Value
Time of FA residence in the core, year	4–6
Average fuel enrichment in the working assemblies, %	2.4–4.0
Average linear heat rate of fuel rod, W/cm	107.0
Maximum linear heat rate of fuel rod, W/cm	265
Average burnup fraction, MW · day/kgU	до 70
Time between refuellings, month	12, 18, 24

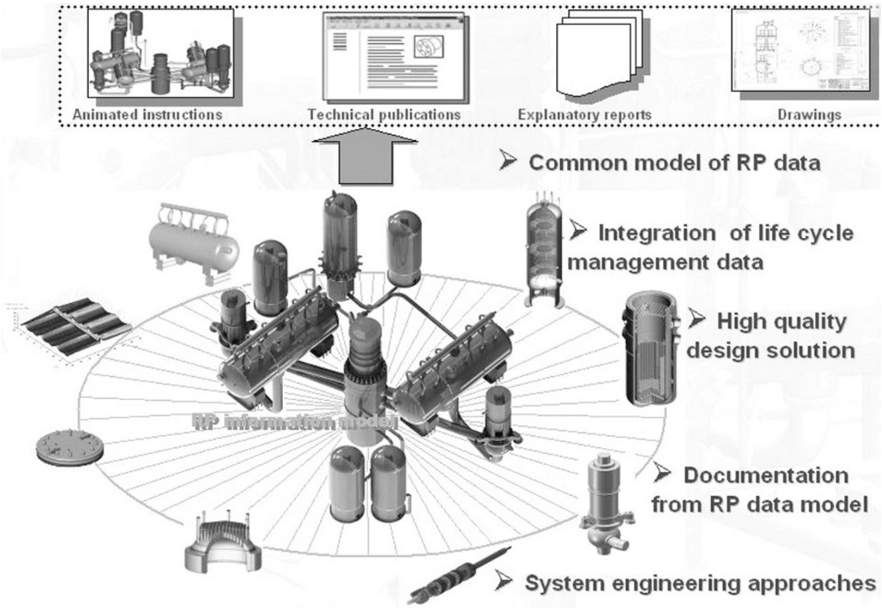
Reactor design solution



Readiness of VVER-300 design

1. The practice and experience in manufacturing the main equipment are available.
2. Layout and mode solutions are based on the experience in construction of Tianwan NPP, “Kudankulam” NPP, “Bushehr” NPP, in designing of AES-2006.
3. Cooperation of designers and manufacturers is established.
4. The certified computer codes are available for justification of design solutions.
5. Preparation of design documentation for the beginning of licensing procedure will take 1.5 years.

Datacentering technology for VVER-600, VVER-300 RP designs



Conclusion

Practical implementation of VVER-600 and VVER-300 RP designs seems to be feasible:

– Practice in manufacturing the main equipment is available.
– Cooperation of design, scientific organizations and manufacturers of equipment is established.
– Basic design solutions for equipment are of reference character.

NATIONAL ASSESSMENT STUDY IN ARMENIA USING INNOVATIVE NUCLEAR REACTORS AND FUEL CYCLES METHODOLOGY FOR AN INNOVATIVE NUCLEAR SYSTEMS IN A COUNTRY WITH SMALL GRID

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Abstract The International Project on Innovative Nuclear Reactors and Fuel Cycles (INPRO) was launched in November 2000 under the aegis of the IAEA. Phases 1A [1] and 1B (first Part) [2] of the Project were dedicated to elaboration, testing and validation of the INPRO Methodology. At the Technical Meeting in Vienna (13–15 October 2004) Armenia has proposed an assessment using the INPRO Methodology for an Innovative Nuclear Energy System in a country with a small electrical grid. Such kind of study helps Armenia in analysis of Innovative Nuclear Energy System (INS), including fuel cycle options, as well as shows applicability of INPRO methodology for small countries, like Armenia. This study was based on the results given in [3] and [4], and also on the main objectives, declared by the Government of Armenia in the paper "Energy Sector Development Strategies in the Context of Economic Development in Armenia" [5].

Introduction

The development of Armenia cannot be achieved without consumption of energy necessary to satisfy the needs of services and the production of goods, which is consumed in different ways: electricity, motor fuels, thermal energy, etc.

Energy systems have such a specific feature: the implementation cycle of the energy generating facilities is, as a rule, longer than that of energy consuming facilities. Consequently, the decision for installing new energy supply facilities or expanding the existing ones should precede the decision of implementing new consumers for several years. This imposes the need to estimate for several years ahead, what would be the consumption level not only in the near future, but in the far future too.

S.A. Apikyan and D.J. Diamond (eds.), *Nuclear Power and Energy Security*,

To satisfy the energy needs for the far future (up to 2050 and more) an Innovative Nuclear Energy System should be investigated. For this purpose the INPRO Methodology was used that must meet the requirements for sustainable development, including strengthening the non-proliferation regime, and solving the energy problems at a global, regional and national level in the twenty-first century.

An assessment is carried out for potential INS, which, in line with the principles of the INPRO methodology, meet the requirements for sustainable development, including strengthening the non-proliferation regime, and solving the energy problems at a global, regional and national level in the twenty-first century. The main goal of the Study was an assessment of the role of INS in providing sustainable energy supply in the twenty-first century and the identification of Research & Development (R&D) directions for further development of this technology.

It should be noted, that the main structure of the Armenian Economy sectors has been changed during the independency years – the Republic is shifting from the Industrial country to the Service providing country. As a result, electricity generation, reached 15 billion kilowatt hours in 1988, has been reduced 2.5 times and stabilized on the level around 5.8–6.0 billion kilowatt hours annually in 2000–2006. According to the Development Strategy of Armenia, all economically feasible domestic energy resources of the country must be utilized. However, there are no enough available indigenous resources to meet the country's demand. Therefore, in the future, Armenia will import (as well as now) the necessary quantity of energy sources envisaged for the Energy sector, and those are: natural gas and/or nuclear fuels only.

Regardless of political situation, social mentality, and attitude toward the nuclear energy, a thorough investigation is needed in the area of Energy sector development. It is very important to research the future of nuclear energy as a practically never-ending resource for generation of the high level form of energy – the electricity.

At the same time, the existing Armenian NPP will have around 2000 spent nuclear fuel assemblies on site after permanent shutdown of the plant in 2016. These fuel assemblies will need to be removed from the plant prior to de-commissioning of the reactor building. A number of alternatives can be identified and evaluated in this plan, including continued wet storage in the reactor building, interim dry storage at the Armenian NPP site or another site within Armenia, and removal of the spent fuel to another country for interim storage and/or disposition. Interim dry storage at the Armenian NPP site is the most feasible option.

Additionally should be mentioned, that Armenia has country specific requirements for INS considerations such as energy security and independence, survivability of the energy system, economical stability within the South Caucasus region, guarantee to get primary energy sources, environment protection, flexibility of NPP operational modes to satisfy different grid regimes, requirement, and rate of employment.

Based on the study of projected electricity demand, as well as taking into consideration some specific requirements of the country, the IRIS (International Reactor Innovative and Secure) reactor [6] has been selected as an Innovative Nuclear Energy System for National Assessment Study using the INPRO Methodology in a country with small electrical grid.

IRIS is a modular, integral-type pressurized light water cooled, medium power (1,000 MWth) reactor. The IRIS concept addresses the top requirements defined by the U.S. DOE for next generation reactors, i.e. enhanced reliability and safety, proliferation resistance, and improved economics. IRIS is an advanced design that does not require new technology development, since it relies on proven light water reactor technology. The IRIS design features an integral reactor vessel that contains all the reactor coolant system components, including the pressurizer, steam generators, and reactor coolant pumps. The IRIS reactor development has employed a “safety by design” approach that has eliminated or reduced the consequences of most accident sequences.

The IRIS design builds on the proven technology provided by 40 years of operating PWR experience, and on the established use of passive safety systems. Be-cause of the safety by design approach, the number and complexity of the safety systems and required operator actions are minimized in IRIS versus the passive loop PWRs. The net result is a design with significantly reduced complexity and improved operability, and extensive plant simplifications to enhance construction.

The integral configuration, extended fuel cycle and extended maintenance intervals allow IRIS to significantly reduce the workers exposure and therefore readily adhere to the as low as reasonably achievable (ALARA) requirement. IRIS is designed with environmental consideration as a priority.

Taking into account the available characteristics of IRIS design, as well as existing Armenian regulation in the field of nuclear energy, the assessment study in different INPRO areas using INPRO Methodology has been completed.

General considerations

According to the objectives and options of INPRO activities in Armenia, as well as the analysis of INPRO published and working documents, the following INS components were selected for subsequent examine in INPRO area: Fuel Transportation to NPP, INS Reactors, Spent Fuel Storage, Interim Spent Fuel Storage, Depository of High Level Waste.

The country specific requirements for INS considerations were formulated as follows:

– Energy security and independence
– Survivability of the Energy System
– Economical stability within the South Caucasus region
– Guarantee to get primary energy sources

– Environment protection
– Flexibility of NPP operational modes for different grid regime requirement
– Rate of employment

Energy security and independence

One of the main strategic issues of development of the Republic of Armenia generally formulated as the Energy security and independence. As it is internationally accepted, nuclear energy is considered the internal energy reserve even though the fuel and considerable expertise come from abroad.

Energy system reliability

The Energy System reliability should be measured by the ability to cover the threshold level of reserve capacity. There are two scenarios:

– Isolated operation of the Energy System, requiring a 30% reserve
– Parallel operation with neighboring energy systems, requiring a 10% reserves

The results of the analysis performed for the first scenario are shown in Figure 1.

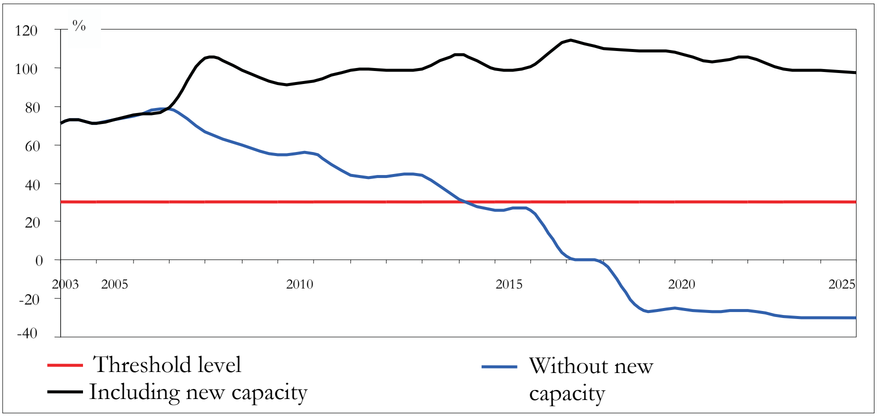

Figure 1. Level of reserve capacity available to cover domestic demand

Operation of existing generation will increase their depreciation. As a result, reliability will decrease. Thus, without new capacity the reserve level will gradually decrease, becoming less than the threshold level by 2014 and causing a deficit after 2017. With new capacity, the level of reserves will cover domestic demand. After 2007, it will reach approximately 100% and will not decline within the review period.

The analysis for the second scenario is provided in Figure 2 below.

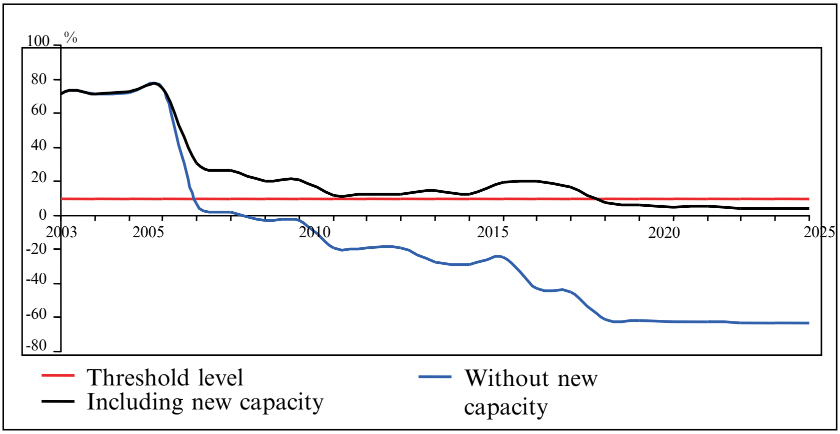

Figure 2. Level of reserve capacity available to cover the total demand

The level of reserves with development of new capacity will be below the threshold level in 2007 and after 2009 a reserve deficit will occur. With new capacity the level of reserves required for the domestic market will be completely assured through 2019; although the reserves will fall below the required level after that year, no threatening reserve deficit will occur for the remaining period.

Survivability of the energy system

One of the main characteristics of the energy system operation is the survivability. The survivability is understood as ability of an energy system to withstand the inadmissible modifications of operation parameters.

Using the algorithms presented in [7, 8], the survivability of Armenian power system was calculated for two scenarios:

1. The isolated mode of operations
2. The parallel mode of operations with Power systems of the neighboring countries

Researches show that the whole system survivability of Armenian national grid that includes Armenian NPP in the first scenario is varying around 0.948–0.952. The better result is in the second scenario, for which the whole system survivability is varying around 0.960–0.992 depending on neighboring country's power system connection.

Economical stability within the South Caucasus region

Strong competition to service regional energy markets will appear in the future. The country with the most rapid implementation of its development programs, especially in areas oriented to export and to creating high added value, will obtain the political and economic advantages. In other words, Armenian policy should be based on developing a political and economic atmosphere that will attract foreign investors. This becomes particularly important for the development of so capital-intensive an industry as the energy sector.

As to future regional cooperation, it is also possible that nuclear power will provide a competitive advantage to countries whose electric systems will not need to incur substantial additional costs to mitigate greenhouse gas emissions from thermal power plants.

Guarantee to get primary energy sources

Analysis and assessment of opportunities to diversify supplies, achieve regional integration, and increase electricity exports are a critical element of Armenia's Energy Sector Development Strategies. Iran, Turkey, and the South Caucasus countries have chosen self-sufficient Power Sector development [3]. This will inevitably bring undesirable changes in the energy balance. Moreover, the energy resources of the Caspian Sea basin will be exported through East–West fuel transportation routes, bypassing Armenia, which will decrease the potential of Armenia to export electricity.

Environment protection

Regional environmental issues regarding the future protection of Lake Sevan (one of highest and biggest fresh water lake) are important. If the Armenian NPP were replaced with thermal generation, serious environmental problems would arise. During the 1992–1994 energy crisis caused by blockade, the hydro potential of Sevan Lake was overexploited by drawing excessive water from the lake for hydro generation. Only re-commissioning of Unit 2 of Armenian NPP gave the possibility to reduce an outflow from the lake up to the level to just cover the irrigation needs of Armenia.

Flexibility of NPP operational mode for different grid regime requirement

Within the Survivability Study (mentioned above), a research of the flexibility of NPP operational modes for different grid regimes was done. Researches show, that for future development of nuclear energy in Armenia, it is highly appreciated the INS, which can operate in load follow mode.

Rate of employment

Countries, like Armenia, which lack energy resources, should plan their energy development based on energy independence and energy safety parameters and should use their own energy sources, including nuclear energy. Armenia has developed a nuclear energy infrastructure, such as nuclear energy institutes, calibration and construction companies and educational institutions, where future nuclear system specialists are educated and prepared.

Abandoning nuclear energy will create social problems. More than 2,200 high quality specialists would loose their jobs, whereas building a new nuclear unit will create more than 10,000 new positions in the construction field. It must be mentioned that the availability of scientific potential that can be directly engaged in the elaborations in the sphere of nuclear technologies is of particular importance.

So, existence of nuclear technologies in Armenia now and in the future has a big positive influence on employment rate in the Energy sector.

Summary

Based of the country specific requirements, mentioned above, the following conclusions can be done:

- Decommissioning of the Armenian NPP will decrease Armenian energy independence.
- Use of domestic renewable energy resources would mitigate the decreased level of independence from decommissioning the Armenian NPP. However, use of domestic renewable energy resources will not substantially change the long-term level of energy independence. Renewable energy reserves are limited and Armenian socio-economic development will increase energy demand.
- Although import of new generating capacity on schedule will ensure reserve capacity adequate to cover domestic demand, the critical situation associated with coverage of total demand, including exports, will not change.
- Decommissioning prior to attracting equivalent capacity will decrease energy system reliability due, in particular, to reduction of the reserve level.
- Premature decommissioning will also reduce the integration of the Armenian Energy System into regional markets and will necessitate attracting new thermal plants earlier than scheduled if obligations are to be met.

Finally, it should be noted, that Armenia today has an operational NPP. Moreover, in the former Soviet time the site for the new units #3 and #4, near to existing Armenian NPP, already was under development. Therefore existing Laws, Governmental Decisions and other legislative documents are already covering several INPRO Methodology requirements and do not specially studied.

Study results

Economics

The base year of the study was 2003, and the study period was selected between 2010–2100, with the intermediate reference years: 2015, 2020, 2025, 2030, 2040, 2050, 2060, 2070, 2080, and 2090.

It should be noted, that assumptions and data for the years after 2030 are very general and have been used just for analyses of some potential INS options in frame of the INPRO methodology, whereas the data for years before 2030 are based on the Reference Energy Development Scenario with Nuclear option [3].

This Scenario was extended up to 2100, and, for years up to 2025, a little corrected according to the analyses of main development prospects given in [4, 5] and [9]. Following Figure 3 is presenting the MAED study results for projected electricity demand by main sectors of economy.

The analyses of the MAED calculations show that the population growth rate in Armenia by the end of twenty-first century is assumed to be around zero (as in many European countries today), and the level of urbanization will reach 78%. The main indicator of level of economic development of a country – the GDP, is expected to reach the level around 65 billion US dollars in a year of 2100 with the aver-age growth rate per year – 3.28%. The total final energy demand by the end of the over-long planning period is expected to be 7.5 times higher than in the base year. One of the most important types of supplied energy in Armenia will be still electricity, the consumption of which will reach the level of 42 TWh in 2100.

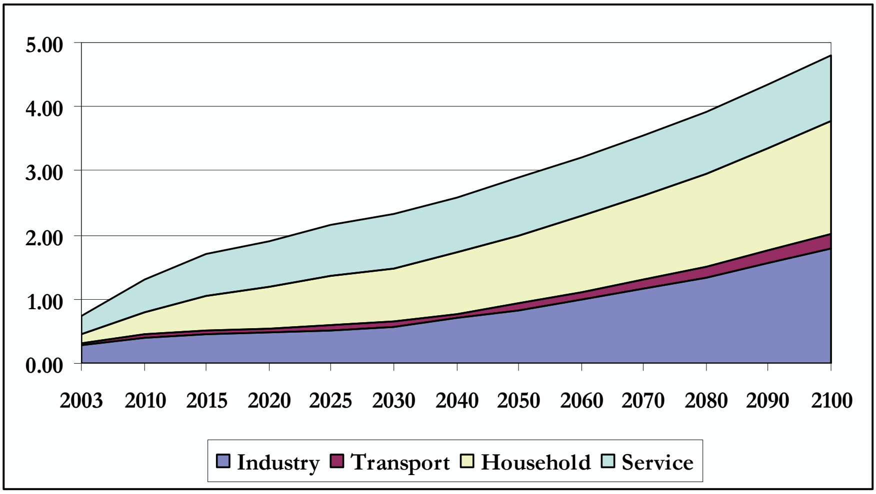

Figure 3. Electricity demand by main sectors of economy, GWa

Figure 3 shows that Armenia will need to increase its installed capacities to meet the electricity demand, which is assumed to be covered by utilizing domestic energy sources (hydro) or by installing new nuclear power unit(s).

The capital cost for utilization the domestic economically feasible hydro potential is around $1,185/kWe [5]. The capital cost of selected IRIS reactor (overnight cost, including interest/financing) is vary from $1,030 to 1,240/kWe. This means that Users Requirement (UR) 1 – Cost of Energy, of Economic Basic Principle (BP) is satisfied and implementation of INS is accepted.

Taking into account the given cost of electricity for IRIS and expected electricity generation cost from new hydro sources both $40/MWh, the calculation of internal Rate of Return (IRR) and Return on Investment (ROI) was done. The results are summarized in Table 1.

Table 1. Summary results of economic parameters calculation

Economic parameters	IRIS	New hydro
Internal Rate of Return (IRR), %	19	12
Return on Investment (ROI), year	5	8
Discount rate, %	10	10

Both parameters related to the Economic UR2 (Ability of finance) are acceptable.

Based on the analyses of the available description of IRIS, the following conclusions, associated to the Economic UR3 (Investment risk) can be made.

- The IRIS design based on proven technology with more that 40 years of operating PWR experience (acceptable for Indicator (IN) 3.1).
- Construction time and project status planned schedule (IRIS deployment is expected around 2015) are realistic and can be accepted in point of IN 3.2.
- The robustness index of IN 3.3 RI = 0.77 is less than one, requested by the acceptance limit 3.3.
- AL 3.4 of IN 3.4 more probably can be satisfied.

Finally, the IRIS design components are suitable for ensuring the Acceptance Limit (AL) 4.1 for IN 4.1 requirement, due to big consortium from different countries have been invited to IRIS project.

So the economic analyses done by using of INPRO Methodology illustrate the ability of IRIS design to meet the necessary requirements of the small country like Armenia.

Infrastructure

This section summarized the assessment study results in the Infrastructure area of INPRO Methodology. Given description is covering all the Infrastructure Basic principles, User requirements, Criteria and Acceptance limits.

Armenia joined to the following conventions and treaties: Non-proliferation Treaty (NPT), Convention on physical protection of nuclear material; Convention on early notification of a nuclear accident; Convention on assistance in case of a nuclear accident or radiological emergency; Vienna convention on civil liability for nuclear damage; Convention on nuclear safety; Improved procedures for designation of safeguards inspectors; Comprehensive nuclear-test-ban treaty, and also signed the following agreements: NPT Related Agreement, and Additional protocol.

According to the Armenian Constitution, if the norms and regulations of the Republic of Armenia are in contradiction with the norms and regulations accepted in the international treaties and/or agreements, the international norms and regulations have the preferable rights.

In the Republic of Armenia the next Laws and Governmental Decrees are adopted: “The Law of the Republic of Armenia for the Safe Utilization of Atomic

Energy for Peaceful Purposes”; The Governmental Decree on Licensing of a number of activities in the field of nuclear energy; Rules for safe transportation of nuclear materials: Rules and norms of radiation safety, population protection in case of nuclear and radiation accidents at the Armenian NPP, etc.

In 1993, the State Inspection for Nuclear and Radiation Regulation was established in Armenia.

The documents “New Nuclear Unit (s) Construction in Armenia Feasibility Study” and “Environmental Impact Assessment of New Nuclear Unit (s) at the ANPP” are currently under the development. After the completing of those documents, the credit lines availability problems can be focused on.

In 2006, the “Republic of Armenia Least Cost Generation Plan” was developed, in which the future energy demand was analyzed taking into account the internal and regional electric energy needs up to 2030.

It is possible to operate a nuclear power unit with the capacity up to 1,000 MW. The evaluation was done taking into consideration the internal and regional needs for the electrical energy, which is determined within the above mentioned document.

In the Republic of Armenia, there are several organizations (of engineering support to operational organizations and nuclear regulatory body, NPP maintenance and adjustment, civil and network dispatching) that provide services to the NPP.

The overall added value of nuclear installation will be considered within the “New Nuclear Unit (s) Construction in Armenia Feasibility Study” document.

According to the RA Law “On Environmental Impact Examination”, it is envisaged that the construction of nuclear power plants is subject to examination for which it is obligatory to conduct the public hearing/discussions.

Waste management

This section summarized the assessment study results in the Waste Management (WM) area of INPRO Methodology. Given descriptions are covering most of the Waste Management Basic principles, User requirements, Criteria and Acceptance limits.

An average discharge burnup of the IRIS design is up to 60 GWd/tU with current US limit on lead rod (62 GWd/tU) and up to 70 GWd/tU with increased limit on lead rod (75 GWd/tU). In mid-term deployment an average discharge burnup of the IRIS design is expected up to 120 GWd/tHM. The annual consumption of natural uranium is 169 tU_{nat}/GW_eyear, based on 60 GWd/tU discharge burnup.

Actually the requirements for minimization and long-term storage of RW should be foreseen in the general design of the NPP. The development of the requirements related to the RW treatment and long-term storage in Armenia will be done in National strategy for spent fuel and radioactive wastes which is in process of development.

Above-mentioned items are mostly acceptable by WM BP1 requirements.

Under the Government Decree, the radiation safety norms and radiation safety rules, as well as the chemical toxins norms in working area were adopted in Armenia and covering requirements of WM BP2.

The issues relating to the UR 3.1 of WM BP3, i.e. availability of technology, time for technology development, availability of resources and safety of the end state, as well as the Waste management cost estimate (UR 3.2 of WM BP3) will be considered in National Strategy for Spent Fuel and Radioactive Wastes, which is in process of development now. This National strategy will cover also topics related to the Waste Classification and Predisposal Waste Management, explained under WM BP4.

Proliferation resistance

INPRO has defined only one Basic Principle in the area of Proliferation Resistance (PR) formulated as follows.

“Proliferation resistance intrinsic features and extrinsic measures shall be implemented throughout the full life cycle for innovative nuclear energy systems to help ensure that INSs will continue to be an unattractive means to acquire fissile material for a nuclear weapons program. Both intrinsic features and extrinsic measures are essential, and neither shall be considered sufficient by itself.”

The requirements of this BP related to IRIS design are fully covered by the corresponding RA regulation, described below.

According to the “Law of the Republic of Armenia for the Safe Utilization of Atomic Energy for Peaceful Purposes” the spent nuclear fuel and Radiation Waste are ownership of the State.

According to the “Law of the Republic of Armenia on Control over the Export and Transit Transportations of Goods and Technologies of Dual Purposes through the territory of the Republic of Armenia”, the Intergovernmental Commission was established to issue licenses for export and transit transportations of goods and technologies of dual purposes through the territory of the Republic of Armenia.

The licenses are issued in accordance with the List which was re-approved under the Governmental Decree “On Approval of a List of Controlled Goods and Technologies of Dual Purposes exported from the Territory of the Re-public of Armenia, as well as being transferred through the territory of the Republic of Armenia in a transit way”.

Physical protections

In the area of Physical Protection (PP) INPRO defines one Basic Principle:

“A Physical Protection Regime shall be effectively and efficiently implemented for the full lifecycle of an INS.”

Armenia joined to the “Convention on Physical Protection of a Nuclear Material”, and physical protection of nuclear facilities and nuclear materials is being performed according to the requirements of this Convention.

There is also the Governmental Decree "On Strategy of Strengthening of the Armenian NPP and Nuclear Materials Physical Protection and Security".

According to the aforesaid documents, the activities mentioned in the INPRO area of Physical Protection are fully covered and implemented.

Environment

Study has been carried out taking into account the current country norms, adopted under the Government Decree "The Radiation Safety Norms" and "The Radiation Safety Rules". According to these documents, the occupational radiation exposure is defined as follows: "For A category personnel up to 20 mSv/year resulting dose averaged for sequential 5 years, but not more than 50 mSv for each individual year.

According to [6], occupational radiation exposure for IRIS design expected to be well below 0.5 man-Sv/year (50 man-rem/year), due to the integral configuration and infrequent reloading/outages.

The collective dose of radiation on Armenian NPP for 2005–2007 was 0.77–0.85 man-Sv/year, which is higher than that proposed in the project IRIS.

In this assessment study, Environmental BP 1 has been considered only as consolidated based on above mentioned occupational radiation exposure of operational and maintenance personnel.

Safety of nuclear installations and of nuclear fuel cycle facilities

The energy units put into the market are already satisfying the End Fuel Cycle safety criteria requirements of the given time period.

To compare safety issues for the existing nuclear units with Innovative Nuclear Systems, in our opinion, is not expedient. For example, is it acceptable to compare IRIS with AP-1000 and draw some conclusions about the advantages of IRIS?

IRIS is the reactor of the Generation III+. It is obvious, that characteristics of IRIS will be better than units of Generation III.

Therefore, for INS units safety requirements are acceptable unquestioningly, so the user has nothing to add. For example, in Table 5.7.-II "Implications Safety by Design Approach" of [6] given characteristics of IRIS Safety Concept can not undergo expertise by User.

Global consideration: judgment on potential of the INS

The available characteristics of IRIS design show applicability of such reactors for operation in a small country like Armenia based on the reasons mentioned below.

1. It has adequate economic indices the most important of which are listed below:

- Plant design life is at least 60 years without replacement of the reactor vessel.
- Capital costs are $1,030–1,240/kWe (overnight cost, including interest/ financing), however they must be brought into correspondence with today's cost level.

- Short lead time is 4 years from owner's commitment to commercial operation and construction schedule is 2 years.
- Refueling and maintenance outages will be significantly less frequent than the current outages.

2. IRIS has improved characteristics of safety some of which are brought below:

- Major safety systems are passive; they require no operator action or off-site assistance for 1 week after the accident, and additional core and containment cooling is provided for a protracted time without AC power.
- Predicted core damage and release frequency are less than 1×10^{-07}/year and 1×10^{-08}/year, respectively, and are significantly less than the Nuclear Regulatory Commission (NRC) 1×10^{-05}/year and 1×10^{-06}/year requirements.
- A significant number of accident initiators is either eliminated outright or their consequences/probabilities are reduced by design, i.e., without any need of active or passive systems (safety-by-design).
- Based on proven technology since the power generating system components are well based on current technology and will be extensively tested before NRC design certification.

3. Operational parameters are sufficiently enhanced i.e.:

- ±5%/min ramp load change within 15% and 100% power.
- ±10% step load change within 15% and 100% power.
- 100% generator load rejection
- 100–50–100% power level daily load follows over 90% of the fuel cycle life.
- Grid frequency changes equivalent to 10% peak-to-peak power changes at 2%/min rate.
- Loss of a single feedwater pump.

However, INS with good design indices, which even can be licensed, in the future can remain unclaimed by the Users. For the solution of this problem, INS prototype should be constructed by supplier and should stay in operation.

Conclusions and recommendations of the study

Conclusions and recommendations regarding the INPRO methodology

Conclusions

Obtained results show that numerous of the Users requirements and Criteria (in terms of INPRO Methodology) applied to the IRIS design are satisfied.

Assessment study demonstrates that the comprehensive INPRO methodology allows the user to lead estimation of selected INS taking into account the specificity at the concrete country level, as well as at the regional and global levels is developed.

Practically all the aspects necessary for carrying out the corresponding research of the country's nuclear development are generalized and reflected in the INPRO Methodology.

Use of the INPRO Methodology allows country Decision Maker to have a deeply enough both comprehensively studied and analyzed issues of future implementation of the Innovative nuclear energy system in the country.

At the same time it should be noted that number of the necessary data, requested by INPRO Methodology, needed for assessment of INS are inaccessible or are absent.

Some of User Requirements do not concern directly to INS such as UR1 and UR3, as well as partly UR2 and UR3 of Infrastructure. Such kind of information is missing in case if country has no nuclear option yet.

There are no User Requirements regarding to transportation issues. As the equipment of the nuclear power plant present separate units of great dimensions and mass, for example, body of the reactor, steam generator and etc., then for landlocked countries their delivery is a complex problem. For this reason, in INS developments it is necessary to take into account the equipment transportation problems.

Nuclear energy besides being a source of energy is also an item of strategic significance. For the RA it has as well a significance of energy independence and safety, as the nuclear energy is considered to be an internal resource. Therefore, in the problems of nuclear energy development planning, it is necessary to take into account not only the economic criteria, but the abovementioned as well, the transferring of which into economic indices is a rather complex problem.

Recommendations

1. The Guidance for the Application of an Assessment Methodology for INS is necessary to translate to the official languages of the IAEA.
2. Finalize development and introduction of the INPRO Information Portal, with inclusion of all corresponding information and links to other Web-sources.
3. Elaboration of INPRO Examination Computer Tool(s) with integrated database, allowing User to put the requested data and to take preliminary results of the INS acceptability analysis (for example, in format like Checklists in Guidance). It is advisable to elaborate some kind of universal index, which will show the level of readiness (ability) of country in implementing an INS.
4. Create a database of default (and/or recommended) values for all Acceptance limits and Indicators as much as possible. Such a database should be integrated in INPRO information portal and INPRO Examination Computer Tool(s).
5. Realize a cycle of trainings on each area of the INPRO Methodology.
6. Create a separate volume of INPRO Manual named “Glossary of the INPRO Methodology terms”.

Conclusions and recommendations regarding future R&D

INS should consider the transportation requirements (by Railways, Roads, Bridges, and Tunnels) in order to provide delivery to any site.

INS should take into account the specific seismic characteristics of the future INS implementation site.

For Armenia, very important issues are attached to the clarification of disposal of spent nuclear fuel storage options.

Supplier providing the INS must provide the User solutions to the problems of further maintenance and burying of spent nuclear fuel and radiation waste as well.

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List of Abbreviations

AL	Acceptance Limit (INPRO Methodology)
ALARA	As low as reasonably achievable
BP	Basic Principles (INPRO Methodology)
GDP	Gross Domestic Product
IAEA	International Atomic Energy Agency
IN	Indicator (INPRO Methodology)
INPRO	The International Project on Innovative Nuclear Reactors and Fuel Cycles

INS	Innovative Nuclear Power Systems
IRIS	International Reactor Innovative and Secure
IRR	Internal Rate of Return
MAED	Model for Analysis of Energy Demand
NPP	Nuclear Power Plant
NPT	Non-proliferation Treaty
NRC	Nuclear Regulatory Commission
PP	Physical Protection
PR	Proliferation Resistance
PWR	Pressurized Water Reactor
R&D	Research & Development
ROI	Return on Investment
UR	Users Requirements (INPRO Methodology)
WM	Waste Management

CANDLE REACTOR: AN OPTION FOR SIMPLE, SAFE, HIGH NUCLEAR PROLIFERATION RESISTANT, SMALL WASTE AND EFFICIENT FUEL USE REACTOR

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Abstract The innovative nuclear energy systems have been investigated intensively for long period in COE-INES program and CRINES activities in Tokyo Institute of Technology. Five requirements; sustainability, safety, waste, nuclear-proliferation, and economy; are considered as inevitable requirements for nuclear energy. Characteristics of small LBE cooled CANDLE fast reactor developed in this Institute are discussed for these requirements. It satisfies clearly four requirements; safety, nonproliferation & safeguard, less wastes and sustainability. For the remaining requirement, economy, a high potential to satisfy this requirement is also shown.

Introduction

In the year 2002 and 2003 in Japan, the Ministry of Education, Culture, Sports, Science and Technology (MEXT) started the "Priority Assistance for the Formation of Worldwide Renowned Centres of Research – The 21st Century Centre of Excellence (COE) Program." This program is based on the competitive principle that selection for support by the program relies on third party evaluation, and by giving priority support to the formation of world-class centres of research it aims to promote the creation of internationally competitive universities that answer to the world's highest standards. From ten fields of study covering medical science to social science 246 centres were selected from a total of 1,075 applications. Each proposal adopted as a COE receives support for 5 years to form a research base at the highest level in the world.

A program proposed by Tokyo Institute of Technology "Innovative Nuclear Energy Systems for Sustainable Development of the World (COE-INES)" was selected as the only one program in nuclear engineering field [1]. The objective is to establish a centre for creative research and education, social relations promotion, and international collaboration as shown in Figure 1. This program is planned to continue for 5 years as already mentioned, and the monetary supports are 196 million yens (2003–2004), 156 million yens (2004–2005), 159 million yens (2005–2006) and 159 million yens (2006–2007).

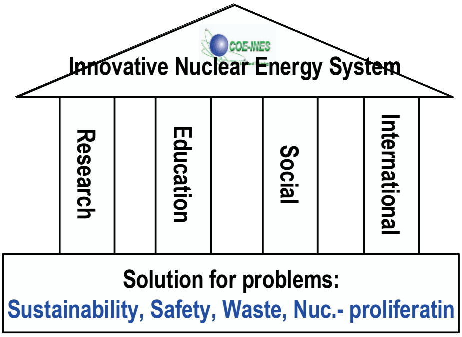

Figure 1. COE-INES

In this program innovative nuclear energy system is pursued, which solves the four problems inherent to the system; sustainability, safety, waste, nuclear-proliferation, as shown in Figure 1. During this program the Center for Research into Innovative Nuclear Energy Systems (CRINES) was established in order to succeed the COE-INES mission after finishing this program. In CRINES the number of requirements which nuclear energy should satisfy is expanded from four to five by adding economy as shown in Figure 2.

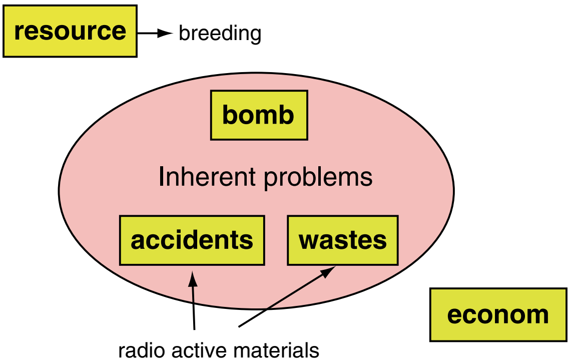

Figure 2. Requirements for nuclear energy

CANDLE burn-up

A new reactor burn-up strategy CANDLE (Constant Axial shape of Neutron flux, nuclide densities and power shape During Life of Energy producing reactor) was proposed [2, 3], where shapes of neutron flux, nuclide densities and power density distributions remain constant but move to an axial direction as shown in Figure 3. The refueling strategy is also shown in Figure 4. Here important points are that the solid fuel is fixed at each position and that any movable burn-up reactivity control mechanisms such as control rods are not required. Namely the above-mentioned motion of the distribution is autonomous.

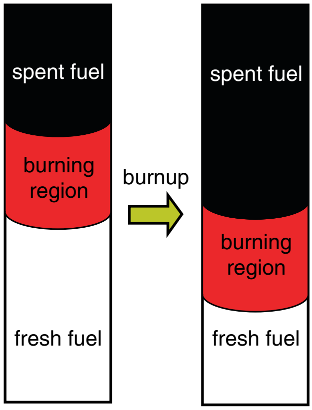

Figure 3. CANDLE burn-up strategy

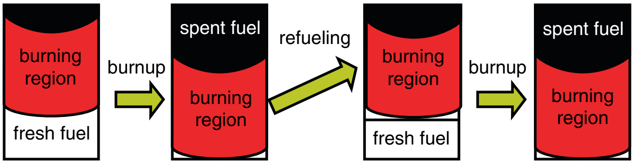

Figure 4. CANDLE burn-up and refueling scheme

CANDLE burn-up strategy can be realized, when the infinite-medium neutron multiplication factor, kinf, satisfies some characteristics. A typical change of kinf along core axis is shown in Figure 5. Here the left side corresponds to fresher fuel region, and the right side corresponds to burned-up fuel region. The kinf value for fresh fuel should be less than unity. After a certain amount of burn-up kinf takes more than unity to keep the reactor critical. Finally it becomes again less than unity caused by the accumulation of fission products (FPs) and consumption of fissile materials. In the area where the fresh fuel region changes to the burning region, kinf increases with time. On the other hand in the area where the burning region changes to the spent fuel region, it decreases with time. Therefore, as the burn-up succeeds, the burning region moves to the fresh fuel region. At the equilibrium state, the shape of power density does not change with time.

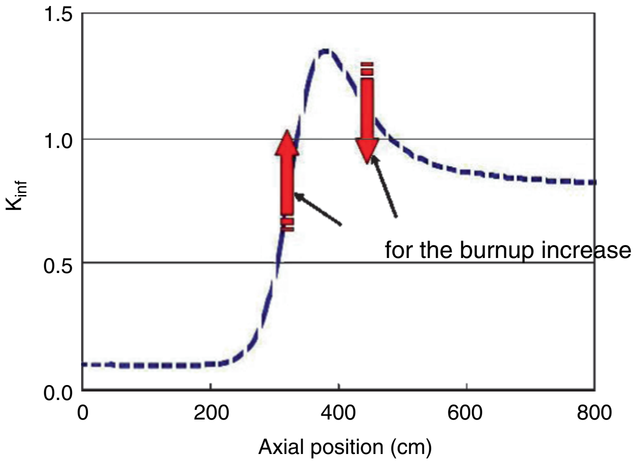

Figure 5. Change of k k_{inf} along core axis

The key in order to realize CANDLE burn-up is enough neutrons available in the core for maintaining core critical and producing fissile materials. CANDLE burn-up can be realized for hard-spectrum fast reactor. In the present paper LBE-cooled small CANDLE reactor is presented.

Calculation methods

Numerical analysis of CANDLE burn-up is more sophisticated than conventional methods. The steady state CANDLE burn-up is obtained by solving a Galilee transformed system of neutron diffusion and nuclide burn-up equations. The description about calculation method is omitted in the present paper, but written in the references [3, 4] for physics design. The computing program system is our original, but group constants preparations are performed by using SRAC code system [5] with JENDL-3.2 nuclear data library [6].

Small candle reactor design

CANDLE reactor requires a lot of neutrons, since they must keep criticality and enough fissile productions at the same time. Then a larger rector can be designed more easily than smaller reactor. However, in this paper we try to design small CANDLE reactor. The better neutron economy can be established in hard neutron spectrum. For the small reactor neutron confinement is very important. Therefore we employ lead-bismuth-eutectic (LBE) cooled fast reactor, since mass number of lead and bismuth are the largest among the all stable nuclides, and also their scattering cross sections for high energy neutrons are large. For fuel nitride fuel is employed, since it is widely used in Russian LBE cooled fast reactor designs. Table 1 shows the reactor design for the present study. The core size is almost smallest limit for performing CANDLE burn-up.

Table 1. Core design parameters

Total thermal power [MWth]	200
Core height [cm]	200
Core radius [cm]	100
Reflector Thickness [cm]	50
Coolant Channel diameter [cm]	0.453
Cladding Thickness [cm]	0.035
Fuel pin thickness [cm]	1.132
Fuel material [-]	Nitride (N-15) enriched natural uranium
Cladding material[-]	HT-9
Coolant material [-]	Pb-Bi(44.5%-55.5%)
Core inlet coolant temperature [K]	600
Core outlet coolant temperature[K]	800

Table 2 shows the calculation results. The present small reactor shows a similar value of discharged fuel burn-up to large reactors. However, the burning region velocity is much smaller than the previous results since the power density is smaller. By this small burning region velocity, long core life is easy to be obtained.

Table 2. Calculation results

k_{eff}		1.0001
Burning region velocity [cm/year]		0.7
Core averaged discharged fuel burn-up	[%]	40.2
	[GWd/tU]	374.2
Peak fuel temperature [K]		824
Peak cladding temperature [K]		801

Five requirements & CANDLE reactors

CANDLE burn-up strategy has several outstanding merits for safety, sustainability, waste and nuclear-proliferation. In this chapter we try to discuss the characteristics of CANDLE reactor along five requirements for nuclear energy mentioned in Chapter I.

(A) Simplicity and safety

Burn-up reactivity control mechanism is not required for CANDLE burn-up. The reactor control becomes simpler and easier. The excess burn-up reactivity becomes zero, and the reactor becomes free from reactivity-induced accidents at operating condition.

Nuclide density distribution for each nuclide does not change with burn-up in the burning region. Therefore the reactor characteristics such as power peaking and power coefficient of reactivity do not change with burn-up. The estimation of core condition becomes very reliable. The reactor operation strategy remains unchanged for different burn-up stage. The inaccuracy of present burn-up calculation is much less important for this reactor compared with for conventional reactors.

Orifice control along burn-up is not required: Since the radial power profile does not change with burn-up, the required flow rate for each coolant channel does not change. Therefore, the orifice control along burn-up is not required. The operational mistakes are avoided.

Fresh fuels after the second cycle are depleted uranium or natural uranium. The risk for criticality accident is small. The transportation and storage of fresh fuels become easy for criticality and physical protection problems. They become simple and safe.

(B) Nonproliferation and safeguard

The most severe parts of fuel cycle system concerning from nonproliferation issue are considered enrichment and reprocessing plants, since both plants produce materials for nuclear bomb.

Enriched fuels are not required after the second cycle of CANDLE reactor. Only natural or depleted uranium is enough to be charged to the core after the second cycle. Namely, if the fuel for the first cycle is available, neither enrichment nor reprocessing plant is required. It is an excellent feature from the safeguard and nuclear nonproliferation.

(C) Less wastes

The present light water reactor (LWR) performs the burn-up of about 4% of the inserted fuel of 4% enriched uranium. On the other hand the burn-up of the spent fuel for CANDLE reactor is about 40%. It is ten times as high as for LWR.

Separation of spent fuel and vitrification may reduce the amount of high level wastes, but total amount of radioactive wastes increases. The once-through fuel cycle of CANDLE reactor system can reduce radioactive wastes. The burn-up of spent fuel becomes ten times. Therefore, the spent fuel amount per produced energy is also reduced to be one tenth.

Even once-through fuel cycle does not waste uranium resources as mentioned in the next section.

The amount of actinides is decreased since they are stored in the core much longer than conventional reactors and fissioned in this period.

(D) Sustainability

The burn-up of the spent fuel is about 40% (400 MWd/tHM): This value is competitive to the value of the presently expected fast reactor system with reprocessing plant. The 40% of natural uranium burns up without enrichment or reprocessing.

The present once-through fuel cycle of 4% enriched uranium in light water reactor (LWR) performs the burn-up of about 4% of the inserted fuel, and it corresponds to the utilization of about 0.7% of natural uranium depending on the enrichment of depleted uranium. For this case about 87% of the original natural uranium is left as depleted uranium. If this depleted uranium is utilized as the fuel for CANDLE reactor, 35% (= 0.87 × 0.4) of the original natural uranium is utilized. Therefore, if the LWR has already produced energy of X Joules, the CANDLE reactor can produce about 50X Joules from the depleted uranium stored at the enrichment facility for the LWR fuel.

If LWRs have already produced energy sufficient for full 40 years and the nuclear energy production rate will not change in the future, we can produce the energy for 2,000 years by using the CANDLE reactors as shown in Figure 5. We need not mine any uranium ore, and do not need reprocessing facility.

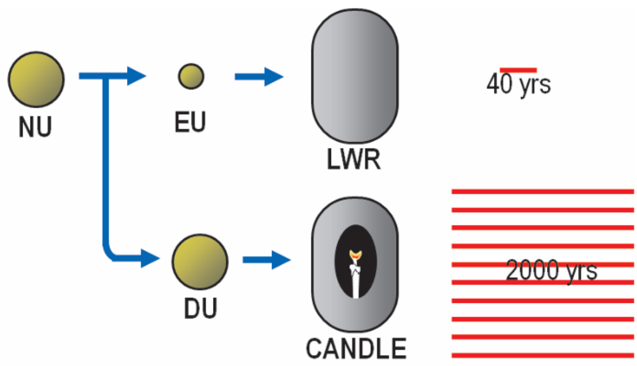

Figure 5. CANDLE reactor operation after LWR operation

(E) Economy

Since the CANDLE reactor is simple, its operation and maintenance cost becomes low. Fuel cycle is also very simple and fuel cycle cost becomes low.

Economical demerits may come from expected lower power density. The higher fuel volume ratio results in the lower power density. However, radial power density distribution can be made very flat. A result for increasing power density is shown in Figure 6.

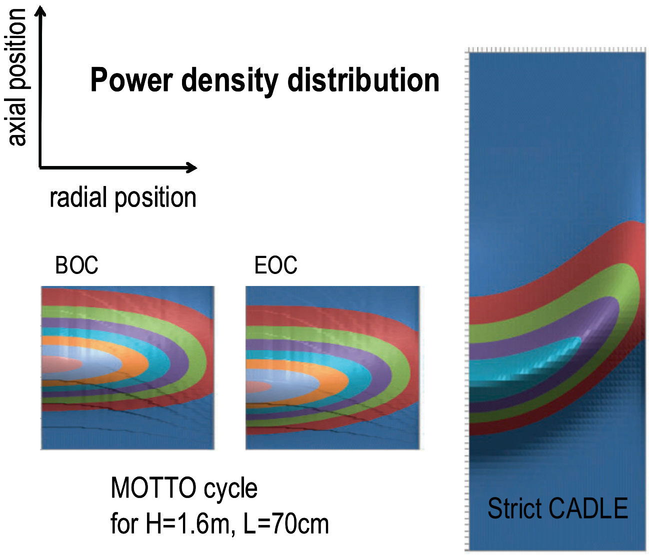

Figure 6. A result for increasing power density

Further detailed economy analysis is required.

Conclusion

Characteristics of small LBE cooled CANDLE fast reactor are discussed for five requirements proposed in CRINES as inevitable requirements for nuclear energy. It satisfies four requirements; safety, nonproliferation & safeguard, less wastes and sustainability. For the remaining requirement, economy, a high potential to satisfy this requirement is also shown.

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EMISSIONS OF THE CORROSION RADIONUCLIDES IN AN ATMOSPHERE

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Introduction

In area of Armenian nuclear power plant location, in atmospheric air in majority of cases log two technogenic radionuclides: ^{137}Cs and ^{90}Sr. Presence of these radionuclides basically is caused by global fall out (consequences of tests of the nuclear weapon and Chernobyl NPP accident), whose contribution to the contents of these radionuclides in atmosphere is incomparably greater, than emissions from the NPP. However there are some cases when in an atmosphere are registered the technogenic radionuclides, caused by emissions from NPP. In the present work such case is considered.

Gas-aerosol releases of NPP in the atmosphere are carefully purified by means of various high-efficiency filters and gas-cleaning systems.

Nevertheless, one should forecast and measure, the possible impact of these releases on the environment in the regions surrounding the NPP.

Radioactive releases of the Armenian NPP (ANPP) contain the set of radionuclides characteristic for NPPs of this type. They may be divided into three groups:

- ^{131}I, ^{137}Cs, ^{134}Cs, ^{90}Sr, and ^{89}Sr fission fragments, isotopes of noble gases krypton and xenon and other radionuclides
- Corrosion originated radionuclides: ^{60}Co, ^{110m}Ag, ^{54}Mn, ^{51}Cr and others
- Activation products of the heat-transfer agent itself

It should be noted that the amount of radioactive materials released in the environment by the ANPP during the whole period of its operation was much lower than the admissible quantities specified in the corresponding legal documents (RSN, NPPSP) acting in Armenia, which are practically identical to the internationally accepted norms. The amounts of releases and their radionuclides composition for the ANPP are given in the Table 1.

S.A. Apikyan and D.J. Diamond (eds.), *Nuclear Power and Energy Security*,

Table 1. Nuclear composition (main radionuclides) and amount of releases during the operation period of the Armenian NPP (in 10^7 Bq/year)

Operation year	Basic nuclides								
	LLN[a]	^{131}I	^{137}Cs	^{134}Cs	^{60}Co	^{110m}Ag	^{90}Sr	^{54}Mn	^{51}Cr
1978	16.9	76	0.10	–	7.80	6.40	0.03	5.60	20.0
1979	633	79	17.2	5.10	31.0	–	1.40	19.1	313
1980	428	77	48.6	46.7	18.1	–	0.30	13.6	70.0
1981	214	35	22.4	15.5	26.9	–	0.60	10.7	11.6
1982	341	80	9.5	10.0	62.8	48.5	0.37	22.3	11.5
1983	884	70	5.0	1.70	20.6	4.80	0.06	5.80	0.70
1984	1785	28	66.3	51.0	28.2	37.0	0.04	4.90	4.60
1985	754	51	60.6	33.1	17.2	71.6	0.11	4.0	16.2
1986	794	44	25.0	12.8	21.7	73.4	0.25	8.40	–
1987	259	53	13.4	5.60	34.7	122.0	0.08	7.20	17.2
1988	338	98	14.9	24.0	128	142.0	0.06	26.8	10.2
1989	181	52	10.1	–	29.4	56.60	–	–	–
1990	113	–	8.8	–	12.3	16.10	0.09	–	–
1991	46.0	–	6.2	4.0	8.9	11.80	0	1.30	–
1994	82.0	–	–	–	60.1	–	–	–	–
1995	193.0	9.70	23.3	–	83.7	–	0.15	–	–
1996	121.0	23.5	15.4	0.80	22.4	25.80	0.12	0.80	11.6
1997	278.0	36.7	11.6	1.27	9. .0	7.24	0.36	0.33	–
1998	238.4	28.8	9.35	1.32	18.4	7.72	0.29	1.89	21.6
1999	44.43	25.8	10.2	0.89	11.94	10.8	0.44	1.22	–
2000	30.7	26.0	4.20	5.97	17.7	22.60	0.38	8.78	–
2001	31.1	18.8	16.5	5.36	23.5	18.70	0.49	3.42	2.24
2002	9.9	59.6	7.90	2.28	6.6	2.50	0.2	0.16	–
2003	29.3	38.1	26.7	5.0	22.1	25.0	0.23	3.23	–
2004	28.5	27.1	5.59	0.38	14.6	11.3	0.04	1.35	2.53
2005	20.9	3.04[b]	7.0	0.83	5.10	1.35	0.03	–	–
2006	18.3	3.65	5.12	0.54	9.45	1.77	0.03	–	–
2007	46.0	1.90	4.88	1.60	7.15	1.17	0.05	0.10	–
2008	7.0	0.47	3.82	1.20	23.7	8.0	0.04	1.45	–
Percentage without taking into account ^{131}I и LLN			**20.59**	1.4	**35.08**	**32.89**	0.28	**6.83**	2.9

[a]Long lifetime nuclides (>24 h).

[b]Since 2005, on ANPP was entered the new, more sensitive equipment of the 131I emissions measurement and a technique of calculation.

As one can see from this table, the amount of releases may significantly vary from year to year. It depends mostly on the character of maintenance works carried out at NPP and the state of releases cleaning systems.

The radioactive noble gases, except ^{85}Kr, have a short half-life period (T1/2) – from several minutes to several days. Thus they are not accumulated in the environment objects. On the other hand, half-life of ^{90}Sr (®1/2 = 29.1 years) and ^{137}Cs (®1/2 = 29.9 years) is long enough. It should be also noted that the quantity of ^{90}Sr in the releases is much less than ^{137}Cs, ^{60}Co, ^{110m}Ag, ^{54}Mn. Thus in a NPP normal operation mode only this radionuclides may represent an insignificant potential danger for population and environment.

The big range of emissions is caused by many factors: condition of filtering device, technological process and other. The repair works are one of the reasons which cause the increasing the emissions in an atmosphere.

The source of ^{60}Co is activated cobalt penetrating the heat-transfer agent from the abrasion-resistant alloys doped by this element, and from stainless austenitic steels. The sources of manganese are the same structural materials. The isotope ^{110m}Ag is generated by silver entering the alloys of electrical heaters of volume compensator and control mechanisms. The major part of corrosion radioactive products is present in the sediments on internal walls of the first-circuit equipment. The transfer processes in the reactor cause re-distribution of these products between the wall sediments and heat-transfer agent, as a result of the agent velocity, temperature and water chemical regime variations. It has been established, for example, that power reduction at Kolskaya NPP is accompanied by activity increase of ^{60}Co by 50-fold, ^{110m}Ag by 80, and ^{54}Mn by 110 times [1]. According to the reference [2], 25% corrosion products exist in the heat-transfer agent in high-dispersion phase, round 75% in colloidal and less than 1% in ion fractions. Concentration of these nuclides becomes maximal in the agent nearly 50 h after drop of power. Therefore the specific activity is reduced, with sedimentation coefficient being smaller than in the stationary regime. Therefore one should expect a significant growth of corrosion products output during start-up, shut-down and maintenance period.

Let us evaluate the contribution of these radionuclides in contamination of environment in the NPP location area. Emission of these nuclides is in homogeneous in time. Their content is usually increased in the maintenance period at a NPP, when the first-circuit equipment is opened and repaired. As an example consider the emission of ^{60}Co, ^{110m}Ag and ^{54}Mn radionuclides in process of several months (including the regular maintenance works period, April–July 2008) described in the Table 2. These radionuclides were detected in the atmosphere during that very period.

Table 2. Total activity of aerosols emission during 9 months of 2008

Month	Activity of aerosol emissions, in 10^7 Bq/month		
	^{60}Co	^{110m}Ag	^{54}Mn
January	1.65	1.30	0.69
February	2.43	3.20	1.30
March	2.60	1.42	0.84
April	20.80	6.75	7.22
May	7.45	7.22	2.37
June	5.21	7.58	13.02
July	4.00	1.85	1.78
August	4.02	2.96	0.91
September	1.66	1.54	0.71

Radionuclides' emission amount depends on the character of repair works with equipment of the first contour. The total activity of emissions in course of some repair works is given for illustration in Figure 1.

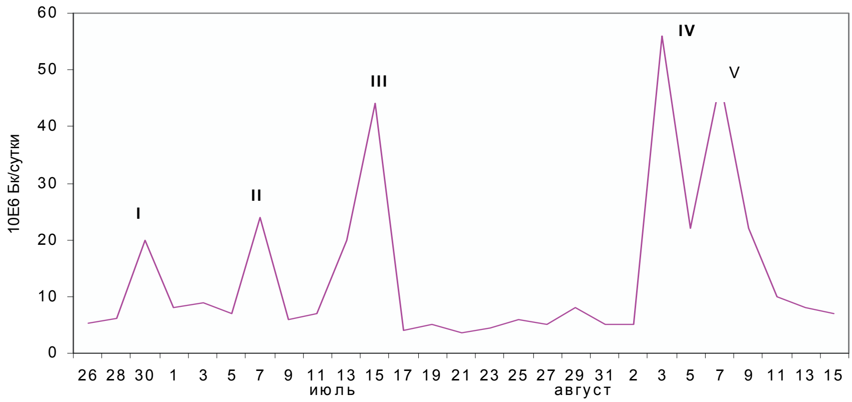

Figure 1. Emission amounts in process of certain repair works: I – cooling of power unit; II – seal failure of the major connector and opening the volume compensator; III – fuel assembly reloading; IV – hydraulic tests, V – transition to nominal power

However, the measurements have shown that presence of these radionuclides in the environment, particularly in the atmosphere and fallouts, is minimal. Only a few cases occurred during the whole operation period when these radionuclides were detected in the air and fallouts by aspirators and cells positioned at a distance of 1 km from the NPP.

Concentrations of ^{60}Co, ^{110m}Ag and ^{54}Mn radionuclides in the air samples obtained by aspirator at a distance 0.5 km away from the nuclear plant during the same period are given in the Table 3. In the next aspiration unit closest to the NPP (2.5 km away) only traces of these radionuclides were detected, while other units have shown their absence.

Table 3. Concentration of corrosion radionuclides in the air at a distance 0.5 km from NPP

Period	Concentration of radionuclides, in 10^{-8} Bq/l		
	^{60}Co	^{110m}Ag	^{54}Mn
Quarter 1	<0.4	<0.4	<0.4
Quarter 2	2.40	4.80	1.60
July	1.70	3.00	1.10
August	0.95	0.80	<0.4
September	<0.4	<0.4	<0.4

For comparison, the average over the whole observation period concentration of ^{137}Cs in air was 4.8×10^{-8} Bq/l. Having data on emission of radionuclides and calculated value of dilution coefficient one can calculate the concentrations of radionuclides in the air. The dilution coefficient was calculated, with account of weather conditions in the NPP location area, by means of expression

$$K_p = \frac{H^2 \sqrt[3]{V \Delta T}}{AFnmaP / P_0}, \quad (1)$$

where:

K_p – meteorological dilution coefficient of an impurity in the air, in m^3/s
H – geometrical height of ventilation pipe
V – the average volume of gas mixture leaving the pipe, outlet in one second
ΔT – the temperature difference of released gas and surrounding air, in °C
A – class of atmospheric stability
F – coefficient depending on impurity fallout rate
n, m – coefficients depending the releases rate out of the ventilation pipe
a – time-averaging coefficient
P / P_0 – wind rose elongation factor

The dilution coefficient calculated by means of relation (1) has the value 1.4×10^6 m^3/s. For comparison, the same parameter for the central part of European territory in Russia is equal to 3.4×10^6 m^3/s.

The calculated data for July sufficiently well match the measurements, as shown in the Table 4.

Table 4. Calculated and measured values of ^{60}Co, ^{110m}Ag, ^{54}Mn concentrations in the atmosphere during Quarter 2

Obtained results	Concentrations of radionuclides, in 10^{-8}Rq/l		
	^{60}Co	^{110m}Ag	^{54}Mn
Calculations	1.8	3.6	0.9
Measurements	2.4	4.8	1.0

One may conclude that corrosion-created radionuclides only episodically are detected in the atmosphere, and at distances less than 3 km, while their concentrations are low. Also their half-life periods are small as compared to ^{137}Cs: 255 days for ^{110m}Ag; 312 days for ^{54}Mn; and 5.26 years for ^{60}Co. Thus the hypothesis on that ^{137}Cs is the main hazardous radionuclide present in the NPP releases is justified.

Conclusions

- In area of the Armenian NPP location the radionuclides of corrosive origin registered incidentally (during period of the repair works, if their emissions is enough big) and only in the nearest point of monitoring.

- The value of the factor of meteorological dilution calculated by us, will allow updating the special computer code for calculation of a dose of an irradiation of the population.

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IAEA SUPPORT FOR OPERATING NUCLEAR REACTORS

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Introduction

The IAEA programme, under the pillar of science and technology, provides support to the existing fleet of nuclear power plants (NPPs) for excellence in operation, support to new countries for infrastructure development, stimulating technology innovation for sustainable development and building national capability. Practical activities include methodology development, information sharing and providing guidance documents and state-of-the-art reports, networking of research activities, and review services using guidance documents as a basis of evaluation. This paper elaborates more on the IAEA's activities in support of the existing fleet of nuclear power plants.

Challenges and opportunities for existing nuclear power plants and the IAEA's role

Generic challenges for expansion and introduction of nuclear power are described in the IAEA's Status and Prospects Report [1]. Those for the existing fleet would be listed as follows, but not limited to:

1. Continued vigilance in safety and safeguards
2. Aging workforce and facilities
    - Plant Life Management (PLiM) including refurbishment to cope with obsolescence issues such as in Instrumentation & Control (I&C)
    - Power uprating
    - Nuclear knowledge management and preservation
3. Further excellence in operation for more carbon-free electricity
    - Capacity factors improved significantly in 1990–2005, now decreased
    - Soft issues (Management systems, communication, learning from others)
4. Uncertainties in spent fuel management
5. Preparation for waste disposal
6. Preparation for decommissioning and generation capacity retention
7. Technology updating

- Utilizing benefits from digital I&C for reliability, modern diagnosis, informed operation
- Lack of financial resources for updating in some countries

8. Stable supply of fuel/Uranium at a reasonable price

- Addressing the gap between supply and demand (U)
- Assurance of supply

9. Security issues

By raising the capacity factor for discussion, the recent trend has been:

(a) Improvement of the capacity factor largely goes hand-in-hand with that of safety performance, as is represented by WANO indicators [2], for instance.
(b) The world has seen a significant increase of nuclear electricity (40%) between 1990 and 2005, half of which came from improved capacity factor, as compared with added nuclear electricity from limited numbers of additional capacity (36%) and from uprating (7%) (Figures 1 and 2).
(c) Nevertheless, there has been a decline of capacity factor in the last several years. PRIS (Power Reactor Operating Information System), operated by the IAEA, enables a more in-depth analysis of data by region (Figure 3).

The reasons for decline are different from region to region, for example, forced shutdown due to earthquake, prolonged shutdown for inspection and repair of components after the falsification of inspection data became a social issue, lack of enough fuel supply, and prolonged shutdown due to refurbishment.

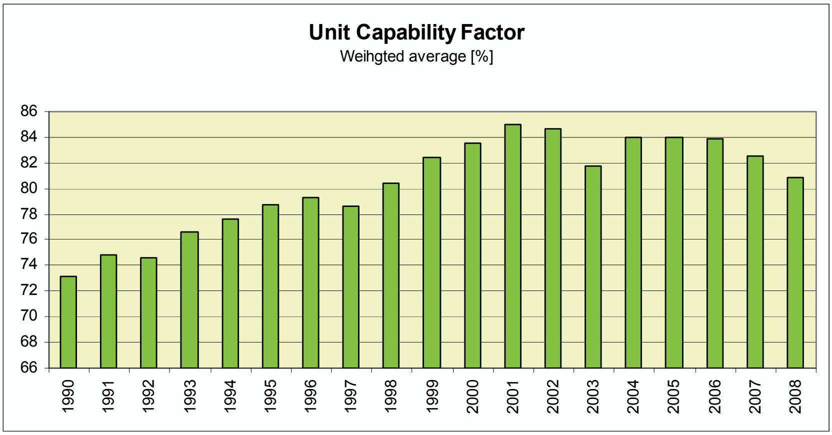

Figure 1. Global capacity factor trend

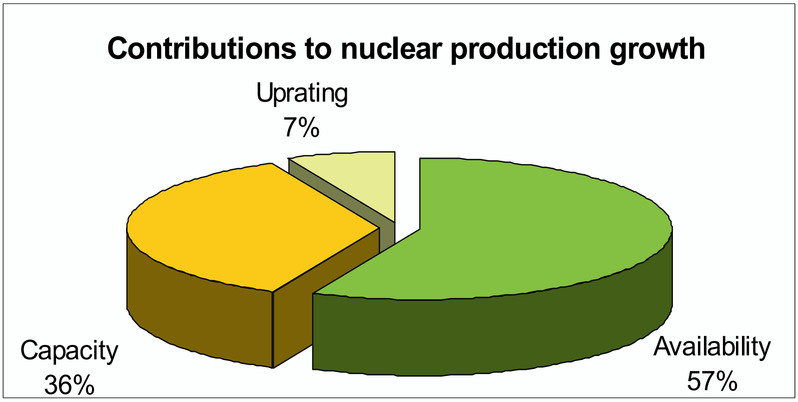

Figure 2. Increase of nuclear electricity between 1990 and 2005 and its reasons

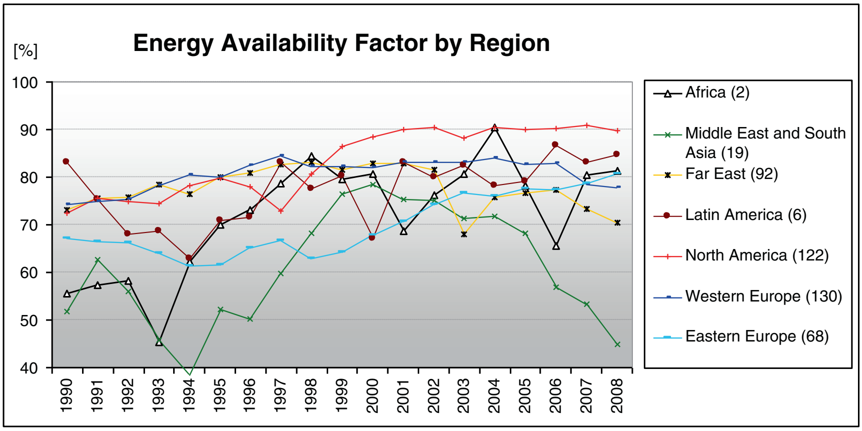

Figure 3. Regional trend of availability factor

Within the environment of capacity factor increases, there will be issues such as:

(a) Sharing of information including operational experiences and lessons learned among operators and regulators through WANO and other activities (hopefully with the IAEA as well), so that best practices may prevail
(b) Consolidation to those who perform best. and
(c) Risk-informed regulation

Given this situation, the IAEA has the important role to disseminate information so that best practices may prevail while securing that the exiting fleet is used safely, securely, and with minimal proliferation risk. The IAEA's activities in this area include methodology development, information sharing and providing guidance documents and state-of-the-art reports, networking of research activities, and review services using such guidance documents as a basis of evaluation. Practically, assistance is given in the form of review missions, workshops, seminars and scientific visits.

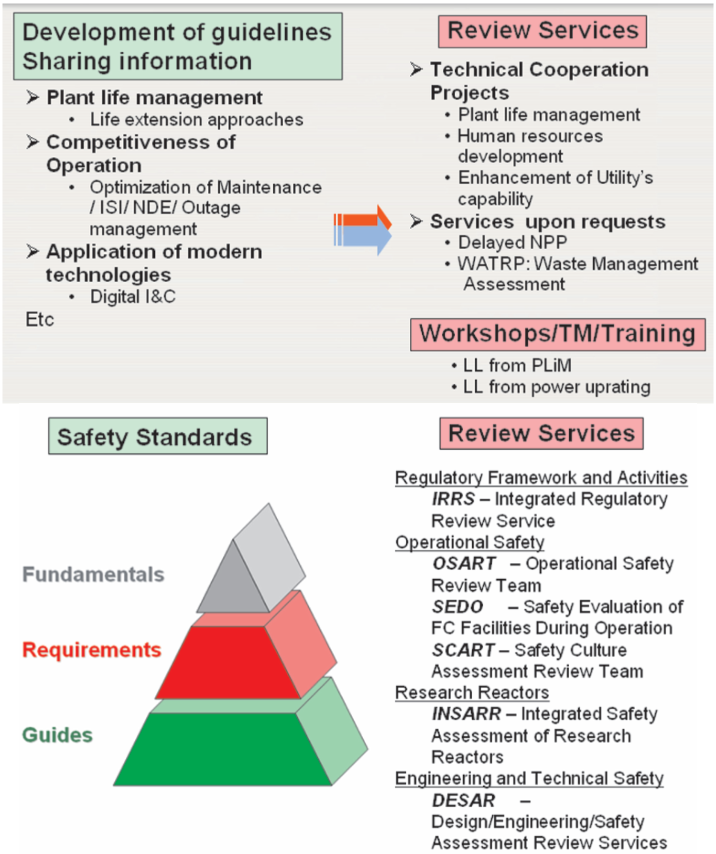

Figure 4. IAEA guidelines/standards and review services

Publication of guide/standards and services

Figure 4 illustrates the type of guidelines provided and their link with review services, workshops, and training seminars in the area of support of existing nuclear reactors. Such relationships between guidelines and standards and review services are not unique to the Science and technology pillar but apply to safety areas as well (Figure 4).

Nuclear Energy Series publications

In regard to this issue, it is worth mentioning the Nuclear Energy Series (NES) publications.

In the Department of Nuclear Energy to which the author belongs, the guidance documents, technical reports on specific subjects, results of Coordinated Research Projects, state-of-the art reports, and other documents are mostly categorized under the IAEA TECDOC Series or Technical Report Series (TRS).

In order to add structure to these documents, enable organized activities to address the gaps in available documents, and, above all, to provide user-friendly information to customers, in 2006, the Department created the Nuclear Energy Series. This Series has a hierarchy and thematic areas as illustrated in Figures 5 and 6. All documents, including already-published TECDOCs, are available through clickable map on the IAEA web site; http://www.iaea.org/OurWork/ST/NE/NESeries/ClickableMap

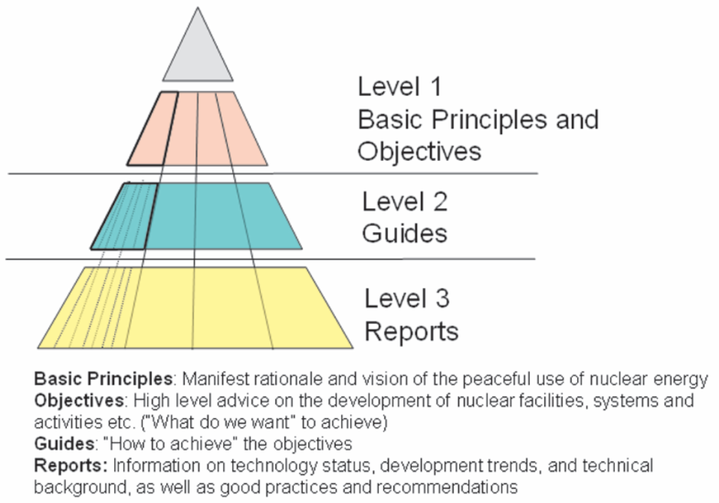

Figure 5. Hierarchy of NES series publications

IAEA database

Various IAEA databases such as PRIS (Power Reactor Information System), CNNP (Country Nuclear Power Profile), ENTRAC (Electronic Nuclear Training Catalogue), IRS (Incident Reporting System) and others will also serve as useful sources for information for nuclear power plant operators and regulators.

Sharing of experiences through workshops on specific topics have been organized as follows:

- BWR core internals cracking: Reactor core internals (June 2003)
- Material degradation and related managerial issues (Feb 2005)
- Tsunami (Aug 2005)
- Electric system (Sept 2007 by SKI in cooperation with the IAEA)
- Reactivity Control (Oct 2007)

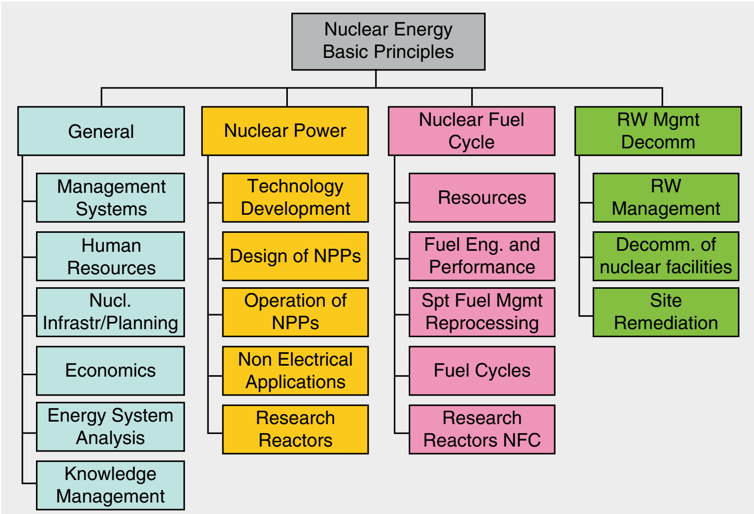

Figure 6. Thematic areas in the nuclear energy series

Technology transfer through Technical Cooperation Projects

Technical Cooperation Projects, funded by approximately 80 million dollars/year, enable support to developing countries in meeting their needs on a variety of topics such as support for infrastructure building in newcomer countries, plant life management (PLiM), and human resources development.

Networking

Coordinated Research Projects (CRPs) are R&D networking opportunities which include developing countries. More information is available from the IAEA web site [3].

Recently, there has been an increased number of networking opportunities coordinated by the IAEA, for instance, in the area of waste:

- International Network of Underground Research Facilities for Geological Disposal (Established in 2001)
- International Decommissioning Network “IDN” (Established in 2007)
- International Network of Low-Level Waste Disposal “DISPONET” (To be established in 2009)
- International Network of Environmental Remediation “ENVIRONET” (To be established in 2010).

In the area of education, ANENT (Asian Network for Education in Nuclear Technology) was established in 2004, its current members include 28 institutions from 12 countries and 5 collaborating organizations. The IAEA is facilitating coordination for networking with regional educational institutions to foster cooperation for sharing information and harmonization of curricula, preparation of shared teaching material, enabling distance learning and other programmes.

Examples of area-specific support

PLiM and structural integrity

As an increased number of plants age (Figure 7), there is increased demand from IAEA Member States for improved methodology for optimization of investment (cost-effectiveness and timing of refurbishment & linkage with power up-rating) and reduced uncertainties in the prediction of component degradation. The IAEA provides the following support, but is not limited to:

- A forum of information exchange by compilation of good practices & lessons learned
- Safety standards and technical guides/guidelines
- Component-wise degradation mechanisms and prediction methods
- Review Services

A recently discussed "i-GALL" (International Generic Aging LL) report by the IAEA is expected to serve as a periodically-updated practical guideline for PLiM.

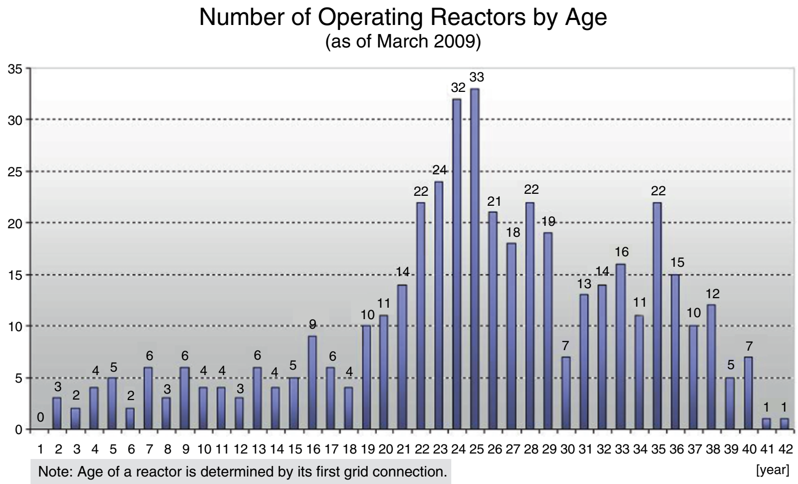

Figure 7. Age of operating nuclear power plants (327/435 as of March 2009 is over or equal to 20 years)

As an example of PLiM activity, maintaining the integrity of key pressure-retaining components of a nuclear power plant for its service life is a critical issue. Embrittlement of Reactor Pressure Vessels (RPV) by bombardment of fast neutrons is a well-known issue. Prediction of the level of degradation, especially considering Pressurized Thermal Shock (PTS) during a reactor transient situation, is a subject of safety concern. The IAEA is contributing to this subject through a CRP by providing an assessment guide on the level of embrittlement and the results of benchmarking for calculation methods to evaluate RPV integrity during PTS (Figure 8). Over 100 organizations and institutes contributed to this CRP and the results are documented as TECDOCs -1435, 1441 and 1442, and TRS- 429 [4–7].

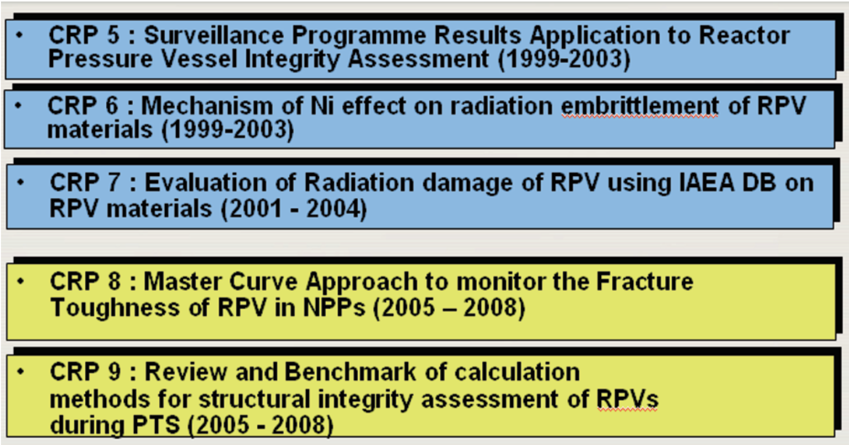

Figure 8. Series of CRPS for RPV integrity assessment

Maintenance

A series of documents have been published on this topic; strategy, technology for maintenance, optimization of maintenance and outages, cost effective approaches, etc. [8–13].

Examples of techniques applied and the production of good results are included in the following strategy areas [8]:

- Developing competences needed in the new environment by eliminating cost-plus thinking, change management, continuous process improvement (CPI) and enhanced ownership and responsibility
- Use of financial analysis in decision-making
- Elimination of obsolete and unnecessary work
- Increase of online maintenance through the use of probabilistic safety assessment (PSA)
- Improving outage planning
- Making appropriate use of contractors
- Implementation of corrective action programmes
- Use of risk management tools (use of risk monitors for outage planning, online maintenance, avoiding the peak of safety risk during an outage, risk-informed ISI, use of PSA to streamline safety regulations)

I&C modernization

The advent of I&C technology makes other technologies utilized for nuclear power stations obsolete and operators of nuclear power plants find difficulty in replacing components. Benefits and drivers of I&C modernization include:

- Responding to obsolescence concerns and ageing
- Improving functionality, better monitoring and diagnosis
- Reducing maintenance costs
- Improving performance, reliability
- Increasing power output by the utilization of margins

The main issues in implementing and licensing digital I&C systems include data communication, independence, cyber-security, reliability, and the qualification of "commercial-off-the shelf" (COTS) components in safety critical applications. For software, design verification and validation (V&V), evaluation, inspection, and testing become important. Defense-in-depth and consideration of diversity is required for important-to-safety components, for which analysis of common cause failure (CCF) is required.

For sharing of relevant operating experience and its use in licensing decisions, the IAEA has several recent publications on the role of I&C systems in power uprating, on-line monitoring, the implementation of digital I&C, etc. [14–16].

Also in development are several documents on protecting against common cause failure (CCF) in digital I&C systems, integration of analog and digital I&C systems in hybrid control rooms, advanced surveillance, diagnostics, and prognostics techniques used for health monitoring of systems, structures, and components in NPPs. In addition, numerous workshops were organized on the subject of I&C modernization.

Conclusion

The IAEA considers the dissemination of information, so that best practices may prevail, the core of its support for excellence in the operation and maintenance of the existing fleet. To support this objective, the IAEA provides many guideline documents and review services. Technical Cooperation Projects tailored for specific country/regional needs and networking also serve as important vehicles to support IAEA's Member States.

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THE SOLID COOLANT AND PROSPECTS OF ITS USE IN INNOVATIVE REACTORS

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The progress of nuclear power demands consideration and development of innovative projects of the reactors having the increased level of safety due to their immanent properties allowing to provide high parameters. One of interesting and perspective offers is the use of a solid substance as a coolant.

Use of the solid coolant of a nuclear reactor core has significant advantages among which an opportunity of movement of the coolant in the core under action of gravities and absence of necessity to have superfluous pressure in the jacket, that in turn means small metal consumption of construction, decrease in risk of emergency and its consequences. Cooling of the core with the help of solid substance is possible at performance of the certain conditions connected to features of the solid coolant. The major requirements are: the uniform continuous movement and minimal fluctuation of its density *on every site of the core; high mechanical durability and wear resistance of particles; as well as good parameters of heat exchange, i.e. high heat conductivity and thermal capacity of the coolant material at the core operating conditions.

The research for use the solid coolant on basis small dispersion graphite particles for thermal reactor core reveals the concrete conditions necessary for performance of the basic solid coolant requirements.

Use of solid substance for the core cooling was conceptually considered in 1960–1970 [1]. Thus both small dispersion solid coolant and coolant on the basis of large particles were considered. However owing to low heat conductivity of large particles the cooling system appeared expensive even at small capacity. In case of small coolant particles the factor of solid surface heat emission increases roughly in inverse proportion to their linear size. However the size of coolant particles cannot be very small. Very fine particles cannot exist in the usual gas environment owing to formation of conglomerates and ability to be stuck together.

Research for dry substance mechanics has allowed to establish, that the major requirement to the solid coolant will realization of indissoluble movement on every site of the core by gravity in view of presence of deterioration dust and split particles. Experiments have shown that for performance of this requirement the particle should have the spherical form of 0.5–2 mm average size of diameter with deviation ±20% at the unsphericity degree no more than 10%. For significant friction reduction the covering of pirocarbon [2] is used. Porosity of filling up of particles thus makes 0.39–0.41. Time of a temperature relaxation of such particles

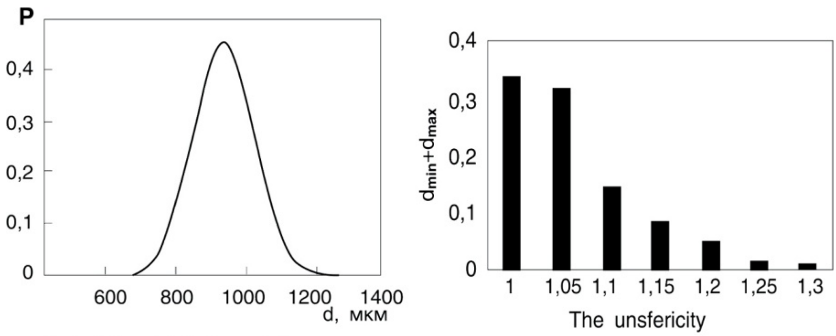
S.A. Apikyan and D.J. Diamond (eds.), *Nuclear Power and Energy Security*,

makes 0.05–0.15 s. Fluidity was estimated visually by filming in a glass tube and on a corner of a natural slope of particles. For new particles the corner has made 23–23°. Fluidity is appreciated as good.

Other basic requirements to the solid coolant:

1. Sufficient mechanical durability
2. High wear resistance
3. Chemical inertness in relation to constructional materials of reactor
4. Low ability to adsorb and exhaust various gases
5. Stability of structure at long work in neutron fields
6. High heat conductivity and thermal capacity
7. High fire resistance and heat resistance
8. Low speed of sublimation and evaporation

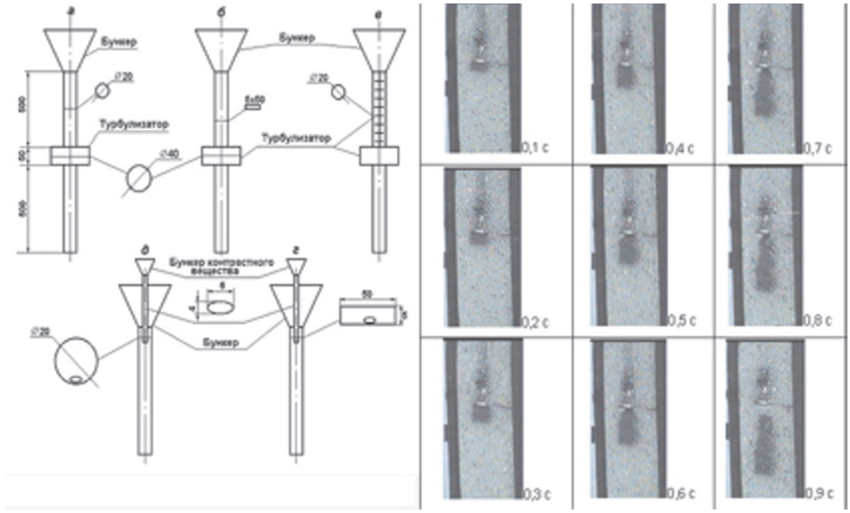
At FSUE "SRI SIA "Lch" the experimental-technological complex has been created. The manufacturing techniques of the solid coolant are developed. The basic moments consist in use pitches of ion exchange for formation of nucleus and drawing multilayered pirocarbon environments by decomposition of gases such asCH4. On this technology three sets of particles (–14 kg) are made. On Figures 1, 2 the measurement data of the geometrical sizes of 200 casual particles are shown.



Probability distribution of the average size of particles $(d_{min}+d_{max})/2$

Stability of solid coolant current was investigated on special installation under geometrical modelling flowing part of the core. Experiments have exposed high stability of the coolant gravity movement. The time variation of about 1 l volume devastation was no more than 0.2%. The visual control of stream structure was made by high-speed filming through transparent wall.

The experimental installation AIST 1-3 has been created to research the heat emission of the particle stream. In this installation working part of the core simulator is executed as a heated up pipe of stainless steel of length –3 m, internal diameter 10 mm with a heater and capacitie-refrigerators on both ends.



After the pipe turns over the particles begins to be poured out of the top into the bottom capacity. The thermocouples and thermal isolation was established outside. First at constant electric capacity a stationary temperature mode was reached. Then the pipe was overturned on 180° for the beginning with movements of particles, and initial temperature was restored by heater capacity increase. The heat emission factor was calculated for additional electric capacity in view of temperature of heating wall and average particle temperature in pipe section after passage of a heated up site. In the best conditions (helium, speed of 0.22 m/s, the wall temperature of 1,073 K, a set of particles with pirocarbon covering of –0.9 mm diameter) the heat emission factor in the round channel of 10 mm diameter without hindrance reached 800–1,000 Bt/(m*K).

Tests for resource wear resistance graphite particles with pirocarbon covering during 1,000 h at temperature 573–673 K and flow speed of –0.1 m/s have not revealed destruction of particles. Only small reduction of their unsphericity and weak increase in roughness owing to space corrosion and mechanical deterioration (within the limits of –3 μm) are marked. Average diameter of graphite particle nucleus is –200 μm, thickness of pirocarbon covering is from 200 to 400 μm. After test the size of particles and pirocarbon covering condition have not changed.

Tests are executed on special installation of continuous operating. Installation consists of heating site simulating reactor core, cooling site simulating heat exchangers, and the mechanical lift to move the coolant from below into the top part for heating.

The research results for fluidity, heat exchange and wear resistance technological parameters of the suggested solid coolant are appreciated as perspective for the further researches.

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INNOVATION PROJECTS OF ATOMIC ENERGY INSTITUTE OF NATIONAL NUCLEAR CENTER RK IN THE AREA OF PEACEFUL USE OF ATOMIC ENERGY

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Introduction

Institute of Atomic Energy of National Nuclear Center RK (IAE NNC RK) is located in Kurchatov. The city is situated at the border of former Semipalatinsk test site. The institute includes two reactor complexes – IGR and Baikal-1, which are rather distant from Kurchatov.

Main activities of IAE NNC RK are:

1. Experimental researches of the nuclear power reactors safety
2. Experimental researches of behavior of the structural materials for fusion and fission facilities under reactor irradiation
3. Management of radioactive wastes
4. Participation in the projects on decommissioning of the fast neutron reactor BN-350
5. Innovation projects:
   - Creation of first Kazakhstan's fusion reactor – tokamak KTM for materials research and testing
   - Development of new technologies (irradiated Be-recycling)
   - Development of new reactor technologies – project on creation of high temperature gas-cooled reactor KHTR

IAE NNC RK jointly with Japanese Atomic Energy Agency and with participation of Japanese Atomic Power Company is performing the activities on experimental substantiation of design of active core of prospective fast neutron reactor.

Main goal of out-of-pile experiments at the EAGLE facility (Figure 1) is obtaining of the information on fuel movement processes under conditions simulating the accident with melting of fast reactor core containing tube-design fuel assembly. Batch mixture is loaded into graphite crucible; then it is melded into electric melting furnace and poured into melt top trap. The outlet pipe is melted by the melt, which is poured into bottom melt trap through the pipe with sodium.

S.A. Apikyan and D.J. Diamond (eds.), *Nuclear Power and Energy Security*,

As a part of Kazakhstan–Japan cooperation the processes were studied, which accompany some stages of severe NPP accidents with melting of active core of fast reactors with sodium coolant.

For the first time in the world 10 kg of uranium fuel was melted in the IGR reactor core and unique information was gathered on high-temperature interaction of fuel melt with liquid sodium (Figure 2). The result of work was published in [1]. Obtained experience allowed to extend research area related to safety of nuclear power reactors and contribute in creation of safe and efficient atomic energy in the Republic of Kazakhstan.

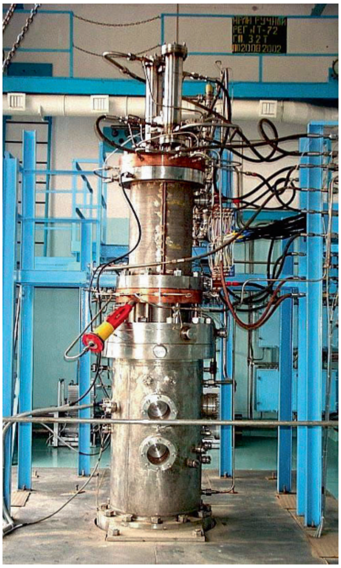

Figure 1. First modification of EAGLE facility

Figure 2. Melt of fuel, steel and sodium into experimental device trap

During last 20 years the main activities carried out at the IVG-1 reactor were directed at study of hydrogen isotope interaction with structural materials of fusion reactors (including materials with protective coatings) under reactor irradiation. There were carried out out-of-pile and in-pile studies of hydrogen isotope interaction with the following materials: beryllium of various grades (TV-56, TShG-56, DV-56, TGP-56, TIP-56) produced by Ulba metallurgical plant, graphites (RG-T, MPG-8), molybdenum, stainless steels ($Cr_{18}Ni_{10}Ti$, $Cr_{16}Ni_{15}$), low-activated steels (V_4Cr_4Ti, V_6Cr_5Ti, MANET, $F_{82}H$), copper alloys (Cu + 1%Cr + 0.1%Zr) and double Be/Cu and triple Be/Cu/steel structures, which are considered as candidate structural materials of fusion reactors.

The results of these activities were published in Refs. [2–4].

Innovative projects

Creating of the 1st Kazakhstani fusion reactor – materials research and testing tokamak KTM

Tokamak KTM is created in IAE NNC RK, Kurchatov, in accordance with RK Prime Minister Decree and Republican Budget Programs. Tokamak KTM is plasma-physical facility – spherical tokamak with aspect ratio A = 2. Working body is the mix of hydrogen and deuterium. Under stationary mode of plasma column burning, all the power, which keeps average temperature of above 107 K, goes to a wall and to divertor area in ratio of 30% and 70% correspondingly. Thus the near-surface plasma flows have all the features of tokamaks' plasma, which are necessary for studies and tests of the materials of first wall and divertor. Organization of stationary flows of near-surface plasma in the divertor area with powers, which are equal or more than the one in the ITER chamber, and study of various materials of divertor tiles are main goal of the facility operation.

Main Goals of KTM tokamak creation are:

- Creation of the experimental base for carrying out systematic studies and tests of materials, technical and technological processes of first wall armor, divertor receiving tiles, methods and systems of heat removal
- Performance of unique studies of boundary magnetic configuration of extremely compact toroids and classical tokamaks
- Study of plasma–surface interaction by simulation of neutron loads with great heat loads (0.1÷20 MWt/m^2)
- Wide international cooperation in the field of material science for fusion

Tokamak KTM will be main facility of unique bench complex for systematic studies of first wall materials and divertor materials under impacts of plasma flows (loads from 0.1 to 20 MWt/m^2) with wide range of expositions (Figure 3).

The basic parameters of KTM are given in Table 1.

Table 1. Basic parameters of tokamak KTM

Plasma major radius	0.9 m
Plasma minor radius	0.45 m
Aspect ratio, A	2.0
Plasma elongation, K95	1.7
Toroidal magnetic field, Bto	1.0 T
Plasma current	0.75MA
Duration of current plateau	4–5 s
Additional RF-heating power	5 MW
Thermal load on the divertor tiles	2 –20 MW/m^2

Figure 3. General view of KTM complex and installation of KTM on a workplace

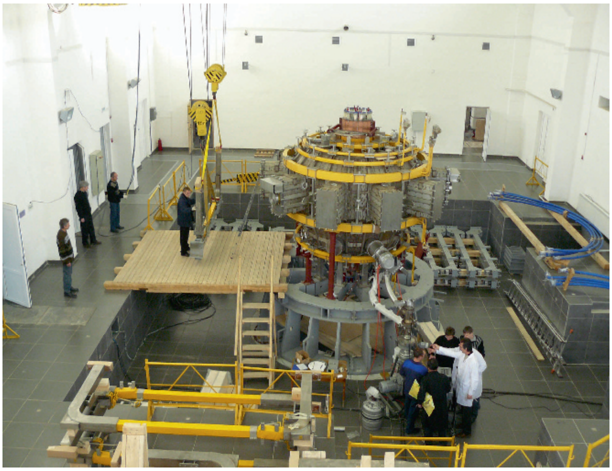

Figure 4. Assemblage of electromagnetic system of KTM and pumping of vacuum chamber

The KTM creation project is implemented in cooperation with Russian organizations: NIIEFA name of D. V. Efremov, TRINITI, Kurchatov Institute, VNIITVCh, and Tomsk polytechnic University. The main results of KTM project activity was published in [5–7].

Status of preparation systems to the first plasma start-up of tokamak KTM (Figure 4):

- Tokamak KTM facility was designed and manufactured by NIIEFA and delivered from S. Petersburg to Kurchatov in December 2007.
- Completion of tokamak KTM mounting is scheduled at the end of 2009.
- System of external power supplies will be put in operation in 2009.
- System of pulse power supplies – installation and adjustment of system in 2009/2010.
- Vacuum system – completion of manufacturing in 2008, installation and adjustment in 2009.
- Manufacturing, delivery, installation and adjustment of the system of preparation of the vacuum chamber (decaying discharge, plasma discharge, warming up VC) is scheduled on 2009.
- Manufacturing, installation and adjustment of the system of water cooling is scheduled on 2008.
- Installation and adjustment of Data Acquisition System(DAS) KTM is planned on 2009/2010.
- Diagnostics systems of KTM. Diagnostics of first order was delivered in 2008, second order will be delivered in 2009.
- System of RF-heating of plasma will be delivered and installed in 2009.
- Preparation for the first plasma start-up, physical start-up of tokamak KTM – 2010/2011.

R&D technology of Be recycling

Good neutron-physical characteristics of beryllium (low neutron-absorption cross-section, high moderating properties due to low atomic weight and high neutron scattering, and readiness to part with one of its own neutrons (n, 2n)) allow for beryllium to be used in fission reactors. It is also proposed to use beryllium as a neutron breeder and protecting wall of plasma catcher in the fusion reactors.

During beryllium operation in neutron field of nuclear reactors its mechanical properties are worsened. Possible durability in this case is determined by that neutron fluence at which minimum allowed quality of beryllium is achieved. Therefore, reprocessing of used beryllium in the nuclear reactor becomes actual task.

It is difficult to reprocess the used beryllium because of high activity of radioactive by-products induced in beryllium structures.

These by-products are generated as a result of reaction of neutrons with ill-removed impurities in beryllium. Main radionuclides, which are generated in beryllium and responsible for most potential radiation impacts, are ^{3}H and ^{60}Co.

The possible solution of this is additional processing of beryllium, which includes its cleaning from radioactive nuclides. The cleaning of irradiated beryllium allows for expansion of possible beryllium applications in atomic energy.

At present there is no industrial technique for cleaning o f irradiated beryllium in world practice. Processing of the beryllium is carried out in the initial stage. This reprocessing of the used beryllium utilizes the reaction between beryllium and chlorine, and beryllium chloride ($BeCl_2$) with sufficiently low melting temperature is generated by this reaction. Separation of $BeCl_2$ from ^3H and ^{60}Co is based on difference of phase change of beryllium chloride and possible products of reaction of chlorine with ^3H and ^{60}Co (including pure ^3H and ^{60}Co).

Project actuality is based on needs of beryllium items' users in industrial processing of irradiated beryllium and its cleaning from radioactively dangerous additives such as tritium and cobalt-60. The main reason for this is:

- Presence of stocks of the spent irradiated beryllium.
- Absence of a technology for cleaning of irradiated beryllium from tritium and cobalt-60.
- Presence of experimental groundwork, which is used as a basis of this project. It lets to expect the positive outcome.

In accordance with expert recommendations, which carried out preliminary studies, the selected technology assumed that a facility will have three main parts:

1. Transfer of metal beryllium into chloride. Metal beryllium is washed with chlorine flows with possible additives of helium, hydrogen, hydrochloric acid. During this stage tritium is removed from beryllium with gas fractions (hydrochloric acid, hydrogen) and cobalt is stayed in beryllium chloride.
2. Cobalt removal stage. Beryllium chloride flow is heated up to 500°C, which is more than its melting temperature. At this case cobalt from $BeCl_2$ melt will precipitate at the walls.
3. Metal beryllium production stage. Cleaned beryllium chloride is heated up to 1,500°C and decomposes into chlorine and beryllium.

Project purpose: study of possibilities to clean irradiated beryllium from radioactive tritium and cobalt by using the technology of beryllium transfer into beryllium chloride.

Project tasks:

- Development of purification technology
- Development of technique to determine purification efficiency of beryllium from tritium and cobalt up to 10^{-3}
- Assessment of approaches for management of beryllium of various purification efficiency by radioactive cobalt
- Development of technological documentation and manufacture of pilot facility for beryllium purification
- Experimental works at the pilot facility in accordance with techniques for determination of purification efficiency
- Analysis of the results and measurements
- Development of recommendations for further activities in this field

The result of this project will be obtained:

- Techniques for determination of purification efficiency of beryllium from tritium and cobalt, which are based on various technological approaches
- Requirements for realization of radiation-dangerous works with beryllium of various purification efficiency by radioactive cobalt
- Technical documentation and pilot facility for beryllium purification from tritium and cobalt
- Experimental data on beryllium purification levels and evaluation of possibility to increase efficiency by improving the technique
- Recommendations for further improvement of activities in this field
- Estimation of possibility to use analogous technology of beryllium purification for production of primary beryllium

The activities are carried out jointly with and under financial support of Japan (Japan Atomic Energy Agency) and EC (SCK-CEN, Belgium). Japan Atomic Energy Agency has the experience of recycling of 10 g irradiated beryllium by using the conversion process from metal beryllium to beryllium chloride and separation of ^{60}Co and ^{3}H under high temperatures [8].

SCK-CEN has the experience in laboratory experiments by using detritiation, chlorination followed by distillation, Be_9–Be_{10} separation by centrifugation and use of electrolysis for generation of pure beryllium.

IAE NNC RK jointly with Ulba Metallurgical Plant (Ust-Kamenogorsk, Kazakhstan) started the activities on development of beryllium recycling technology and irradiated beryllium purification facility pursuant to working plan of ISTC K-1566 Project.

Development of new of reactors technology – KHTR project

At present many countries joint their efforts to research and design new IV-generation reactors. Some countries with extensive nuclear power use give great consideration to creation of high-temperature gas cooled reactors (HTGR) and development of the related technologies.

HTGR can produce both electricity and coolant (with temperature of up to 1,000°C), which is necessary for development of high-temperature technologies in various industrial areas including production of energy carrier – hydrogen for fuel elements of transport vehicles, as well as the areas related to oil refinement, coal gasification, production of ethylene, styrene, ammonia and steel.

The most prospective solution of organization of wide production of hydrogen for industrial needs is creation of its production by using reactor heat. The technology of high temperature gas-cooled reactors opens new market areas got atomic energy as for non-electric applications and, in particular, hydrogen power engineering.

Japan and Kazakhstan expressed preliminary intentions of joint realization of the project on creation of pilot-demonstration NPP of low power (NPP LP), including development of conceptual design and determination of engineering-and-economical performance of NPP LP – Kazakhstani High-Temperature Gas-Cooled Reactor of Low Power (KHTR) in Kurchatov, Kazakhstan. Goal of long-term cooperation – creation of Generation-4 NPP on the basis of KHTR technology as a part of industrial–technological complexes as a source of high-temperature heat for production of hydrogen, crude oil purification, production of polyethylene, ammonia, steel, coal gasification and production of electricity in gas turbine cycle.

At present there are political, organizational and scientific-technical preconditions for advancement of the activities on creation of HTGR in the Republic of Kazakhstan.

Political and organizational background

- Joint statement of Nursultan Nazarbaev, the President of the Republic of Kazakhstan, and Yasuo Fukuda, the Prime Minister of Japan, made in June 20, 2008, welcomed "cooperation between National Nuclear Center and Japan Atomic Energy Agency in realization of advanced research and development in the field of atomic energy and fusion, in particular, research on high-temperature gas-cooled reactor and its application technologies…"
- Cooperation Agreement between NNC RK and JAEA (Japan) on creation of high-temperature gas-cooled reactor (signed in January 2009, in Japan)
- Draft of the State Program for nuclear-power industry development on 2009–2030, where the activities are provided on development of KHTR of low and average power

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- Experimental base of National Nuclear Center RK – three research reactors and out-of-pile test-benches suitable for tests and trials with fuel, fuel assemblies and design components of KHTR, study of structural materials of reactor and gas-turbine unit
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- Opportunities to produce KHTR fuel in Kazakhstan (Ulba Metallurgical Plant) – transfer of technologies from Japan

Main goal of creation of pilot NPP of low power with HTGR reactor is demonstration of efficiency of HTGR for production of thermal and electric power and industrial production of hydrogen. Creation and further operation of NLL LP in Kurchatov allows for acquiring of practical experience in designing, construction and operation of HTGR, corroboration of real technical–economic characteristics and reasonability of further development and realization of serial project of NPP LP with HTGR in Kazakhstan, and to lay the foundation of atomic and hydrogen power engineering.

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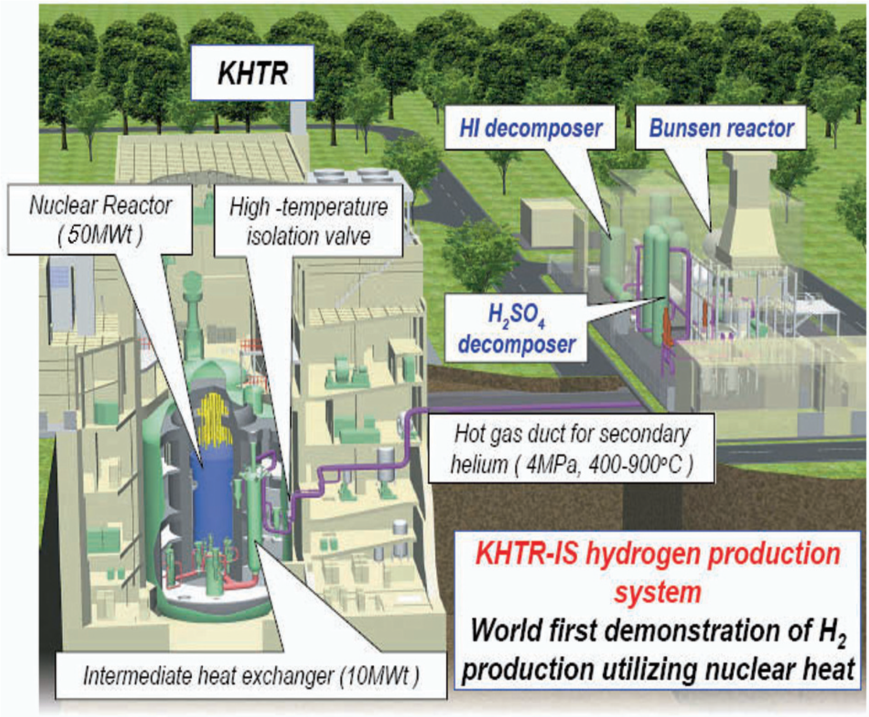
Main parameter of KHTR reactor power – 50 MWt , electricity production – 15 MWt, heat production – 20 MWt, hydrogen production – 25,000 nm^3/day.

The general view of KHTR site is represented in Figure 5.



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IAE NNC RK can carry out the studies for justification of design solutions of KHTR by using its extensive knowledge, experience in operation of experimental test-benches and research gas-cooled reactors, extensive experience in studies for justification of nuclear facility safety, in the field of radiation material studies, etc.

Currently activities are carried out for development of preliminary feasibility study for justification of KHTR creation in Kurchatov.

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INNOVATION PROJECTS OF ATOMIC ENERGY INSTITUTE OF NATIONAL NUCLEAR CENTER RK IN THE AREA OF PEACEFUL USE OF ATOMIC ENERGY

E. Kenzhin, I. Tazhibayeva, Y. Vasiliyev, A. Kolodeshnikov, A. Vurim

Institute of Atomic Energy of National Nuclear Center RK, Kurchatov, Kazakhstan

Introduction

Institute of Atomic Energy of National Nuclear Center RK (IAE NNC RK) is located in Kurchatov. The city is situated at the border of former Semipalatinsk test site. The institute includes two reactor complexes – IGR and Baikal-1, which are rather distant from Kurchatov.

Main activities of IAE NNC RK are:

1. Experimental researches of the nuclear power reactors safety
2. Experimental researches of behavior of the structural materials for fusion and fission facilities under reactor irradiation
3. Management of radioactive wastes
4. Participation in the projects on decommissioning of the fast neutron reactor BN-350
5. Innovation projects:
   - Creation of first Kazakhstan's fusion reactor – tokamak KTM for materials research and testing
   - Development of new technologies (irradiated Be-recycling)
   - Development of new reactor technologies – project on creation of high temperature gas-cooled reactor KHTR

IAE NNC RK jointly with Japanese Atomic Energy Agency and with participation of Japanese Atomic Power Company is performing the activities on experimental substantiation of design of active core of prospective fast neutron reactor.

Main goal of out-of-pile experiments at the EAGLE facility (Figure 1) is obtaining of the information on fuel movement processes under conditions simulating the accident with melting of fast reactor core containing tube-design fuel assembly. Batch mixture is loaded into graphite crucible; then it is melded into electric melting furnace and poured into melt top trap. The outlet pipe is melted by the melt, which is poured into bottom melt trap through the pipe with sodium.

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As a part of Kazakhstan–Japan cooperation the processes were studied, which accompany some stages of severe NPP accidents with melting of active core of fast reactors with sodium coolant.

For the first time in the world 10 kg of uranium fuel was melted in the IGR reactor core and unique information was gathered on high-temperature interaction of fuel melt with liquid sodium (Figure 2). The result of work was published in [1]. Obtained experience allowed to extend research area related to safety of nuclear power reactors and contribute in creation of safe and efficient atomic energy in the Republic of Kazakhstan.

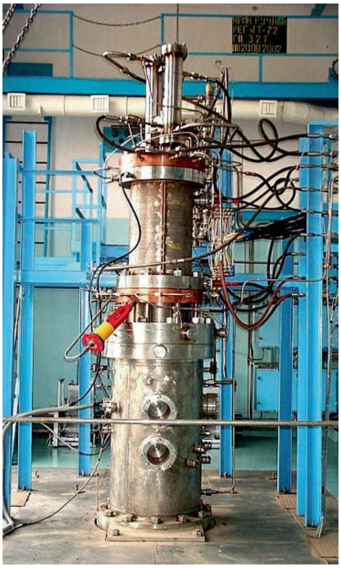

Figure 1. First modification of EAGLE facility

Figure 2. Melt of fuel, steel and sodium into experimental device trap

During last 20 years the main activities carried out at the IVG-1 reactor were directed at study of hydrogen isotope interaction with structural materials of fusion reactors (including materials with protective coatings) under reactor irradiation. There were carried out out-of-pile and in-pile studies of hydrogen isotope interaction with the following materials: beryllium of various grades (TV-56, TShG-56, DV-56, TGP-56, TIP-56) produced by Ulba metallurgical plant, graphites (RG-T, MPG-8), molybdenum, stainless steels ($Cr_{18}Ni_{10}Ti$, $Cr_{16}Ni_{15}$), low-activated steels (V_4Cr_4Ti, V_6Cr_5Ti, MANET, $F_{82}H$), copper alloys (Cu + 1%Cr + 0.1%Zr) and double Be/Cu and triple Be/Cu/steel structures, which are considered as candidate structural materials of fusion reactors.

The results of these activities were published in Refs. [2–4].

Innovative projects

Creating of the 1st Kazakhstani fusion reactor – materials research and testing tokamak KTM

Tokamak KTM is created in IAE NNC RK, Kurchatov, in accordance with RK Prime Minister Decree and Republican Budget Programs. Tokamak KTM is plasma-physical facility – spherical tokamak with aspect ratio A = 2. Working body is the mix of hydrogen and deuterium. Under stationary mode of plasma column burning, all the power, which keeps average temperature of above 107 K, goes to a wall and to divertor area in ratio of 30% and 70% correspondingly. Thus the near-surface plasma flows have all the features of tokamaks' plasma, which are necessary for studies and tests of the materials of first wall and divertor. Organization of stationary flows of near-surface plasma in the divertor area with powers, which are equal or more than the one in the ITER chamber, and study of various materials of divertor tiles are main goal of the facility operation.

Main Goals of KTM tokamak creation are:

- Creation of the experimental base for carrying out systematic studies and tests of materials, technical and technological processes of first wall armor, divertor receiving tiles, methods and systems of heat removal
- Performance of unique studies of boundary magnetic configuration of extremely compact toroids and classical tokamaks
- Study of plasma–surface interaction by simulation of neutron loads with great heat loads (0.1÷20 MWt/m^2)
- Wide international cooperation in the field of material science for fusion

Tokamak KTM will be main facility of unique bench complex for systematic studies of first wall materials and divertor materials under impacts of plasma flows (loads from 0.1 to 20 MWt/m^2) with wide range of expositions (Figure 3).

The basic parameters of KTM are given in Table 1.

Table 1. Basic parameters of tokamak KTM

Plasma major radius	0.9 m
Plasma minor radius	0.45 m
Aspect ratio, A	2.0
Plasma elongation, K95	1.7
Toroidal magnetic field, Bto	1.0 T
Plasma current	0.75MA
Duration of current plateau	4–5 s
Additional RF-heating power	5 MW
Thermal load on the divertor tiles	2 –20 MW/m^2

Figure 3. General view of KTM complex and installation of KTM on a workplace

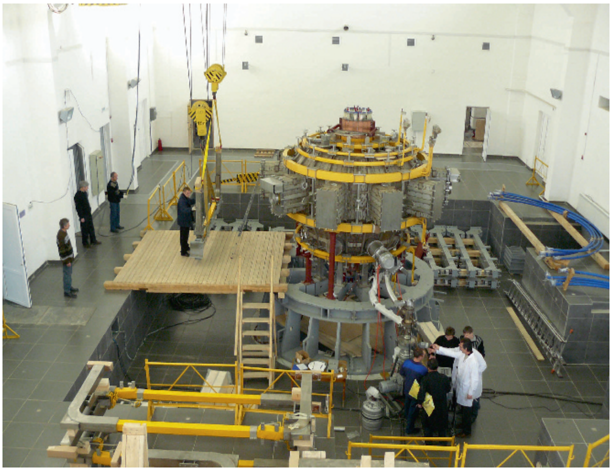

Figure 4. Assemblage of electromagnetic system of KTM and pumping of vacuum chamber

The KTM creation project is implemented in cooperation with Russian organizations: NIIEFA name of D. V. Efremov, TRINITI, Kurchatov Institute, VNIITVCh, and Tomsk polytechnic University. The main results of KTM project activity was published in [5–7].

Status of preparation systems to the first plasma start-up of tokamak KTM (Figure 4):

- Tokamak KTM facility was designed and manufactured by NIIEFA and delivered from S. Petersburg to Kurchatov in December 2007.
- Completion of tokamak KTM mounting is scheduled at the end of 2009.
- System of external power supplies will be put in operation in 2009.
- System of pulse power supplies – installation and adjustment of system in 2009/2010.
- Vacuum system – completion of manufacturing in 2008, installation and adjustment in 2009.
- Manufacturing, delivery, installation and adjustment of the system of preparation of the vacuum chamber (decaying discharge, plasma discharge, warming up VC) is scheduled on 2009.
- Manufacturing, installation and adjustment of the system of water cooling is scheduled on 2008.
- Installation and adjustment of Data Acquisition System(DAS) KTM is planned on 2009/2010.
- Diagnostics systems of KTM. Diagnostics of first order was delivered in 2008, second order will be delivered in 2009.
- System of RF-heating of plasma will be delivered and installed in 2009.
- Preparation for the first plasma start-up, physical start-up of tokamak KTM – 2010/2011.

R&D technology of Be recycling

Good neutron-physical characteristics of beryllium (low neutron-absorption cross-section, high moderating properties due to low atomic weight and high neutron scattering, and readiness to part with one of its own neutrons (n, 2n)) allow for beryllium to be used in fission reactors. It is also proposed to use beryllium as a neutron breeder and protecting wall of plasma catcher in the fusion reactors.

During beryllium operation in neutron field of nuclear reactors its mechanical properties are worsened. Possible durability in this case is determined by that neutron fluence at which minimum allowed quality of beryllium is achieved. Therefore, reprocessing of used beryllium in the nuclear reactor becomes actual task.

It is difficult to reprocess the used beryllium because of high activity of radioactive by-products induced in beryllium structures.

These by-products are generated as a result of reaction of neutrons with ill-removed impurities in beryllium. Main radionuclides, which are generated in beryllium and responsible for most potential radiation impacts, are ^{3}H and ^{60}Co.

The possible solution of this is additional processing of beryllium, which includes its cleaning from radioactive nuclides. The cleaning of irradiated beryllium allows for expansion of possible beryllium applications in atomic energy.

At present there is no industrial technique for cleaning o f irradiated beryllium in world practice. Processing of the beryllium is carried out in the initial stage. This reprocessing of the used beryllium utilizes the reaction between beryllium and chlorine, and beryllium chloride ($BeCl_2$) with sufficiently low melting temperature is generated by this reaction. Separation of $BeCl_2$ from ^3H and ^{60}Co is based on difference of phase change of beryllium chloride and possible products of reaction of chlorine with ^3H and ^{60}Co (including pure ^3H and ^{60}Co).

Project actuality is based on needs of beryllium items' users in industrial processing of irradiated beryllium and its cleaning from radioactively dangerous additives such as tritium and cobalt-60. The main reason for this is:

- Presence of stocks of the spent irradiated beryllium.
- Absence of a technology for cleaning of irradiated beryllium from tritium and cobalt-60.
- Presence of experimental groundwork, which is used as a basis of this project. It lets to expect the positive outcome.

In accordance with expert recommendations, which carried out preliminary studies, the selected technology assumed that a facility will have three main parts:

1. Transfer of metal beryllium into chloride. Metal beryllium is washed with chlorine flows with possible additives of helium, hydrogen, hydrochloric acid. During this stage tritium is removed from beryllium with gas fractions (hydrochloric acid, hydrogen) and cobalt is stayed in beryllium chloride.
2. Cobalt removal stage. Beryllium chloride flow is heated up to 500°C, which is more than its melting temperature. At this case cobalt from $BeCl_2$ melt will precipitate at the walls.
3. Metal beryllium production stage. Cleaned beryllium chloride is heated up to 1,500°C and decomposes into chlorine and beryllium.

Project purpose: study of possibilities to clean irradiated beryllium from radioactive tritium and cobalt by using the technology of beryllium transfer into beryllium chloride.

Project tasks:

- Development of purification technology
- Development of technique to determine purification efficiency of beryllium from tritium and cobalt up to 10^{-3}
- Assessment of approaches for management of beryllium of various purification efficiency by radioactive cobalt
- Development of technological documentation and manufacture of pilot facility for beryllium purification
- Experimental works at the pilot facility in accordance with techniques for determination of purification efficiency
- Analysis of the results and measurements
- Development of recommendations for further activities in this field

The result of this project will be obtained:

- Techniques for determination of purification efficiency of beryllium from tritium and cobalt, which are based on various technological approaches
- Requirements for realization of radiation-dangerous works with beryllium of various purification efficiency by radioactive cobalt
- Technical documentation and pilot facility for beryllium purification from tritium and cobalt
- Experimental data on beryllium purification levels and evaluation of possibility to increase efficiency by improving the technique
- Recommendations for further improvement of activities in this field
- Estimation of possibility to use analogous technology of beryllium purification for production of primary beryllium

The activities are carried out jointly with and under financial support of Japan (Japan Atomic Energy Agency) and EC (SCK-CEN, Belgium). Japan Atomic Energy Agency has the experience of recycling of 10 g irradiated beryllium by using the conversion process from metal beryllium to beryllium chloride and separation of ^{60}Co and ^{3}H under high temperatures [8].

SCK-CEN has the experience in laboratory experiments by using detritiation, chlorination followed by distillation, Be_9–Be_{10} separation by centrifugation and use of electrolysis for generation of pure beryllium.

IAE NNC RK jointly with Ulba Metallurgical Plant (Ust-Kamenogorsk, Kazakhstan) started the activities on development of beryllium recycling technology and irradiated beryllium purification facility pursuant to working plan of ISTC K-1566 Project.

Development of new of reactors technology – KHTR project

At present many countries joint their efforts to research and design new IV-generation reactors. Some countries with extensive nuclear power use give great consideration to creation of high-temperature gas cooled reactors (HTGR) and development of the related technologies.

HTGR can produce both electricity and coolant (with temperature of up to 1,000°C), which is necessary for development of high-temperature technologies in various industrial areas including production of energy carrier – hydrogen for fuel elements of transport vehicles, as well as the areas related to oil refinement, coal gasification, production of ethylene, styrene, ammonia and steel.

The most prospective solution of organization of wide production of hydrogen for industrial needs is creation of its production by using reactor heat. The technology of high temperature gas-cooled reactors opens new market areas got atomic energy as for non-electric applications and, in particular, hydrogen power engineering.

Japan and Kazakhstan expressed preliminary intentions of joint realization of the project on creation of pilot-demonstration NPP of low power (NPP LP), including development of conceptual design and determination of engineering-and-economical performance of NPP LP – Kazakhstani High-Temperature Gas-Cooled Reactor of Low Power (KHTR) in Kurchatov, Kazakhstan. Goal of long-term cooperation – creation of Generation-4 NPP on the basis of KHTR technology as a part of industrial–technological complexes as a source of high-temperature heat for production of hydrogen, crude oil purification, production of polyethylene, ammonia, steel, coal gasification and production of electricity in gas turbine cycle.

At present there are political, organizational and scientific-technical preconditions for advancement of the activities on creation of HTGR in the Republic of Kazakhstan.

Political and organizational background

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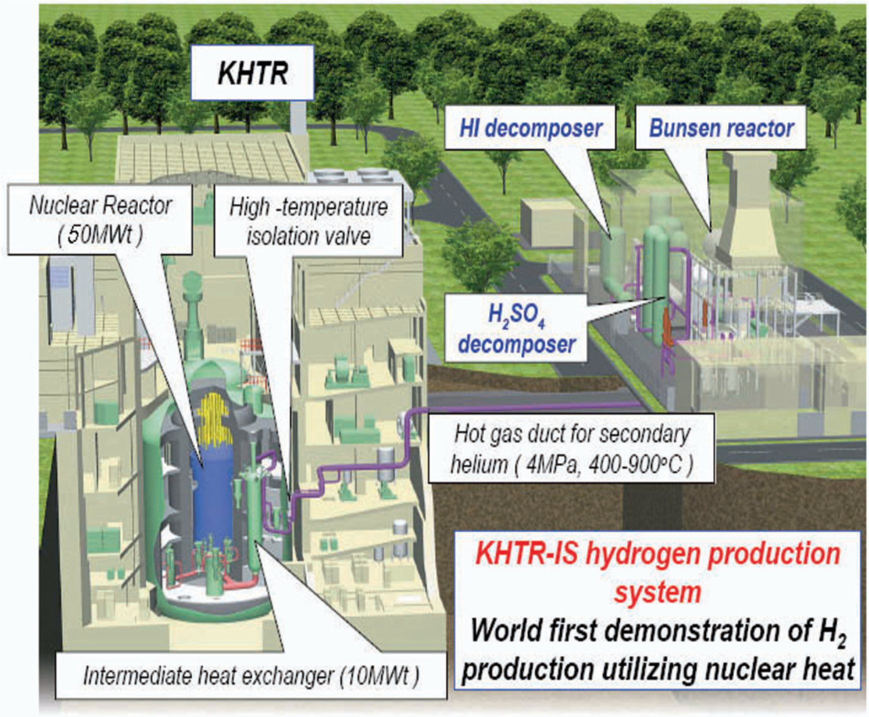

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INNOVATIVE DESIGNS OF NUCLEAR REACTORS

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Abstract The world development scenarios predict at least a 2.5 time increase in the global consumption of primary energy in the first half of the twenty-first century. Much of this growth can be provided by the nuclear power which possesses important advantages over other energy technologies. However, the large deployment of nuclear sources may take place only when the new generation of reactors appears on the market and will be free of the shortcomings found in the existing nuclear power installations. The public will be more inclined to accept nuclear plants that have better economics; higher safety; more efficient management of the radioactive waste; lower risk of nuclear weapons proliferation, and provided that the focus is made on the energy option free of $\nabla\in_2$ generation. Currently, the future of nuclear power is trusted to the technology based on fast reactors and closed fuel cycle. The latter implies reprocessing of the spent nuclear fuel of the nuclear plants and re-use of plutonium produced in power reactors.

Keywords: nuclear power, innovative nuclear energy system, NIKIET, Uniterm reactor, BREST fast reactor, innovative reactor, reactor design, small power plants, Generation IV, INPRO, non-proliferation of nuclear weapons, safety, waste

Introduction

The scenarios of world development predict on average a 2.5 time increase in the global consumption of primary energy in the period from 2000 to 2050, and a 4.7 time growth of electricity demand [1, 2]. Currently, there are no universal solutions to energy problems. However, there exist realistic ways of providing adequate energy supply that will help ensure sustainable development of mankind in, at least, the next several decades. They include:

- More efficient generation and use of electricity produced at conventional fossil plants
- Wider application of renewable, such as wind, solar and geothermal energy, and biomass
- Deployment of nuclear sources

S.A. Apikyan and D.J. Diamond (eds.), *Nuclear Power and Energy Security*,

Most scenarios predict a sustainable and considerable growth in the use of nuclear energy. The expectations and predictions concerning the nuclear power development and application in different regions have undergone dramatic changes over the relatively short (50 years only) history of nuclear power, ranging from highly enthusiastic to very pessimistic. Noteworthy is that the role of nuclear has been reappraised even in some countries in which it originated [3].

At present, the world's nuclear park includes predominantly thermal reactors with water cooling. These are second-generation PWRs, BWRs, CANDUs, Russian VVERs and RBMKs. After a long period of stagnation, the world's nuclear power has been showing stable positive trends in the beginning of the twenty-first century. To meet the high energy demand, the society will have to resort to all energy alternatives, including nuclear which has a huge potential for addressing the future energy needs without adding to CO_2 and other pollutant emissions.

It is evident now that nuclear power can develop further only provided that its safety and economics are improved; the radioactive waste are managed in a more efficient way; the risk of nuclear weapons proliferation is reduced, and the society opts for the energy free of CO_2.

In the ongoing transition period, the countries with well-developed nuclear power are upgrading the existing nuclear plants (which belong to the second generation) and starting to construct new plants of the third generation, designed after Chernobyl. These plants (EPR, AP-1000, ABWR, AES-2006) meet modern safety and environmental standards and requirements, and resolve the current energy problems. However, they do not fully meet the new requirements for the plant economics, fuel supply and proliferation resistance. New reactors and nuclear fuel cycle technologies (Generation IV) should come to take their place, to ensure gradual transfer to the safe and competitive heat and electricity generation with the unlimited fuel resources relying on inherent production of fissile isotopes.

Main challenges facing nuclear power

The international projects INPRO and Generation IV have looked into the steps imperative for keeping nuclear as viable energy alternative capable of reducing greenhouse gas emissions and meeting the growing electricity demand. After the studies, experts have come to conclusion that successful deployment of large-scale nuclear power depends on its ability to meet the four principal challenges:

Cost: In the existing free market, the cost of the electricity generated at new nuclear plants is noncompetitive with that at the coal and natural gas stations. However, this difference can be abridged by reducing investment, operational and maintenance costs, and by shortening the construction period. The carbon emissions trading, if decided at a governmental level, may give certain cost advantages to the nuclear.

Safety: The lessons learnt from the Three Mile Island and Chernobyl accidents have translated into additional safety measures taken at the nuclear plants all over the world to prevent and mitigate the most likely (design-basis) and severe (beyond-design-basis) accidents. The designs of modern nuclear reactors provide for a very low probability of serious accidents. However, apart from the safety of reactor operation, we know little about the fuel cycle safety in general.

Waste: The deep geological disposal of the waste is technically feasible but should be further investigated and demonstrated.

Non-proliferation of nuclear weapons: The existing international safeguarding regime is not up to the security challenges associated with large deployment of nuclear sources envisaged in the global development scenarios. The existing system of spent nuclear fuel reprocessing which involves plutonium recovery is not free of the risk of unauthorized proliferation of nuclear weapons.

The type of the fuel cycle is of crucial importance for the further development of nuclear power: which fuel to use; which reactor types to choose to "burn" fuel; how to dispose of the spent fuel. The fuel cycle should address all four principal challenges facing nuclear power: cost, safety, non-proliferation of nuclear weapons, and waste disposal. At present, the greatest interest is shown in three representative fuel cycle alternatives:

- Traditional thermal reactors with an "open" fuel cycle in which fuel is removed from reactors and sent to a disposal site.
- Thermal reactors with a "closed" fuel cycle in which the wastes are separated from non-utilized fissile materials that can then be processed to fabricate the nuclear fuel. Such fuel cycle is currently used in some countries (France, Russia, Japan). Plutonium is extracted from the spent fuel and then re-used to fabricate the once-through mixed uranium – plutonium oxide (MOX) fuel.
- A two-component system incorporating thermal reactors with an "open" fuel cycle and a properly balanced number of fast reactors burning actinides separated from the spent fuel of the thermal reactors. The fast reactors, fuel reprocessing and fabrication facilities should be placed together in safe nuclear "parks".

Innovative concepts of nuclear reactors

The nuclear power may become a sustainable energy source for many decades if it manages to resolve the problems which plague it today. As compared with other energy technologies, it possesses important distinctions which allow it to meet a big part of the growing energy needs and help stabilize and even reduce the consumption of fossil fuels:

– The nuclear fuel has potentially non-exhaustible resources and millions of times greater energy concentration, which allows significantly reducing the quantities and costs of energy resource shipments.
– The nuclear wastes are not so big in quantity and can be safely isolated whilst the most hazardous waste can be "burnt" in nuclear reactors.

The global electricity demand in the next 50–100 years can be met using the fourth-generation reactor facilities that will be free of the shortcomings of their predecessors and will have unlimited resources that they themselves will produce [4]. Reactor systems of this type do not exist yet but their development has been initiated not so long ago in the framework of the international programmes Generation IV and INPRO. Russia is an active participant in these programmes. Six reactor concepts capable of meeting the new requirements have been chosen by now. One or two of them will be recommended for deployment though the final selection is not expected to be made before 2025, when the relevant studies are to be completed (Table 1).

Table 1. Generation IV systems

	Neutron spectrum	*Fuel cycle*	*Power*	*Applications*
Very high-temperature reactor (VHTR)	Thermal	Open	Medium	Production of electricity, hydrogen, process heat
Supercritical water reactor (SCWR)	Thermal, fast	Open, closed	Large	Production of electricity
Gas-cooled fast reactor (GFR)	Fast	Closed	Medium to large	Production of electricity and hydrogen; burning of long-lived isotopes (actinides)
Lead-cooled fast reactor (LFR)	Fast	Closed	Small to large	Production of electricity and hydrogen; burning of long-lived isotopes (actinides)
Sodium-cooled fast reactor (SFR)	Fast	Closed	Medium to large	Production of electricity; burning of long-lived isotopes (actinides)
Molten salt reactor (MSR)	Thermal	Closed	Large	Production of electricity and hydrogen; burning of long-lived isotopes (actinides)

A Technology Roadmap for Generation IV Nuclear Energy System. DOE, USA, 2002

Today, the future of nuclear power is largely associated with fast reactors and closed fuel cycle. This implies reprocessing of spent fuel and utilization of plutonium produced in power reactors. Hence, energy potential of the fuel resources of nuclear power could be increased by approximately 100 times. Importantly, owing to their unique neutronics, fast reactors can burn the most long-lived nuclear wastes difficult to dispose of. Because of this, fast reactors have been chosen as a baseline in the Strategy of Nuclear Power Development in

Russia in the First Half of the twenty-first century and selected as a promising energy technology in the international programme Generation IV undertaken by the leading nuclear countries.

Thus, nuclear technology may have the following stages in its development in the twenty-first century:

- Near-term (the next 10–20 years):
  - Evolutionary development of reactor and fuel cycle technologies (LWR, aqueous reprocessing); development and trial operation of advanced and innovative reactor and fuel cycle technologies (fast reactors, HTGR, small reactors, dry reprocessing)
- Middle-term (30–40 years):
  - Fast growth of nuclear power (four to fivefold); demonstration and introduction of innovative technologies; high-temperature reactors; small reactor facilities; use of nuclear reactors for hydrogen production and water desalination
- Long-term (50–100 years):
  - Large-scale deployment of the innovative technologies of naturally safe fast reactors and fuel cycle; fuel breeding; closed U-Pu and Th-U cycles; utilization of valuable isotopes and burning of hazardous nuclides; long-term geological isolation of radioactive waste

Innovative developments at NIKIET

NIKIET has performed substantial studies and has been developing a number of innovative systems, such as naturally safe fast reactors with heavy liquid metal coolant (BREST); simplified vessel-type boiling reactor with natural circulation of coolant (VK-300); advanced pressure-tube reactor with inherent safety features (MKER); transportable nuclear power plants for heat and electricity supply in the far-away and difficult-of-access regions (Uniterm); multi-purpose reactors of small power (RUTA, RUTA-IT [5–7]. Some of them that may be of interest to the conference participants are briefly described below.

BREST nuclear energy technology

BREST-1200 reactor (1,200 MWe) (Figure 1) may become a pivotal innovative facility for the large-scale deployment of nuclear power. The natural safety of BREST reactors is provided by:

- High-boiling radiation-resistant low-activated lead coolant which does not react with water and air and hence affords low-pressure heat removal while excluding the possibility of fire, chemical and thermal explosions in the event of circuit failure, steam generator leakages and any temperature surges in the coolant.
- High-density highly heat-conductive mononitride fuel operating at low temperatures ($T_{max} < 1,150$ K, with $T_{melt} = 3,100$ K), which limits the

radiation swelling (~1% per 1% burnup) and fission gas release under the cladding.

- Core and lead reflector design, the composition and geometry of which affords fuel breeding (CBR ≈ 1), provides small and negative power, temperature and void effects of reactivity, and small reactivity inventory in the core ($\Delta k/k < \beta_{eff}$) which rules out uncontrollable prompt criticality excursion in the event of inadvertent withdrawal of all control rods in any reactor condition.

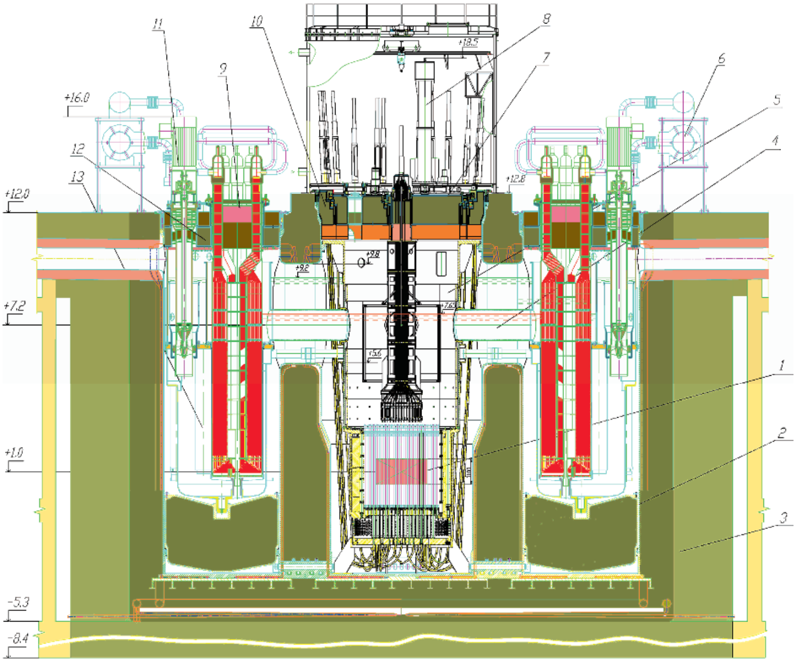


Figure 1. BREST-1200: 1 – steam generator, 2 – heat insulation, 3 – pressure plenum, 4 – refuelling mechanism, 5 – rotary plugs, 6 – upper plate, 7 – gas plenum, 8 – circulation pump,9 – concrete vault wall, 10 – support grid, 11 – core

The implementation of the above principles allows abandoning some engineered safety features to make this reactor facility significantly cheaper than other fast reactors developed today. The comparative analysis has shown that the construction and operating costs of BREST reactors will not exceed those of the LWR plants.

Vessel-type boiling reactor with natural circulation of coolant (VK-300)

VK-300 has been designed based on the well-proven Russian technologies, considering the industrial capabilities for the manufacture and supply of reactor equipment and components, and with the intent of keeping the R&D at a minimum. A nuclear power plant with VK-300 is intended for combined generation of electricity and heat (Figure 2). The turbine unit operating in a single circuit with the reactor has been technologically optimized to suit district heating requirements. VK-300 is a vessel-type integral boiling facility: steam separators of cyclone type are placed inside the reactor vessel. Many plant components (turbine, heat exchanging equipment, pumps) also have operating prototypes. At the same time, VK-300 has a number of innovative features.

In all conditions, the core cooling is provided by the natural circulation of coolant. The unique system of coolant circulation and multi-stage separation allows enhancing natural circulation, owing to the lower hydraulic resistance in the circuit due to the small mass flow rate via the cyclone separators provided by preliminarily extraction of moisture from the flow (upstream of the separators) and its delivery back to the downcomer at the core inlet.

Operating experience of nuclear sources with single-circuit heat transport systems:

- Prototype VK-50 for heat and electricity generation
- Bilibino nuclear co-generation plant

Heat supply at RBMK plants

The existing operating experience of the nuclear plants proves that the boiling reactor VK-300 can provide safe and dependable district heating.

Characteristic	Value
Installed capacity: • In condensation mode, MWe • In a heat supply mode: – Electricity, MWe – Heat, Gcal/h	 250 150 400
Reactor power, MWth	750
Capacity of the heat supply system, Gcal/h	400
Configuration	Single-circuit
Turbine type	T-150/250-6, 6/50

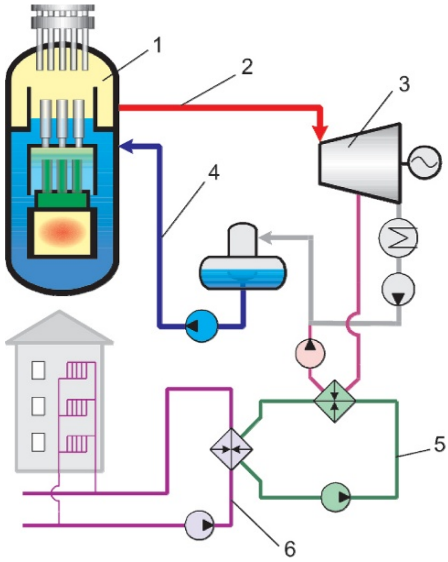


Figure 2. VK-300 plant: 1 – VK-300 reactor, 2 – steam supply to turbine, 3 – turbine set, 4 – feedwater delivery to reactor, 5 – heat supply unit, 6 – heat load

The high safety level of the plant is provided by a system of engineering and administrative measures, including consistent implementation of the defence-in-depth concept; mature inherent safety features; design philosophy of the safety systems based on the principles of redundancy; separation and segregation; single failure; diversity.

In normal operation, public exposure at a distance of 5 km away from the plant will amount to 100th parts of the health limits. The basic design of a co-generation nuclear plant with VK-300 reactor includes a rationale proving that the plant buffer zone may be limited to the site area and the emergency planning area may be restricted to 3 km. Emergency planning area for public evacuation is not required at all. Hence, the safety features of the reactor and the plant allow siting VK-300 facilities near residential areas and in the vicinity of water sources.

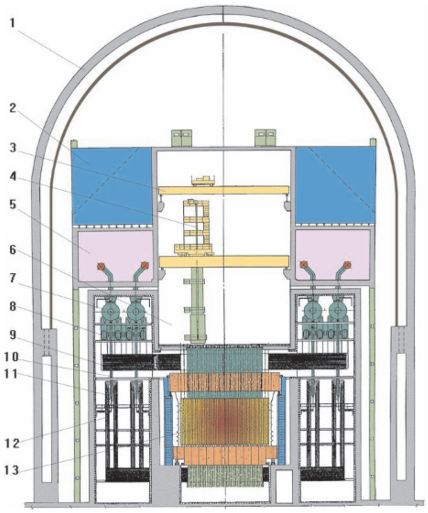
Pressure-tube power reactors (MKER)

MKER facilities have been developed to continue, evolutionary, the line of large-power water-cooled graphite-moderated reactors (RBMK). Much attention has been given to the latest national and international safety requirements, including IAEA safety criteria and recommendations for innovative reactor facilities. The key requirement governing MKER development is safe and cost-effective performance of the plant.

It was assumed in the development that the new plants with pressure-tube MKER reactors would replace the RBMK-1000 NPPs on the end of their service. MKER plants are being developed as monoblock facilities intended for safe and cost effective production of electricity, heat and isotopes. A team of NIKIET (Moscow), VNIPIET (St. Petersburg), Kurchatov Institute (Moscow) and Moscow AEP engineers designed units for the Leningrad NPP whose personnel also made a great contribution to this effort.

The design work on MKER facilities was started in 1989 when a technical proposal was issued for developing a pressure-tube water-graphite boiling reactor of enhanced safety (MKET-800). The developments completed so far include a sketch design of an 860 MWe plant with MKER-800; a basic design of a 1,000 MWe plant with MKER-1000, and a technical proposal for MKER-1500 reactor facility with the electrical power 1,500 MWe.

Physically, MKER-800 and MKER-1000 are similar (see Figure 3).



1 - containment;
2 – tank of passive cooling system;
3 – overhead crane;
4 – refuelling machine;
5 – steam line box;
6 – reactor hall;
7 – steam drum separator;
8 –cladding leak detection box;
9 – steam-water lines;
10 – pressure pipeline;
11 – distribution header;
12 – water line;
13 – core

Figure 3. MKER-1000 (800). Cross-sectional view

MKER plant is a single reactor-turbine unit (monoblock). Deaerators are designed to operate under 1.2 MPa. The feedwater pumps combined through a common pressure header deliver the feedwater to the outlet nozzles of the injector pumps via feedwater controllers. Each circulation loop of the reactor circuit has its own feedwater control valve.

Refuelling and isotope retrieval can be done both off-load and on-load, without load shedding. These operations are performed by a refuelling machine which is a part of the retrieval system. The biological shielding of the reactor has been designed so that the equivalent dose rate in the reactor (central) hall would not exceed 29 μSv/h (2.9 mrem/h) during on-load operation, owing to which this area may be attended by personnel.

The studies have demonstrated that because of the plant performance characteristics, the thermal power of 3,000 MWth is the maximum level for which it is reasonable to provide natural circulation of coolant with jet water-water pump enhancement. Therefore, forced circulation provided by circulation pumps has been chosen for the core cooling in MKER-1500 which has bigger power.

Nuclear plants for heat and electricity supply in far-away and difficult-of-access regions (uniterm)

The area of de-centralized power supply in Russia extends to the two thirds of the country's territory. There are many isolated energy loads there, each up to 3–5 MWe. In total, this means more than 6,000 diesel plants with the overall installed capacity over 3,000 MWe and high specific consumption of fuel (500–600 g of fuel/kWh). Power supply in such regions can be provided by small-power nuclear plants which can operate throughout the entire period of the reactor facility service life without refuelling, are environmentally clean and proliferation-resistant. A small-power nuclear plant Uniterm developed by NIKIET is such a facility.

The thermal hydraulic system of the plant includes three interconnected hydraulic circuits, the last of which houses all heating loads (turbogenerator set, district heating or process steam boilers).

Uniterm has been designed to incorporate as much as possible the well-proven engineering solutions used, in particular, in integral reactors designed by NIKIET (Figure 4). All primary circuit components (the core, intermediate heat exchangers, pressurizer, reactivity control and shutdown rods) are integrated in one vessel. Due to this, the plant does not have any non-isolated primary pipework; ionizing sources and potentially dangerous working fluid, i.e. primary coolant, are confined within a very limited space (compact arrangement). The reactor system design ensures core cooling and heat transport due to the natural convection of the primary coolant.

The reactor facility has no active elements with continuously moving mechanical parts, such as circulation pumps and various valves, and control elements do not move in the course of reactor operation. During on-load operation, all changes take place owing to the natural processes. The safety systems are passive, i.e. they do not require external power supply to perform their functions. In scram conditions, the reactivity compensation elements fall into the core by gravity and due to compressed spring energy. An independent heat removal system, operating all the time, removes the decay heat and cools the reactor. The plant safety relies on the intrinsic features of the core and reactor facility, on small heat release in the core and five barriers in the way of radioactivity propagation (fuel matrix; fuel cladding; pressure boundary; safeguard vessel; containment).

The most attractive features of the plant include:

- Load-following operation irrespective of external conditions, such as short-circuits in a transmission line, disconnection of heat and electricity consumers
- No refuelling during 25 years of plant operation
- No need for spent fuel storage facility
- Air cooling of safety systems and turbine condensers

On the end of its design lifetime, after appropriate cooling, the reactor system is completely removed from the site and delivered to a dedicated plant to be dismantled and disposed of.

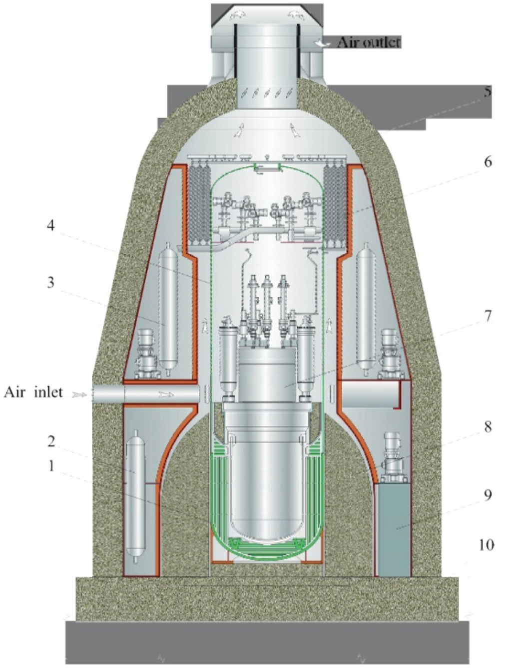


Figure 4. Uniterm: 1 – iron-water shielding tank, 2 – gaseous waste storage tanks, 3 – liquid poison supply system, 4 – containment, 5 – shock-proof shell, 6 – heat exchanger of the cooling system, 7 – steam generating unit, 8 – biological shielding blocks, 9 – liquid and solid radioactive waste storage facility, 10 – foundation

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DEVELOPMENT OF DEVICES FOR HANDLING WITH BN-350 RADIOACTIVE WASTE

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Introduction

Decommissioning of a nuclear facility is a major industrial undertaking that can take many years, depending on the approach strategy. The BN-350 reactor facility (BN-350 RF) with the fast neutron reactor with liquid metal coolant had been in operation since 1973 through 1999 as part of the production complex of the Mangyshlak atomic energy complex. The Reactor facility was designed for supplying steam for turbogenerators and sea water desalinization. The designed thermal power of the reactor is 1,000 MW.

The BN-350 reactor facility includes BN-350 reactor, special water treatment complex, storage facilities for liquid and solid radioactive waste, fresh nuclear fuel storage facilities.

On April 22, 1999 the Government of the Republic of Kazakhstan adopted the Decree No. 456 on Decommissioning of BN-350 Reactor Facility. This Decree defined the concept, which provides for conducting the BN-350 decommissioning in three main stages:

1st stage – Placement of BN-350 RF to the state of long-term safe storage (SAFSTOR state)

Criteria of the stage completion: Removal of spent nuclear fuel from the site (I priority); drainage and processing of radioactive sodium (II priority); Processing and placement for long-term storage of all the radioactive wastes (Liquid RW – III priority, Solid RW – IV priority); preparation of buildings, structures and equipment for long-term storage, organization of monitoring (V priority).

S.A. Apikyan and D.J. Diamond (eds.), *Nuclear Power and Energy Security*,

Stage completion criteria:

- Nuclear fuel has been discharged from the BN-350 RF and placed for long-term storage.
- Liquid metal thermal carrier has been removed from the RF, processed, the radioactive processing wastes placed for the long-term storage.
- Radioactive wastes (RAW) have been processed and placed for the long-term storage.
- The radiation monitoring of BN-350 RF, of sanitary protection zone and surveillance zone has been provided.
- The composition of systems and equipment intended for further operation, the systems and equipment to be dismantled and laid up have been determined.
- The dismantling and laid up works have been performed.

2nd stage – Long-term safe storage during 50-years

Stage completion criteria:

- Fifty-years term of storage expired
- The decision on commencement of dismantling and wastes burial project adopted

3rd stage – Partial or complete dismantling of the equipment, of buildings, structures and burial of wastes

Stage completion criteria:

- The partial or complete dismantling of equipment, buildings and structures performed
- Complete radioactive decontamination and rehabilitation of the territory accomplished
- RAW placed for long-term storage or buried

D&D activity

At present BN-350 facility is prepared to be placed into SAFSTOR in accordance with Plan of Priority Measures (PPM). PPM consists of five main directions which include the following activities [1–2]:

- Placement of spent fuel of BN-350 reactor for long-term storage
- Handling of liquid metal coolant of BN-350 reactor facility
- Handling of liquid radioactive wastes of BN-350 reactor facility
- Handling of solid radioactive wastes of BN-350 reactor facility
- Preparation of buildings, structures and engineering systems of BN-350 for long-term safe storage

The following activities shall be carried out in order to place BN-350 reactor facility into SAFSTOR:

- Removal of spent nuclear fuel from the BN-350 site
- Processing of radioactive sodium into sodium hydroxide and geocement stone
- Processing and conditioning of liquid radioactive wastes
- Processing and conditioning of solid radioactive wastes
- Decontamination of equipment and pipelines of primary circuit
- Decontamination of another contaminated equipment and pipelines
- Preparation of buildings, structures and engineering systems of BN-350 reactor facility for long-term safe storage
- Dismantling of some equipment
- Long-term safe storage
- Final dismantling of reactor facility

According the PPM the responsible organization for the BN-350 RP decommissioning is NAC “Kazatomprom”. The main organizations of the Republic of Kazakhstan involved in the implementation activity: MAEK “Kazatomprom”, KATEP, NTSC and IAE NNC RK. The main organizations of the Russian Federation involved in the implementation activity – “VNIPIET”, MosNPO “Radon”, and JSC “METR”.

Spent fuel management is realized by “KATEP” from Kazakhstan, radioactive sodium projects are realized by NTSC (Nuclear Technology Safety Center), Kazakhstan, and the leading company of the LRW, SRW management and BN-350 decommissioning of V stage Projects is JSC “METR” (Management. Engineering. Technologies. Research) that is the leader of the Russian institutions Consortium – stakeholders of the BN-350 decommissioning activity. The main design organization for spent fuel and radioactive sodium handling projects is Institute of Atomic Energy of National Nuclear Center RK.

Sodium coolant handling project status [3–5]

- Primary circuit coolant was cleaned of cesium nuclides using cesium traps.
- Equipment for drilling of the reactor vessel pressure manifold was fabricated and mounted. Drilling was performed at the depth 13.4 m in sodium with the temperature 280–300º.
- Designing activity for coolant draining from the BN-350 reactor vessel was done.
- Sodium had been drained from primary and secondary circuits of the reactor.
- Measures for safe sodium storage before its processing had been implemented.
- Project for placement of secondary circuit sodium into 100-l drums and their transportation for recycling was implemented.
- Project for sodium residual removal by steam nitrogen technique and bicarbonization is in progress now.

The technique was selected for sodium dissolution while injecting its melt into alkaline solution of sodium hydroxide by using sodium processing facility (SPF).

The construction of SPF building and SPF start-up activity with secondary circuit sodium was done in the end of 2008.

In a framework of the project realization 610 m^3 of sodium and 20 m^3 of NaK alloy will be processed into 35% caustic (estimated volume H2,200 m^3), for the following processing into geocement stone.

The geocement stone facility (GSF) is planned to be built in future. Realization of GSF project will allow to process ~2,200 m^3 of 35% caustic solution into geocement (H22,000 pcs. of 200-l containers with geocement) – the product which meets Kazakhstan regulations for long term storage and the following final disposal of radioactive waste.

Liquid and solid radioactive waste handling

Since 1972, during the BN-350 reactor plant operation history, the considerable amount of liquid and solid nuclear waste were produced. Total collected liquid waste is 3,320 m^3. Liquid waste activity (free of "pure" beta- and alpha-emitting nuclides activity) – 2.66×10^{14} Bq. Total solid waste collected – 6,620 t. Solid waste activity (free of "pure" beta- and alpha-emitting nuclides activity) are estimate as 5.45×10^{14} Bq. A complex of facilities for processing of the BN-350 liquid and solid waste has been proposed:

- Facility for RLW ion-selective decontamination
- Facility for cementation
- Facility for pressing of solid waste in metal casks
- Depository for interim and long-term storage of casks and containers

RLW Management Plan includes reprocessing by means of additional evaporation and residue drainage in the RLW storage, and final treatment of condensate in the ion-exchange facilities.

The chart of Liquid RW handling is represented in Figure 1.

The following facilities will be used for processing of liquid and solid radioactive wastes generated during operation of BN-350:

- Ion selective sorption facility for LRW
- Cementation facility
- Compacting facility for SRW compaction in metal drums
- Incineration facility for solid and liquid radioactive waste
- Storage facility for interim and long-term storage of drums and containers

LRW handling strategy consists of following parts:

- Processing by evaporation with precipitation draining into LRW storage and condensate cleaning at ion-exchange facilities
- Two-stages cleaning of LRW decantates from nuclides
- Ozonation and filtration of decantate to remove slag with the following infiltrate immobilization in the cement matrix in NZK containers

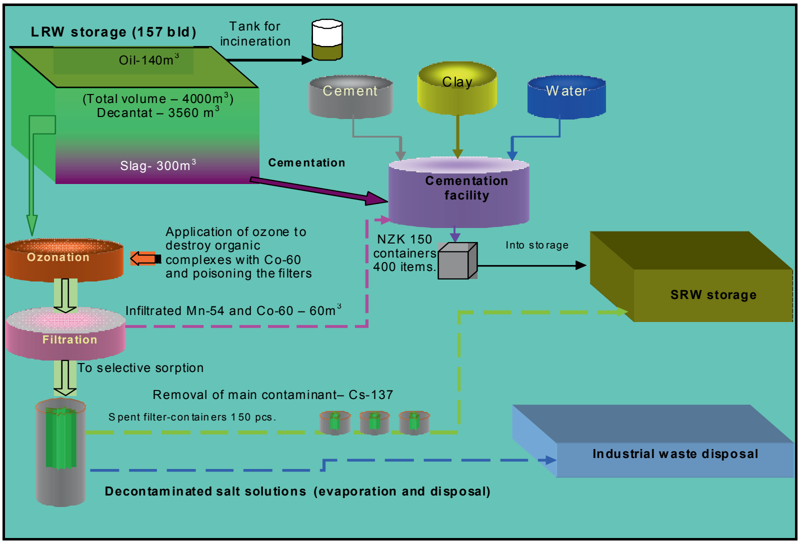

Figure 1. Liquid RW handling chart

- Selective sorption of main Cs-137 nuclide with the following removal of filter-containers as a high-level waste
- Removal of slag and it following solidification by cementation
- Placement of cement compound into NZK containers
- Transportation by special transport and NZK placement in special SRW storage facility (building 158A at the BN-350 site)

The chart of solid RW handling are represented in Figure 2.

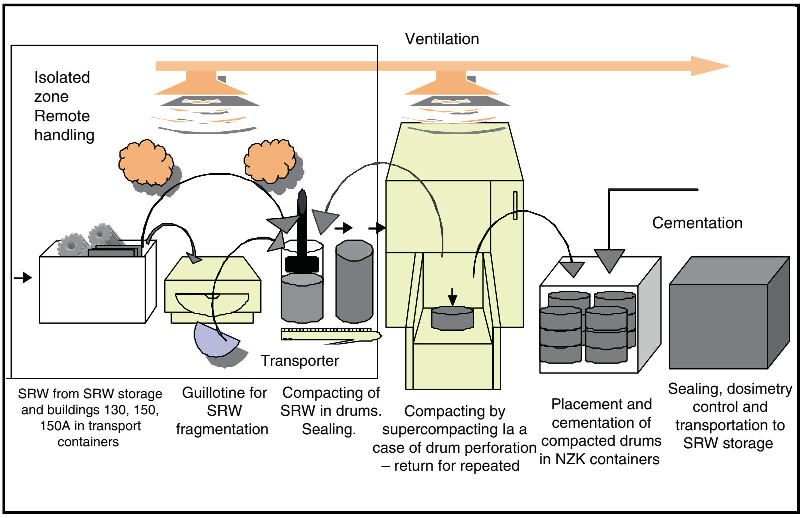

Figure 2. Solid RW handling chart

Status of RLW/RSW management projects

- The RLW RC Project has been developed and undergone expertise, working documentation is under development.
- Volume, composition and activity level of the radioactive waste produced in the course of the BN-350 RP operation have been analyzed.
- The RSW RC Project has been developed and is at the completion stage of endorsement and expertise.
- Volume, composition and activity level of the radioactive waste produced in the course of the BN-350 RF operation have been analyzed.
- Material balance of the reprocessed radioactive waste according to the volume, type, activity level, processing method has been made up.
- The technique for RW handling in the fast breeder reactor decommissioning has been developed. The complex of processing techniques and RW conditioning proposed has been included in the RLW, RSW and storage RC Projects for safe long-term storage (50 years) of solid and hardened RW.

Completed activities of stage V

- Engineering inspection of the buildings, systems, equipment and external communications of the BN-350 reactor plant has been performed.
- The technological systems of the RF buildings 130, 150, 150ℵ, 157 have been examined for radiation.
- Radiation inspection of the external communications of the BN-350 reactor plant.
- Data acquisition/classification, preparation of summary tables on the BN-350 systems, and determination of isotopic composition of radionuclides localized on the internal and external surfaces of the BN-350 systems, measuring of total removed activity of ®-emitting nuclides have been completed.
- The Project on preparation of buildings, constructions and equipment for safe long-term storage has been developed.

Other projects

- The sanitary protection area and radiation control area Project has been justified and developed.
- The Projects not included in Stages I–IV are under development:
    - Management of highly active RW
    - Management of organic RLW

Funding for D&D activity

Funding are collected from different sources: funding from the Republic of Kazakhstan, international support (USA, United Kingdom, TACIS).

The work within the spent fuel and sodium coolant management Project is carried out under the sponsorship and technical support of the USA. Some parts of the liquid-metal coolant handling, cesium traps management, examination of the hot cells repository projects are funded by the United Kingdom trough ISTC Projects. The basic scope of work including RLW/RSW management is funded by the Republic of Kazakhstan.

Complexity and multi-aspect of the activity scheduled and their international nature require the creation of modern project management schemes.

Conclusion

The package of activity performed proves the correctness of the concept accepted by the Government of the Republic of Kazakhstan on the BN-350 decommissioning (three successive steps above) targeted at minimization of cost, exposure and amount of radioactive waste.

Decommissioning of the high power fast breeder reactor plant is carried out for the first time and therefore the normative documents and design decisions elaborated, accepted technologies and estimation of capital expenditure and maintenance costs may enrich the database and serve as orientation for decommissioning of similar units.

According to the concept accepted the BN-350 decommissioning is the process of top level of complexity that is characterized with the requirement of concurrent execution of a large scope of work by means of international teams from Kazakhstan, Russia, USA, EC, etc. Such approach needs the creation of modern effective organization schemes of interfaces and management of the Projects and will be further used in other complicated Projects.

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INSTITUTIONAL SUPPORT TO THE NUCLEAR POWER BASED ON TRANSPORTABLE INSTALLATIONS

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Abstract Existing nuclear power uses large-power nuclear plants (more than 1,000 MWe) and enriched uranium fuel (^{235}U). Each plant is treated as an exclusive costly project. As a result, large NPPs are operated predominantly in highly developed big countries. In many countries, construction of large power units is not reasonable because of the economic conditions and national specifics. This calls for the use of small- and medium-power nuclear plants (SMPNP), especially transportable nuclear installations (TNI). TNI feature small power (up to 100 MWe); serial production, and transportability. Small- and medium-power nuclear plants could serve to produce electricity and heat; perform water desalination; provide temporary and emergency energy supply. The authors discuss some findings of the studies carried out on the various aspects of the TNI life, as well as the legal and institutional support to their development, construction and operation. The studies have been performed in the framework of the INPRO Action Plan.

Keywords: nuclear power, innovative nuclear energy system, reactor design, small power plants, GNEP, INPRO, non-proliferation of nuclear weapons, safety, waste, transportable nuclear facilities, institutional support to the nuclear power, NPP life

Introduction

The world's nuclear power has been developing in the last 50 years based on large-power plants (more than 1,000 MWe) using enriched uranium fuel (^{235}U). Today, there are more than 400 nuclear units in operation across the world. Each plant is treated as an exclusive and very costly project. Because of this, large NPPs are used predominantly in big countries with well-developed technologies. Thus, in France nuclear accounts for 77% of the electricity generation, in Japan – for 28%, in the USA – for 20%.

At present, BRIC countries (Brazil, Russia, India, China) have clearly defined plans for a large deployment of nuclear sources in the twenty-first century. Many developing nations have been showing great interest in the services provided by the nuclear power. More than 50 countries have stated their intention to join the civil nuclear club. However, the economic conditions and specifics of many countries make construction of large power units there unreasonable. Together with the level of their economic development, this suggests application of small- and medium-power plants (SMPNP), especially transportable nuclear installations (TNI).

TNI may come as large-block plants with pre-fabricated components delivered to the operation site and assembled there, or as mobile facilities operated directly on transport platforms (wheel-, crawler- or track-mounted, or floating) in a point-to-point position. The terms "transportable" and "mobile" are taken from the terminology of the 1950s–1970s, when the facilities of this kind were constructed and operated in Russia and in the United States.

The specific features of transportable nuclear installations include small power (up to 100 MWe); serial production; transportability.

At present, there exist objective trends pointing to a growing interest in the plants with small and medium power (SMPNP):

- Nuclear vendors have suggested more than 50 designs of small (up to 150 MWe) and medium (up to 700 MWe) facilities.
- The international programme "Global Nuclear Energy Partnership" (GNEP) has declared the intention to supply small- and medium-power plants in the framework of international cooperation.
- Russia has started construction of the world's first 70 MWe floating nuclear plant "Michail Lomonosov" with ice-breaker reactors.

Small- and medium-power nuclear plants could:

- Produce electricity, heat and fresh (desalinated) water for local markets
- Deliver emergency energy supply granted to a country or a region by the world community (UN) in certain circumstances and on certain conditions
- Provide temporary energy supply (within a limited period of time) for power-consuming industrial projects and activities

On the other hand, there is considerable expertise in the construction and operation of small nuclear facilities, since some countries have been building and running naval and marine nuclear power installations in parallel with the construction of large nuclear units. Hundreds of small facilities were built primarily in the USA and Russia. An important distinction of the shipboard nuclear facilities is serial production. In addition, Russia has been successfully operating for a long time the world's sole small-power nuclear plant – Bilibino at Chukotka. Taken together, this experience and the advancement of reactor technologies could make a good foundation for supplying serial small- and medium-power nuclear plants to various users.

The authors present some findings of the studies on the various aspects of the TNI life, as well as the legal and institutional support to their development, construction and operation. The studies have been performed by a team of Russian nuclear experts lead by Academician E.P. Velikhov (Russian Research Center "Kurchatov Institute") in the framework of the IAEA INPRO Action Plan.

Potential interface in the course of TNI development, construction and operation

Potential interface between the key actors in TNI development, construction and operation is shown in Figure 1. The system incorporates Vendor, Client, Third Party and IAEA.

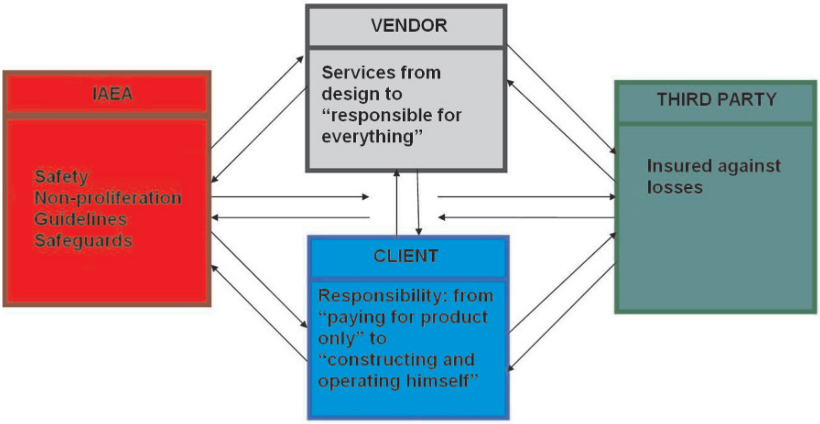

Figure 1. Interface during TNI development, construction and operation

Vendor produces a TNI project and offers it to Client. The offer may range from simply selling a TNI to a Client to the case when Vendor takes all responsibility for the entire TNI life, site selection and preparation for TNI operation at the Client's, and for all legal and institutional aspects.

Client expresses intention to use nuclear services, takes necessary technical, infrastructure, legal, social and political steps at the national level within the limits of its sovereignty and jurisdiction; gets go-ahead from IAEA; contacts Vendor of the services sought (TNI); makes decision concerning the extent of its own involvement in the implementation of the nuclear project offered by the Vendor (ownership, operation, safety, and, finally, responsibility/liability; pays for the services and uses the energy produced at TNI. The distribution of responsibility/ liability between Vendor and Client is also a matter for investigation.

Third Party is provided with the international safeguards with regard to the indemnity associated with TNI operation.

IAEA, as a UN entity, develops relevant guidelines and maintains the safe-guards system to ensure efficient and safe operation of TNI.

Interface of the key actors in TNI development and construction

There may be various ways of the TNI Client–Vendor interface. In this study, the authors have looked into the extreme case when Vendor is responsible for everything, and investigated the TNI life in these conditions (Figure 2). In this option, Vendor bears responsibility for all life stages of the TNI itself, its fuel cycle, selection and preparation of the Client's site. The only thing for the Client to do in this case is to state its intention to acquire nuclear services (products); fulfil necessary minimum initial prescriptions; join the IAEA safeguards system, and pay for the product supplied. The portion of Client's responsibility/liability for safety, non-proliferation, etc. is defined by national regulations complying with the relevant agreements with Vendor, IAEA and other stakeholders.

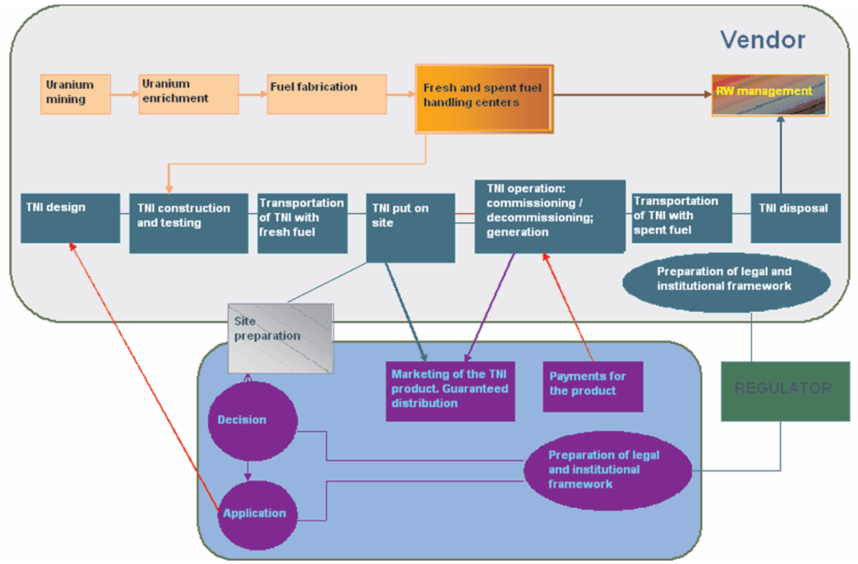

Figure 2. TNI life ("Vendor responsible for everything")

The TNI life may differ from that of traditional stationary nuclear plants by having no fuel handling at operation site; featuring possibility to shut TNI down and take it away from the Client's site to a storage place, or transfer it to a new site and re-start as necessary.

Infrastructure required for TNI

Even with maximum Vendor responsibility, the important task for the Client is to prepare a system of requirements concerning the legal, administrative, infrastructure, social and political support to ensure efficient and safe acquisition of the nuclear services provided by TNI. The most important aspects include:

- Rules for announcing and rendering civil nuclear services
- Economical schemes/mechanisms of life implementation
- Licensing
- Certification
- List of considered hazards and physical protection
- Emergency plan
- Civil liability for nuclear risks
- Monitoring, accounting and control of nuclear materials

At present, the legal and institutional support to the world's nuclear power is tailored to stationary nuclear plants of large power. In our case, the distribution of responsibility/liability between Vendor, Client, IAEA and third countries is important.

The analysis has shown that the following issues should be properly addressed to enable TNI deployment:

- Establish international requirements concerning the TNI Vendors and Clients
- Ensure TNI safety and security
- Ensure sustainable fuel supply
- TNI transportation and international law of the sea
- Protect interests of the countries not involved in the TNI system as Vendor or Client (third parties)
- Define the IAEA role in the development, construction and operation of the TNI system

Steady demand for TNI may open the door to the market to unscrupulous players who may jeopardize the safety of the nuclear sources and compromise non-proliferation. Therefore, new rules will have to be established to put additional barriers to prevent unscrupulous Vendors from entering the market.

Role of safeguards during TNI development and construction

It will not be an exaggeration to say that all regulatory and institutional support to the nuclear power is meant to ensure its safety. Generally, safety is one of the principal factors influencing further development of nuclear power and requiring multi-facet approaches and analysis for its provision. For TNI, safety will be one of the key factors defining their optimum configuration. Figure 3 illustrates the interconnection between safety and the main aspects of the institutional support to TNI. In our opinion, basically, it will be necessary to demonstrate convincingly that the design safety level of TNI will be higher than that of the stationary NPPs.

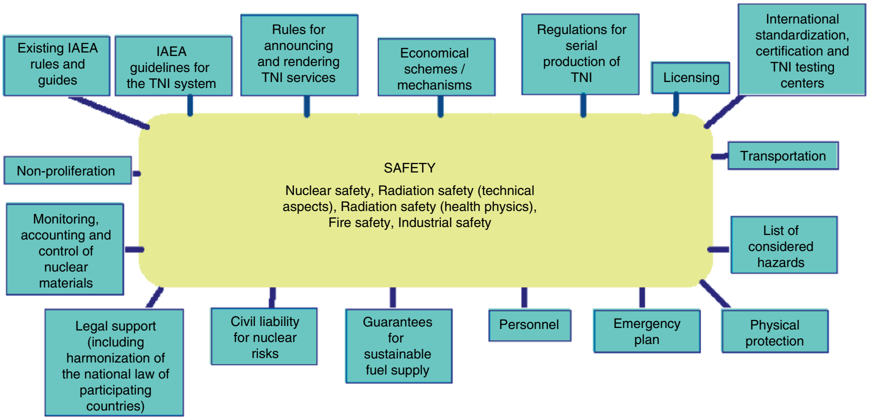

Figure 3. Interconnection between TNI safety and institutional support

Guaranteed fuel supply will be important for TNI. International nuclear fuel centers could take care of this. It is highly desirable to have no refuel lings at the TNI operation sites, including the final retrieval of the spent fuel during TNI decommissioning on the end of its life.

One of the efficient and safe ways of TNI deployment could be creation of an international nuclear power corporation capable of performing the role of the Vendor of the nuclear services provided by TNI and an integrator of large nuclear projects with maximum responsibility for the entire TNI life and legal and institutional support to the creation and operation of the TNI system.

Finally, it should be pointed out that successful deployment of TNI is dependent on other important conditions not discussed in this paper: governmental support, interest of the business sector, provision of infrastructure, improvement of the regulatory framework, public relations.

INTERNATIONAL COOPERATION AND SECURITY IN THE FIELD OF NUCLEAR ENERGY IN ARMENIA

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Abstract In the report presented/discussed are the ecological-humanitarian disasters and the related policy of the international organizations, especially IAEA, NATO and others on ensuring security of vital activity of people in the sphere of energy and particularly nuclear energy. Possessing the only nuclear power station in Trans Caucasus and the store of toxic wastes of reactive fuel the Government of Armenia and the Ministry of Emergency Situations of the Republic of Armenia always take into consideration the many-sided aspects of prevention, warning about accident in energy buildings including nuclear accidents and modern response in case of occurring the latter ensuring security for ANPP personnel and the inhabitants of the settlements of the possible contingency zone. In their daily activity the workers of the Emergency Situations of the Republic of Armenia, especially those of the Armenian Rescue Service base on the experience and logistic support of international community some aspects of which are presented below.

Keywords: International cooperation, nuclear, energy, radiological security, Armenia, emergency situations, exercises, modeling, NATO, public diplomacy

Introduction

Radiological energy and power security being held by the NATO Public Diplomacy Division in the framework of advanced academic conferences ARW has a global importance in terms of space and time and includes not only all the fields of human activity but also its destiny. Atom bombs thrown on Hiroshima and Nagasaki, 715 nuclear experimentations/tests from 1954 to 1990, 559 of which for war purposes only in USSR (456 in Simipalatinske, 130 in Novaya Zemlya) (Strelets 2004), accidents in nuclear power plants (NPP) of Chernobyl, former USSR, Seinfeld, Dounri in United Kingdom (Figure 4), in radiochemical enterprises such as Chelyabinsk-65, "Mayak", Tomsk-7, Krasnoyarsk-26; accidents of submarines

Komsomolets and Koursk (Valyaev 2008), Nuclear tests of USA, France, United Kingdom and other nuclear super powers; accidents in nuclear power stations in USA, Great Britain and other countries; unprecedented scales of terrorist acts connected with: historically generated conflicts between countries and nations on territorial issues and other reasons; great migration of particularly poor layers of the population of the world nations which makes changes in the demographic status of the accepting countries; religious factor; natural–manmade catastrophes, and with other factors all over the world urged the whole world to cooperate internationally in the most dangerous and difficult field of science, namely in the sphere of nuclear and energy security. In this process involved are the leaders of super powers, UN and its international organizations, especially IAEA and OSCE; NATO, and other international, governmental, public organizations, as well as thankful work of some individuals with whom the Ministry of Emergency Situations cooperates, for preventing, warning and eliminating the consequences of God Save emergency situations.

Armenia and nuclear energy

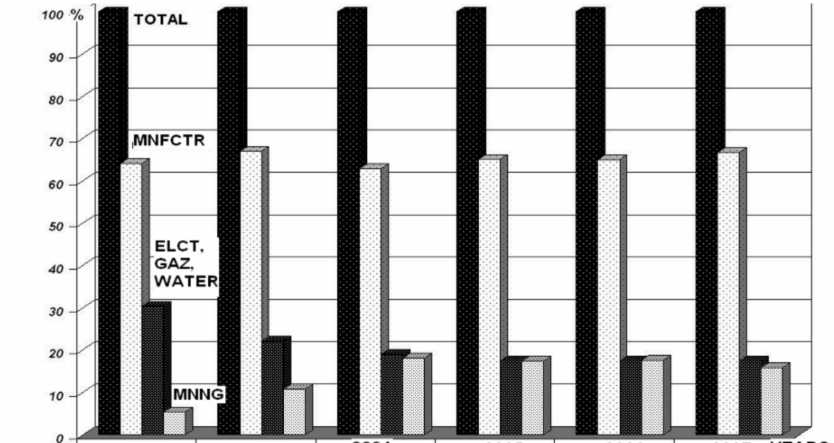
The first block of the Armenian Nuclear Power Plant was exploited in 1976 and the second block – in 1980, and it was closed down in 1989 after the Spitak (7 December 1988) earthquake, though numerous check-ups evidenced that there had been no damage to the station. In 1995 the second block was exploited/operated again because of energy deficiency connected with long interruptions of gas supply across Georgia and Azerbaijan, and the exploitation was realized with the assistance of Russian organizations, and the systematic assessment and improvement of the security of this block were carried out with the assistance of IAEA, European Union and USA and Russian organizations (Technical task New Block, 2 July 2008).

The Energy Security for Armenia is particularly actual and significant because of poverty or the lack of the country in natural resources of fuel. This is in case when energy in the structure of industrial production together with gas and water supply comprises its significant part (Figure 1).

According to the power capacity the first place in energy balance of Armenia with 66.4% takes thermal power plants (in 1999 – 49%) working at the expense of imported gas. The data analysis shows that the thermal power plants in energy balance has decreased in comparison with 2004–2005, in case that the share of hydroelectric plants have increased, and in 2006 and 2007 wind energetic stations started to operate though producing only 0.05% of the total amount of electricity.

Energetic resources – pressure tool, the aim of the struggle for their possession, energy security – capacity to run reasonably energy policy, to face boldly the internal and external political pressures, to find a way out of emerged disastrous situations (Khachatryan et al. 2009). The energy security urged Armenia to restart the operation of the second block of the Armenian nuclear power plant (ANPP) in 1995 the operation of which was suspended after the Spitak earthquake in 1988.

The restart of the operation of the second block allowed increasing the energy security up to 51% at present. In case of closing down the ANPP (according to the decision of OSCE in 2004), the energy security would have decreased to 21% in 2005, 11% – in 2006, and the energy independence – from 20% to 9% respectively.



	2000	2003	2004	2005	2006	2007 YEARS
■ TOTAL	100	100	100	100	100	100
□ MNFCR	64,2	67	62,9	65,1	65	66,7
▣ ELGW	30,4	22,1	19	17,5	17,4	17,4
▨ MNNG	5,4	10,9	18,1	17,4	17,6	15,9

Figure 1. The share of electrical energy, gas and water supply in the industrial production of Armenia for the years 2000–2007

The energy security of Armenia is conditioned not only by the continuous/ uninterrupted and normal functioning of the Armenian nuclear power plant but also by the normal operation of others, namely hydroelectric and thermoelectric power plants and in case of accidents in them, the role of the ANPP increases. So, in 1996 the accident in the spillway of the Reservoir of Argel hydroelectric power plant (HPP) led to the backwater of the River Hrazdan and because of this in the tail water the water with stone-mud slush filled the turbine building of Argelsk hydroelectric power plant. The cleaning, the setting up and recommencement of the operation of the HPP took a lot of efforts and time straining the energy crisis during that hard time for Armenia (Figure 2).

The energy security and the security in general of any country consists in shifting the energy with alternative, local energy resources in which at present Armenia is not rich according to the current research data. That is way nuclear energy for Armenia is the most rational energy resource, especially after the close-down of the second power unit in 2016.

Figure 2. The look of ANPP from the mount Ararat (a photography from the cover page of the book on "Technical Tasks for the New Block", 1st edn, 2 July 2008)

However, the development of nuclear energy has brought increased ecological and humanitarian risks and rise of catastrophes in unprecedented numbers. It should be mentioned that the most expensive catastrophes for last 100 years according to The Virtual Nuclear Tourist are connected with energy buildings or energy and among them the leader is Chernobyl Nuclear Power Plant. Let's present the following list:

1. The explosion of the reactor of the forth power unit of the Chernobyl NPP on 26 April 1986 – US$200 billion.
2. The explosion of space shuttle **Columbia**, on 1 February 2003. Only on the research of the reasons of the catastrophe US$13 billion was spent – the most expensive investigation.
3. The wreck of the tanker **Prestige**. Only the overall cleaning of water cost is US$12 billion.
4. The explosion of space shuttle **Challenger,** 23 January 1986. Francis Scobey, Michel Smith, Ponald McNairy Alison Onuosun. – US$5.5 billion.
5. The explosion at oil platform **Piper Alpha**, in the Northern Sea on 6 July 1988, from 226 people only 167 survived. – US$3.4 billion.
6. The shipwreck of the tanker **Exxon Valdez,** on 24 March 1989 in Alaska, gulf of Prince William. As a consequence there was a huge damage not only to fish population but also to brown bears, reindeers and minks – US$2.5 billion (Figure 3).

7. The crash of the strategic bomber B**-2 (Stels),** on 23 February 2008 in airbase Andersen (Guam) – US$1.4 billion.
8. The collision of the passenger train **Metrolink** with cargo truck, on 12 September 2008, Los Angeles, USA, the biggest since 1993 – US$500 million.
9. The fall of petrol tank truck from the bridge and explosion in Germany, on 265 August 2004 – US$358 million.
10. During the shipwreck of the **legendary** Titanic which was the biggest liner at the time, on its first voyage on 14 April 1912 only 706 people were survived and the cost of it is equivalent to US$150 million.

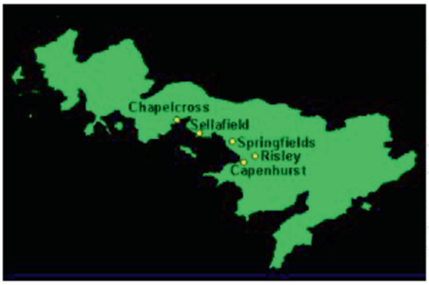
Besides this official statistical data there are numerous accidents the losses of which are difficult to calculate and these losses exceed many of the abovementioned. Some of them we have already cited in the introduction (Valyaev 2008). Let's stop at one example of them to understand the scales of the unaccounted. On 29 September 1957 there was an explosion in the tanks with liquid radioactive wastes in the radiochemical enterprise "Mayak" of Sverdlovski region and it caused radiological infectiousness of 335,000 people in 391 settlements; 9,000 were evacuated. After only 21 years economical activity was recommenced in that (Strelec 2004a).

The biggest ecological–humanitarian catastrophe of Chernobyl

Nuclear energy emerging as an accompanying branch of nuclear weapon was considered to be energy guarantee for any country in the first decades before the cases of the catastrophic accidents taking place one after another all over the world. The result of one the accidents of nuclear –energy sets is presented in Figure 3. Accidental leakages of radio-active nuclides are I-131, Cs-137, Sr-89, Sr-90, Po-210, which exceed the limit norms of acceptable concentration (LAC).

Special attention should be given to "record" explosions on forth reactor of CHNPP (Figure 4). As academic A.I. Vorobev is mentioning [1], "main mistake of all nuclear and not only nuclear accidents is not complete preparedness. The accidents in USSR were not modeling …

After the tragedy in Armenia the necessity of modeling the consequences of severe earthquakes was emphasized (1988). Everything was out of sense". On the roof of burning reactor the fire-fighters were working in boots but not in protecting boots, there was no dosimeters, they were working too long and were having mortal doses, 6–8 Gr. The population of the surrounding area wasn't informed about the accident and about the necessity to take iodine solution (two to three iodine drops for a half-cup water), which brought to the absorption of radioactive iodine by the thyroid gland among women and children, which became the reason for cancer of that organ.



Radionuclide	Estimated Range of Release (Curies)
I-131	16200 - 20000
Cs-137	600 - 1240
Sr-89	80-137
sr-90	6-9
Po-210	~ 240

Reference: M. Eisenbud, *Environmental Radioactivity* (1987)

Figure 3. Map of England and Scotland withy data on radio-active leakages of Sepafield accident in 1987

Figure 4. Forth block of CHNPP

"The Chernobyl accident has caused harm to 7 million people and it will hurt even more people, including those who are not born yet. The means spent on the liquidation of accident consequences can exceed the economical income received from the Nuclear Power Plants of the whole territory of the Soviet Union" [2]. According to Doctor Klas Rosen the Chernobyl accident has touched Sweden and Northern countries. We should mention that the territories of Belarus, Ukraine, Eastern Europe, Western countries of the Soviet Union, Trans-Caucasus were under contamination. That's why atom demands respects to itself, as it touches upon vital interests of millions of people.

Accident in the forth reactor of Chernobyl Nuclear Power Plant showed that in case of such kind of emergency situations there takes place not only contamination of people and biosphere, but also fires, collapses, and in the period of liquidation – burying of radioactive wastes and constructions, dezactivization of the inhabited environment, monitoring of the state of not only radioactive background of biosphere, but many other measures should be undertaken. That is why the structures that are called to fight against the energetic safety and security in general, should be prepared to accidental consequences, know the current events and news, to accept international experience, taking into consideration the national interests, to carry out the requests of competent international organization in the mentioned spheres. The main goal and activities of the MES RA is directed to the fight against emergency situations, including extreme situations at energy objects.

Armenian Nuclear Power Plant and toxic wastes of atomic reactors found their place on the map of "Environment and Security" published by the UN Development Program, Un Environment Program, Organization for Security and Cooperation in Europe (Figure 5). The realization of danger from Nuclear Power Plants, including ArmenianNuclear Power Plant demands maximum efforts, it is the responsibility of not only government of RA, but also international organizations.

The Cooperation of the Ministry of Emergency Situations of the Republic of Armenia with international organizations in the sphere of nuclear safety

According to overall experience the accidental process at nuclear power plants origin because of:

- Operators' faults
- Defects in the constructions of the equipment
- Worn-out state of the equipment
- Diversions, terrorist acts
- Martial actions
- As a result of these natural disasters and their synergetic actions (earthquake, eruption of volcano , tsunami, snowfall, landslides and etc.).

In accordance with international scale of INES, radiation accidences are subdivided into:

1. Minor accident
    - Middle severity accident
    - Serious accident
    - Accidents within ANPP – choice of radioactive products, not exceeding radiation norms for population

2 Accident having the risk for environment (necessity to introduce population and staff protection system in limited zone in the region of ANPP)

- Sever accident
- Global accident

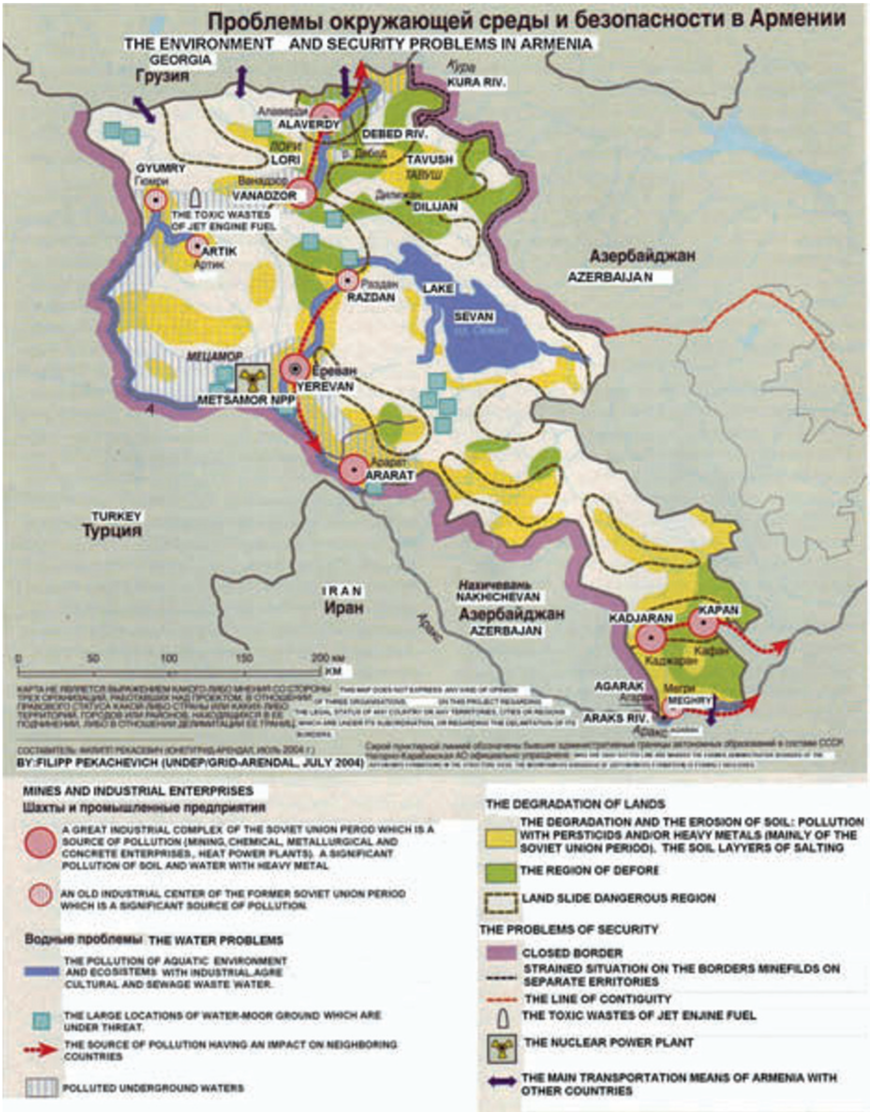


Figure 5. The problems of the environment and security in Armenia (pointed to the ANPP)

Taking into the consideration territorial limitations of Armenia, population density in the territories to be effected in case of ANPP accident can be classified into five categories, as accidents – six categories, in some cases into seven categories. That is why in nation-wide scale the activities in this direction has significant importance.

International cooperation of MES is developing in all directions of activities for provision of safety and live hood in nuclear energetic catastrophes. First of all with organizations of UN: International Atomic Energy Agency – IAEA, Agency of Coordination of humanitarian problems UN/OCHA, NATO /PfP /IPP, NATO/ARW, International civil defense organization – ICDO, European Disaster Response and Coordination Center – EADRCC, MES of Russian Federation, Government of US, Rescue Service of Estonia and Sweden, Kansas National Guardian – US, etc.

One of main directions of cooperation with IAEA is introduction of unique technique of measuring and monitoring system: organization, strategy, consistency of decisions and activities during accidental monitoring and taking of samples, choosing of necessary devices, observation of main classes of equipments, role of GIS system in case of radiological accidents, instructions on personal protection of accidental employees (concrescence and unique system of staff training etc. (IAEA-TECDOC 2002)

Figure 6. The managers of the training: Minister of Emergency Situations of the Republic of Armenia M. Shahgeldyan (in the center) close to him Deputy Head of Armenian Rescue Service, Major-General A. Tananyan

An example of international cooperation in the sphere of nuclear safety is exercise held on December 17, 2008 under the authority of USA embassy on “National Population Protection plan against Nuclear and Radiological accidents of ANPP. Aim of exercise is: testing of preparedness of managers of state and local governmental bodies and cooperation with international organizations in current catastrophe, possibility of operative awareness of population, first medical aid provision to injured ones, radiological investigation of the area, population evacuation.(Emergency paper No46 (271)19–25 February, 2008.). According to the operative radiological investigation, the incident on international scale of INES is estimated of five category and threat the lives and health not only the staff, but also 95,000 population situated close to the location of Aknalij, Arshaluys, Mayisyan, Ferik Armavir and Nor Edes of Aragacotn region. For evacuation of the population 695 micro buses, 30 passenger wagons were prepared, the places of evacuation were defined, it is necessary to provide with medicines, medical staff, preparing of the hospitals for accepting the injuries of different degree of severity, the tasks and interconnection of ES of all territorial subdivisions (Armavir, Kotayk, Aragacotn, Shirak and others) was defined (Figure 6).

The process of the training was being watched by the representatives of IAEA, the representative of United States Nuclear Regulatory Commission Francis (Skip) Young (Figure 7) and the representatives of the other countries.

Figure 7. The representative of United States Nuclear Regulatory Commission Francis (Skip) Young is following the process of the training (Artakarg tert N46 (271)

The training revealed the some weak sides and defects which should be regulated by the managers of corresponding ministries, representing their structures during the training. The general management of the training was conducted by the Minister of ES of Armenia M. Shahgeldyan (Figure 8).

In accordance with the Decree of the Government of RA on construction of second shift of ANPP also after earthquake in Spitak in 1988, IAEA often implemented serious examination of seismic and geo-technique conditions of ANPP region. Only from the list of recommendations it becomes clear that experts are seriously alarmed and how difficult it is to implement their requirements. Among these requirements normative documents are pointed out serving as a base for research activities. Here are the requirements, reports, conclusions linked with ANPP safety issues:

Figure 8. Radiation investigation group is clarifying the scope of radiological contamination

1. International Atomic Energy Agency, Safety Requirements NS-R-3,Site Evaluation for Nuclear Installations, IAEA, Vienna (2003)
2. International Atomic Energy Agency, Quality Assurance for Safety in Nuclear Power Plants and Other Nuclear Installations, Safety Series No. 50-C/SG-Q, Code and Safety Guides Q1-Q14, IAEA, Vienna (1996)
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7. NUREG 0800 §Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants¦
8. Safety Standards Series No. §Volcanoes and associated topics in relation to nuclear power plant sitting¦ July 1997 (8)
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Examining the necessary documents more than once the Ministry of Emergency Situations (before the formation MES and ARS) has made remarks and proposals about cooperation in the sphere of elimination of mistakes, gabs and remarks.

With the help of international organizations 119 rescuers of RA have been trained in abroad among them the representatives with leading, higher, middle and low ranks, rescuers-firefighters and fire fighters providing first medical aid (France, Sweden, Estonia) (Figures 9–11).

Figure 9. Medical point in the zone contamination radionuclide

Figure 10. Radiological measurements in area Metcamor city

Fire vehicles and other equipments have been received from France; some negotiations are being conducted on purchase of such kind of equipments from Japan within the framework of Japan Grand. SDC has provided 49 detachments of all Marzes of Armenia with containers with special equipments for rescuers-fire fighters. All these things contribute the improvement of the skills of fighting in case of radiation safety, radiation accident.

The participation in international scientific conferences of NATO, IAEA allows the world community to pass and accept the successes, experience and to handing over the colleagues, the scientific circles and the community of Armenia.

Figure 11. Put out a fire in area accident nuclear

The international scientific conference of NATO on nuclear energy and energy security in the framework of Advanced Science and Technology Center (ASTEC) that has been conducting consciously serves as an example. The subjects of the given conference are:

NATO-ARV-1, “Countering Nuclear /Radiological/Terrorism (CNRT – 2005), 2005, [12]

Protection, Detection and Response to Nuclear and Radiological Threat (PDR-1), 2007 (2008)

Nuclear Power and Energy Security, 2009

Threat Protection, Response and consequence Management Associated with Nuclear and radiological terrorism (PDR – 3), 2008, Brussels, Belgium, in accordance with the vital activity and ecological science and the Ministry of Emergency Situations

The workers of the Ministry of Emergency Situations took part, take part (Apikyan et al. 2010) and we hope that will take part in the given conferences.

Conclusion

In the report the issues of energetic safety of the republic are examined in the base of functioning of the objects of nuclear energy in complex with hydro energetic and other alternative sources of energy generation.

Emphasizing the significance of efficiency of generating electric energy by means of exploitation of ANPP, the authors based on the international experience on catastrophes of objects of nuclear energy recognize the necessity of using state approach for risk assessment on the base of monitoring, modeling and preparing the specialists for ES, Planning of protection procedures and control over their implementation.

While implementing this kind of activities the assessment of cooperation of MES of RA with international organizations in the field of nuclear safety in the republic is also taken into the consideration.

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APPLIED MODEL OF THROUGH-WALL CRACK OF COOLANT VESSELS OF VVER-TYPE REACTORS

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Abstract We propose an applied-model of Through-Wall Crack (TWC) for VVER-type units primary vessels. The model allows to simulate the main morphological parameters of real TWC, i.e. length, area of inlet and outlet openings, channel depth and small and large size unevenness of the crack surface. The model can be used for developing and improving the coolant-leak detectors for the primary circuit vessels of VVER-units. Also, it can be used for research of the coolant two-phase leakage phenomenon through narrow cracks/channels and thermo-physical processes in heat-insulation layer of the Main Coolant Piping (MCP) during the leak.

Introduction

The actions to prevent sudden large-scale accidents involving breakdown of high pressure and temperature vessels (HP&T) of VVER-units are regulated by the special concept known as “Leak Before Break” (LBB) [1]. This concept together with the requirements imposed to design, development and manufacture, lay down certain requirements to the operation too, supposing to apply the super-sensitive and reliable technical tools (based on the measurement results) with the ability of detecting the small-size coolant-leaks from MCP in VVER-type nuclear reactors. So, special technical tools and methods are needed for modelling both the coolant and its leakage through the artificial cracks of HP&T vessels. At the same time, the correct solution of the mentioned problems allows to solve also the following two more important and interrelating problems: (1) evaluation of coolant mass flow-rate through the crack with known geometrical parameters of the crack; (2) evaluation of crack parameters using measured coolant flow-rate through the crack.

As a rule, at the solution of similar tasks the large facilities with rather limited capabilities for controlling the artificial-crack parameters were been needed [2, 3]. In this regard we proposed a new idea of the model-crack based on simple geometry of conical crack-nozzle (CCN) [4].

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In this paper we briefly consider the following topics

- Physical principle of crack-opening displacement (COD) in the flat plates
- Methods of estimation of TWC area in MCP of VVER units depending on the conditions of a pipe-loading
- Principle and design of TWC-model of HP&T vessel based on the geometry of conical crack-nozzle
- Scheme of the experimental facility with using of TWC-model for the researches of both the phenomenon of two-phase leakage through the wall-cracks and thermo-physical processes of propagation of steam-air mixture through the heat-insulation layer on MCP in a case of leak of coolant through TWC

Brief description of COD in HP&T vessels

The TWC in HP&T vessels may be located at the different points of the structure, have different geometrical locations and different morphological structures. In general, the crack-inlet and outlet openings may have different sizes and crack channel profile may be described by irregular curve. The laws of opening of cracks in HP&T vessels were derived on the base of Dugdail's work that have performed researches with the patterns of metal flat-sheets with elasto-plastic properties under external loading [5] (Figure 1).

Dugdail demonstrated that at the end of crack, the narrow plastic zones spring up along the direction of a crack due to relatively strong deformations there. The lengths of zones depends on the relation of membrane stress $-\boldsymbol{\sigma_m}$ to material yield stress $-\boldsymbol{\sigma_F}$. Crack contour together with the plastic zone is modeled in a form of oblong narrow ellipse with the length of semi-axis $-$ $\mathbf{L} = (\mathbf{a} + \mathbf{s})$, where $\mathbf{a}$ – is the physical semi-length of crack, $\mathbf{s}$ $-$ length of plastic zone. It is considered that outside of a crack contour the material has elastic properties. The Dugdaile's work served as a base for further theoretical and practical researches (see for example [6–8]).

Based on the results mentioned above Wütrich proposed another method and corresponding formulas for describing a COD at the curved layers under external loading [9]. Particularly, he proposed the following formula for calculation of COA in HP&T vessels

$$A = \alpha(\lambda)\cdot\gamma(s)\cdot A_0 \qquad (1)$$

where, $\mathbf{A_0}$ is crack opening area (COA) in plane sheet which is determined by following formula

$$A_0 = 2\cdot\pi\cdot\sigma_m\cdot a^2/E' \qquad (2)$$

$\mathbf{a}$ is the half-length of the crack, $\boldsymbol{\sigma_m}$ is the membrane stress, $\mathbf{E'}$ is the Young's modulus for plane-strain condition (in general, $\mathbf{E'} = \mathbf{E}(1 - \boldsymbol{\nu})$, where $\boldsymbol{\nu}$ is Poisson coefficient), $\boldsymbol{\alpha(\lambda)}$ depends on $\boldsymbol{\lambda}$ parameter which expresses the geometrical and physical characteristics of a pipe material, $\boldsymbol{\gamma(s)}$ is a polynom expressing the plastic property of a material.

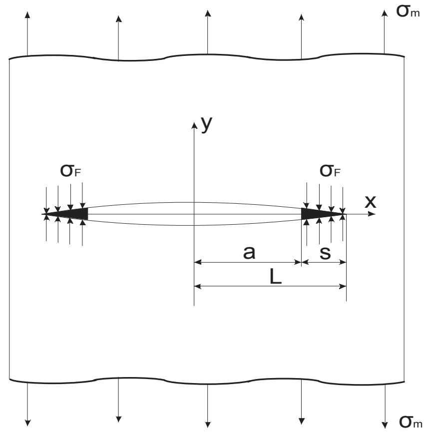

Figure 1. Scheme of COD in a flat plate. $\boldsymbol{\sigma_m}$ – membrane stress; $\boldsymbol{\sigma_F}$ – material yield-stress; **a** – half physical-length of crack; **s** – length of a plastic zone

The principle of evaluation of COA for MCP of VVER-type reactor depending on mechanical loading conditions

Two interdependent circumstances have to be considered at development of TWC applied-model.

1. Applied-model of slit is assigned for simulation of the small coolant leaks in MCP of VVER-units in accordance to LBB concept where leak rate of about 4.0 l/min is postulated as a minimal value of sensitivity for detection systems.

2. The experimental facility for simulation of the coolant and its leak through the model crack-channel shall cover the certain range of possible leak rate values around the mentioned value. We may establish the following logical boundaries around this leak-rate value: Q_{min} = 0.1 l/min and Q_{max} = 40 l/min.

Taking it into the account we can evaluate also the corresponding boundaries of COA for HP&T vessels by a formula [4].

$$Q = \sqrt{\frac{2\Delta P}{\rho}} \cdot S_0 \cdot \mathrm{K}(\Delta, \xi_M) \tag{3}$$

where $\mathbf{S_0}$ is a geometrical area of COA, $\mathbf{K(\Delta,\xi_M)}$ is a function representing the losses on frictions due to the unevenness $\boldsymbol{\Delta}$ on the crack surface at liquid outflow, the coefficient $\boldsymbol{\xi_M}$ takes into account the flow-losses at the inlet, $\boldsymbol{\Delta P}$ is a pressure difference in and outside of the vessel, $\boldsymbol{\rho}$ is a coolant density at the given temperature. However, we have to take into account also that there is a upper limit for a COA (in HP&T vessels), which is determined by critical value at given loading onto the piping [7].

In practical estimations of crack-model parameters we have to start from choosing the leak-rate for given initial object parameters i.e.: crack length and level of loading onto the piping. Then, we need to estimate the corresponding measurements of COA by formula (1). Notice that the crack length **a** plays the role of a parameter in formula (2), σ_m expresses the loading level onto the vessel and may be expressed by the difference between the pressure in and outside of the vessel, if no other load sources existing.

The scheme of applied model of through-wall crack based on the conical slot-nozzle (CSN)

If the farctate cone with vertex angle φ is put in a conical nozzle with height of **t** and same angle at the vertex and is moved along the common symmetry-axis OO_1 at the distance λ, as shown in Figure 2, then channel in the form of CSN will be formed. The ends openings of the channel have ring forms EDD_1E_1 and BAA_1B_1 of arising at the revolving of the segments E_1D_1 and A_1B_1 around the cones' common symmetry axis (OO1).

The geometry of CSN allows modeling the main morphological characteristics of the real crack in a mechanical structure.

In particular, the inlet and outlet openings of CSN are side-surfaces of the truncated cones with the corresponding diameters D_1 and D_2 and with the same height – $t_1 = \delta \sin(\varphi/2)$. These circular openings have lengths:

$$\left.\begin{aligned} l_1 &= \pi D_1^* = \pi(D_1 - \lambda/2\sin(\varphi/2)) \\ l_2 &= \pi D_2^* = \pi(D_2 - \lambda/2\sin(\varphi/2)) \end{aligned}\right\} \quad (4)$$

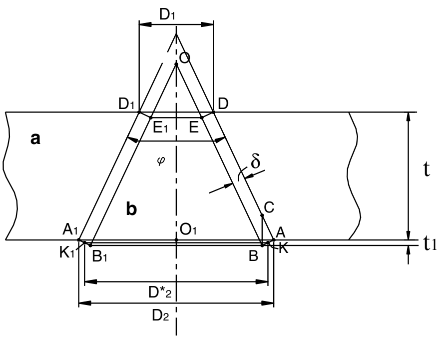

Figure 2. Schematic layout of the axial sectioning of CSN. $\mathbf{OO_1}$ – cones symmetry axis; **a** – conical nozzle; **b** – movable conical embedding; δ – width of the conical nozzle slot-channel ; $\mathbf{D_1}$ and $\mathbf{D_2}$ – diameters of openings of the fixed conical nozzle; $\mathbf{h = AD = BE = t/\cos\varphi/2}$ channel depth

The guarantee of equivalence between real crack opening areas and its model, for given set of the geometrical parameters of model φ, $\mathbf{D_1}$ and $\mathbf{D_2}$ is provided as follows. For given mechanical loadings onto the structure and for given length of crack **2a** the area of its opening **S** is calculated by above formula (1). Then, the constructive width of the model-channel δ is calculated by formula $\boldsymbol{\delta} = \mathbf{S/2a}$

(herein, for simplicity, it assumed that the width of the channel doesn't depend on its depth) and finally, the key design parameter **λ** is determined by formula **λ** = **δ**/sin(**φ/2**). Another specificity of the model has to be noted. We can provide any ratio between end-areas of channel for given geometric parameters **φ**, $\mathbf{D_1}$ and $\mathbf{D_2}$ of the model: For this, we can simply close the certain part of the areas on the end-openings of channel. In particular, if we want to have equal areas for the inlet and outlet openings, we have to cover the certain angular sector on the appropriate openings in accordance to the formula **ω = 2π· D2/D1**. As regards the modeling of the surface roughness of a crack, we can turn to the handbooks to obtain the desired values of the global $\mathbf{\mu_G}$ and local size $\mathbf{\mu_l}$ unevenness's and choose the appropriate ratios $\mathbf{\delta/\mu_G}$. Technical difficulties must no arise at the modeling this kind of unevenness.

The scheme of experimental facility for investigating the thermo-physical processes during the leak of coolant through the crack-channel in MCP

The scheme of experimental facility containing the applied model of TWC is shown on the Figure 3. The facility can be used for the investigation of both thermo-physical processes at the coolant leak area and for the approbation of separate elements during designing of new coolant leak diagnostic systems.

The experimental facility works as follows

The modelling of the coolant is performed as a separate water tank (4), with a heater implanted (not shown on the figure). The tank outlet is joined to the model slot-channel via the flow rate-meter and heat-insulating tube. The model slot cha-nel is mounted on the wall of the model-segment of MCP heated by special heaters (not shown on figure).

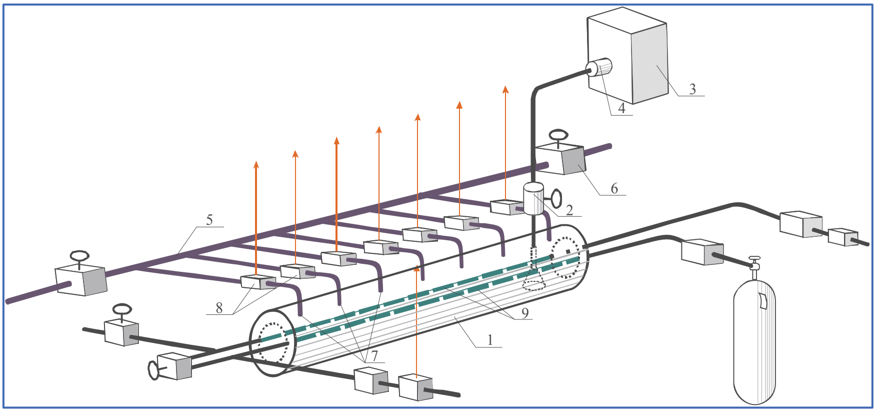

Figure 3. Schematic layout of the experimental facility: 1 – model-segment of MCP of the VVER reactor; 2 – slot-channel model node based on the geometry of conical slot-nozzle; 3 – module of the coolant modeling; 4 – flow rate meter; 5 – collector; 6 – air pump; 7 – diffusion sensors; 8 – boxes of measurement of temperature and humidity; 9 – perforated narrow tubes

Special sensor tubes of small diameter Ø 10 mm (9), perforated in 40–50 mm with the holes of Ø 1–2 mm, are mounted under the thermal insulation along the length of model MCP tube in a diametrically opposed positions. The sensor tubes with air-pump are to be connected to the collector (5). With the step of 40–50 mm in peripheral zones of the thermal insulation layer of the model MCP the diffusion sensors (7) are put in, which are parallelly connected to the outlet-collector via the chamber of temperature and humidity measuring. The initial drying of the sensor-perforated tubes before the start of experiments is performed by dry-nitrogen. The corresponding electric signals of the temperature and humidity sensors from chamber 8 are analysed by multi-channel data and software equipment, not shown on the figure.

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INDEX