Operating Nuclear Reactors in Ukraine: Enhancement of Safety and Performance

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Abstract. Significance of nuclear power industry in the Ukrainian fuel and energy complex continually increases. Nuclear energy development program has envisaged construction new power facilities during next 20 years. It should be noted that for new nuclear power plants (NPP) more strict requirements for safety (comparing to existent NPPs) are established. The safety has to be ensured by means of NPPs proper siting, design, construction and commissioning, followed by the proper management and operation of the plant. International and national researches show that the design and operation of existent NPPs meet internationally approved safety principles. However, understanding significance of safety, existent plants promote activities to meet safety requirements for new NPPs. These activities include (but are not limited) such directions, as safety upgrade program (for all plants), continuous enhancement of operational safety, implementation of quality assurance system, periodic safety review and life extension/management for older plants. This paper presents an overview of activities in the safety enhancement and performance of NPPs operating in Ukraine.

1. INTRODUCTION

Currently four NPPs with 15 nuclear reactors of water-water energy reactor (WWER) type produce more than 50% electricity in Ukraine. The initial design of these plants and their safety have been continuously improved over the years by taking into account the feedback from operational experience. It can be considered that the safety of these NPPs designed to earlier standards is sufficient and meets internationally approved safety principles. Furthermore, in light of the strategy for further growth and development of the nuclear power sector, safety enhancement of operating NPPs is one of the major tasks of the state policy in this area.

2. SAFETY UPGRADE ACTIVITIES

Understanding significance of safety, the State Nuclear Regulatory Committee of Ukraine intends to ensure that operating NPPs maintain safety level comparable to the plants designed and constructed today. To attain this goal, stable regulatory system is needed, and regulatory requirements should not be excessively conservative. In order to achieve a stable regulatory system, new regulatory rules must be carefully considered. The rules should be such that Utilities can use their resources for those improvements, which are essential to safety rather than on items, which are less important, and only marginal to safety. Therefore, the rules should quantitatively define the safety goals. Top level regulatory document [1], numerically defines the safety goals for operating NPPs. These goals (as well as the whole document) are consistent with the IAEA safety standards. As a most effective tool in evaluating and comparing NPP safety against safety goal, probabilistic approach is used. As a result of industry activities on Probabilistic Safety Assessment (PSA), three pilot units, which represent three types of WWER reactors (South Ukraine NPP Unit 1 - WWER-1000 of “small series”, Zaporizhzha NPP Unit 5– ‘serial’ WWER-1000 and Rivne NPP Unit 1 - WWER-440) operating in Ukraine, have developed safety analysis reports with PSA chapters. New units (Khmelnitsky NPP Unit 2 and Unit 4 of Rivne NPP) also have completed reports.

Important outcome from PSA and safety analysis reports has been updating Safety Upgrade Program for Ukrainian NPPs 2006-2010. Previous programs for “old” units, as well as modernization program for "new" units have been developed on engineering basis. Implementation status and interrelations between different safety programs for Ukrainian NPPs are presented in Figure1.

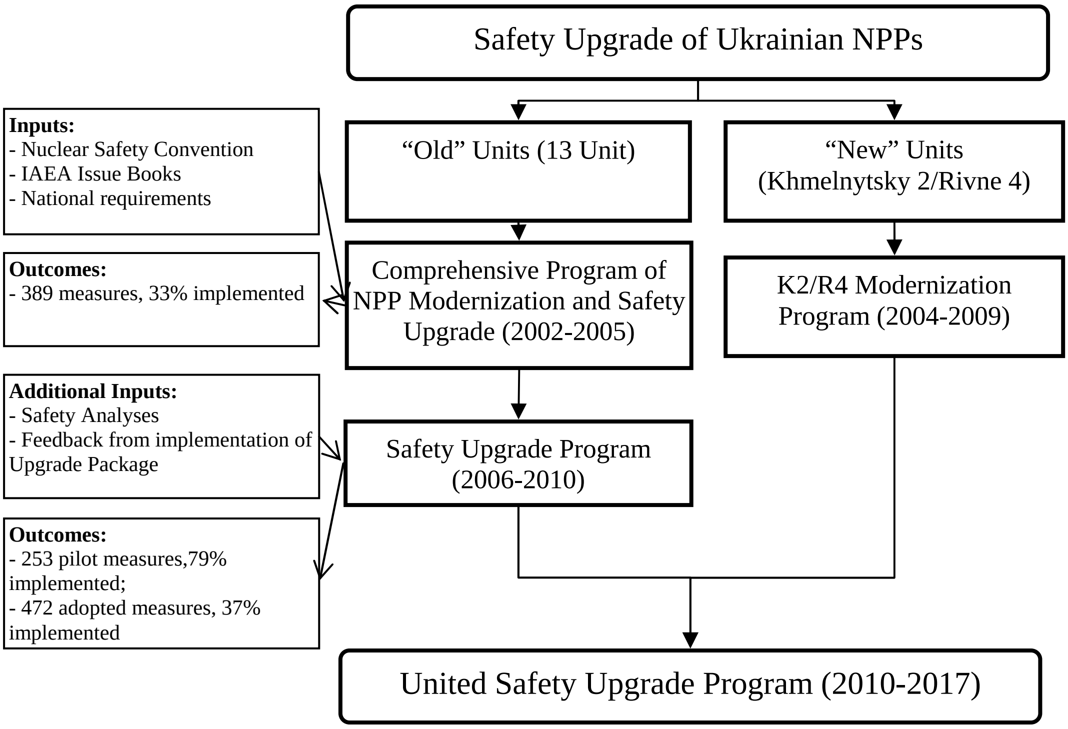

Fig. 1. Safety upgrade programs for Ukrainian NPPs

Taking into account the results of implementation of safety upgrade and modernization programs, outcomes from joint IAEA-EU-Ukraine project and strengthening national regulatory requirements (during 2005-2009 years), United Safety Upgrade Program has been developed. The main goal of the United Safety Upgrade Program is to further enhance safety of the Ukrainian NPPs to account for enforcements in regulations and best current practices in rational and the most efficient way. The United Safety Upgrade Program includes safety enhancement areas and associated measures developed using information on risk from safety analyses, considering qualitative and quantitative outcomes from safety analysis PSA, previous activities, international recommendations/advanced international experience, etc.

Regulatory Authority gives special attention to implementation of the safety upgrade program and continuous enhancement of operational safety. It was decided that implementation of safety upgrade measures should be performed by step-by-step procedure, taking into account their safety efficiency.

3. SAFETY IMPROVEMENT WITH ACCOUNT FOR IMPACT ON RISK

Implementation of the Safety Upgrade Program has resulted in significant enhancement of safety of all Ukrainian NPPs. Example is provided for South Ukraine NPP, which undertakes huge efforts on plant modernization. First PSA level 1 for internal initiating events for SUNPP Unit 1 was developed in 1998 under international cooperation in the framework of the in-depth safety assessment program. As a result, total core damage frequency (CDF of 1.5E-04 1/year was evaluated. Contribution of initiating events (IE) to CDF 1998 is presented on Figure 2.

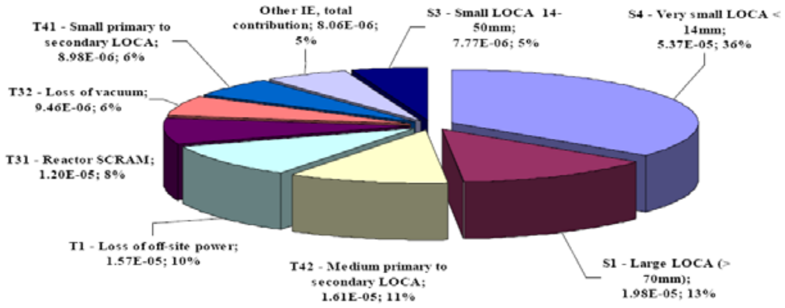

Fig. 2. Results of PSA 1998

In 2009 the PSA was updated in order to introduce new knowledge about physical processes and plant behaviour, to account for plant modifications during last 10 years and to reduce unnecessary conservatism in probabilistic models. The analysis shows that SUNPP-1 safety was substantially improved. Total CDF was decreased by 25 times, to 6.01E-06 1/ year. IE contribution to CDF 2009 and their comparison with PSA 1998 results are shown on Figure 3.

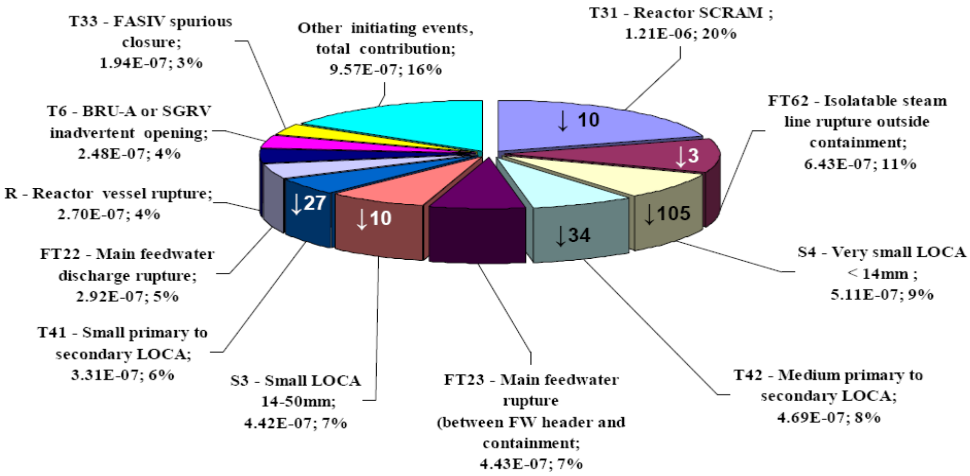

Fig. 3. Results of PSA 2009

Despite on modelling new IEs, the total CDF was decreased. The main reason is the plant modernization activities. Such activities are shown below for selected IE.

3.1. Initiating events

Medium primary to secondary LOCA. This IE has been the most complex for control. This is because of IE diagnostics is difficult, emergency control is complicated for personnel, time available for human actions is limited with coolant inventory for make-up, high probability of stuck opening of BRU-A (and SG RV) on affected SG (due to non-qualification of water/steam mixtures), and as a consequence, radioactivity releases outside containment.

Safety issue resolution implies the complex of tasks including:
(a) preventive measures which decrease the probability of the IE occurrence (use of 100% non-destructive monitoring of SG manifold metal and welded splices, implementation of adequate water-chemical mode, etc) and constrain the leakage rate;
(b) organization measures: revision of the emergency procedures aimed on leakage localization within the affected SG, prevention of containment bypass and excluding or minimization of the radioactive releases; and personnel training using the full-scale simulator;
(c) plant modifications directed on expansion of safety systems capabilities to mitigate IE and to facilitate the personnel tasks on emergency control. Main modifications are:

• automatic diagnostics of the LOCA and affected SG;
• replacement of BRU-A, SG RV on ones qualified for water/steam mixtures;
• providing emergency make-up of the containment sump using spent fuel pool;
• implementation of new automatic algorithm to prevent releases through BRU-A of affected SG;

As a result, CDF for the IE was decreased by over 30 times, from 1.6E-05 to 4.7E-07 1/year.

Very small LOCA. This IE was the most dominant contributor to CDF (36%). This occurred due to two main reasons: very high frequency of IE and insufficient reliability of long term primary heat removal. To improve safety, the following was performed: modernization of systems and components (HPIS, LPIS, Secondary systems), and human reliability was improved by using full-scope simulator and undated EOP. Also, strategies for mitigation of the LOCA were evaluated using PSA results. Areas for improvement include: IE identification; secondary cooldown (e.g., excessive requirements on SG feeding and boron injection preclude early cooldown); primary pressure control (has not been provided in EOP); maintaining long term cold shutdown state (has not been provided in EOP). Proposed strategy was evaluated by thermal hydraulic analyses and validated on full-scope simulator. The strategy takes into account realistic time window, number of available equipment, order of human actions, etc.

As a result, CDF for very small LOCA was decreased by over 100 times, from 5.4E-05 to 5.1E-07 1/year.

3.2. Safety functions

Evaluation of PSA results and associated plant modifications were conducted also from safety functions point of view. CDF due to unavailability of safety functions is shown on Figure 4.

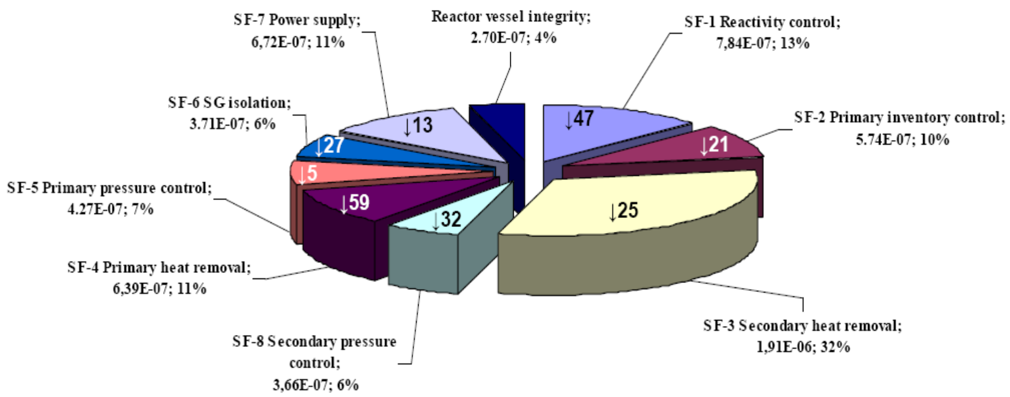

Fig. 4. CDF due to unavailability of safety functions (PSA 2009 vs PSA 1998)

Reliability of all safety functions was improved due to plant modifications. Main measures that enhance safety functions reliability are the following.

For primary heat removal function: Installation of PORV qualified for water/steam mixtures; Introduction of feed&bleed mode; Modernization of ECCS sump filters; Replacement of thermal insulation on primary circuit; Installation of high pressure ECCS discharge control valves and ensuring make-up pumps operation via ECCS sumps; Ensuring HPIS operation on primary circuit at primary pressure < 40 bar.

For reactivity control function: Modernization of reactor protection system (two-sets scram, new signals for scram actuation); Automatic supply of boric acid to make-up pumps during reactor scram; Ensuring HPIS boron pumps operation on primary circuit at primary pressure up to 180 bar.

For secondary pressure control function: Modernization of SGRV and BRU-A to ensure their operation on water/steam mixtures; Modernizations of safeguards for control of primary to secondary LOCA (automatic algorithm to prevent releases through BRU-A of affected SG).

For SG isolation function: Modernization of FASIVs to ensure their operation on water / steam mixtures; Monitoring of primary to secondary leaks by nitrogen 16; Modernizations of safeguards for control of primary to secondary LOCA (automatic algorithm to to prevent releases through BRU-A of affected SG); Automatic isolation of emergency feedwater during uncontrolled overcooling.

For secondary heat removal function: Modernization of SGRV and BRU-A to ensure their operation on water / steam mixtures; Ensuring power supply of demineralized water pumps from diesel generators; Separation and water insulation of emergency feedwater compartments; Emergency SG feeding by fire water.

Measures that have impact on all safety functions: Using full scope simulator to improve qualification and reliability of operators; Symptom based EOP; Implementation of measures on additional power supply during blackout.

4. INDEPENDENT SAFETY EVALUATIONS OF EXISTING NPPS

On 1 December, 2005 Ukraine and EU signed the Memorandum of Understanding on cooperation in the field of energy between the European Union and Ukraine in the context of implementation of the EU-Ukraine Action Plan.

The main objective of the Memorandum is to extend the cooperation between Ukraine and EU in the energy field aimed at the energy markets integration. The Memorandum specifies how both parties are planning to organize activities to integrate energy markets, and establishes a common strategy for gradual integration of the energy market of Ukraine within the EU market. It includes Roads Maps covering the following areas: Nuclear safety; Integration of energy and gas markets; Security of energy supplies and the transit of hydrocarbons; Coal sector.

In the framework of the Road Map for Nuclear Safety the parties agreed to conduct a safety evaluation of all the operating Ukrainian NPPs covering the following areas:

1. NPP design safety;
2. NPP operational safety;
3. Waste management and decommissioning;
4. Regulatory issues.

The assessment will verify the compliance of Ukrainian NPP safety with current IAEA nuclear safety standards, on the basis of safety improvements at Ukrainian NPPs that were carried out so far and scheduled to be implemented under the ongoing Ukrainian NPPs safety upgrading programs.

To implement this action the EC-IAEA-Ukraine Project “Safety Evaluation of Ukrainian Nuclear Power Plants" was launched.

4.1. Design Safety

The specific objective of the Design Safety evaluation is to conduct an overall evaluation of the compliance of the design of each of the Ukrainian NPPs (15 units) with the current IAEA Safety Standards for design of NPPs. NS-R-1 “Safety of Nuclear Power Plants: Design” NS-R-1 was a basis for Design Safety evaluation.

The general methodology of a design safety review is based on the following approach:

– A self-assessment performed by the Ukrainian Counterpart, followed by
– An independent safety evaluation organized by the IAEA with external experts being

involved, including EU-JRC experts

– Discussion of the mission reports with the Ukrainian Counterpart

The three pilot units (Khmelnitski 2, (WWER-1000/320), Rivne 1 (WWER-440/213), South Ukraine 1 (WWER-1000 small series)) selected for the first reviews were chosen on the basis of being representative of the three types of reactors now operating in Ukraine.

Main findings (summary)

– Full compliance with most NS-R-1 requirements;
– Non full compliance but good progress in areas of:
  - Equipment qualification
  - Consideration of severe accidents
  - Seismic design margin
  - Control of containment hydrogen concentration
  - Waste storage
  - Probabilistic risk assessment
  - Demonstration of plant safety characteristics

4.2. Operational Safety

The methodology used to implement the Operational Safety Assessment based on the standard IAEA's OSART Missions' format, procedures and guidelines.

Main findings

– There are no issues at any of the plants which have been determined to have "insufficient progress to date"
– Results indicate good alignment of actions taken with other plants worldwide
– High degree of cooperation between plant personnel and OSART/EM teams

4.3. Waste and decommissioning

Main findings

It was noted that particular attention over the next years should be paid to:

– Clearance criteria
– Waste acceptance criteria
– Refinement of end-point criteria for decommissioning
– Interdependencies between units in operation and under decommissioning

4.4. Regulatory issues

The methodology used to implement the Regulatory evaluations followed the IAEA guidelines for conduct of Integrated Regulatory Review Service (IRRS) missions.

The IRRS team identified the following notable strengths of the SNRCU's policy, framework and regulatory oversight:

– SNRCU is effectively regulating nuclear safety and areas of radiation safety within its responsibility; a comprehensive legal infrastructure that addresses international requirements and includes all the relevant international conventions is in force.

– The legislation clearly specifies that regulatory requirements shall be developed with strict consideration of the recommendations of competent international organizations. This will inevitably support worldwide harmonization of nuclear and radiation safety requirements, as highlighted by INSAG-21.

– SNRCU is de facto an effectively independent regulatory body, however, to strengthen its de jure independence its status should be established in law.

Recommendations and Suggestions with the high priority for implementation:

– The Government of Ukraine should define and guarantee the statute of the SNRCU in law.
– At the earliest opportunity the Government should approve the "National Programme on

Radioactive Waste Management" and the funding mechanism necessary to guarantee its implementation.

– The Government should consider enacting legislation that assigns responsibility to SNRCU for the authorization of the siting and design of new reactor units.

– The Government should take steps to allocate funds to ensure the methodological unity of dose monitoring in Ukraine, as well as to establish a national dose registry.

– SNRCU and the Ministry of Health should agree a memorandum of understanding clarifying the responsibilities of each of the authorities as well as the mechanisms for implementation of effective cooperation in regulating and controlling radiation protection, waste safety and other common activities that arise.

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[1] STATE NUCLEAR REGULATORY COMMITTEE OF UKRAINE, "General provisions of NPPs safety", Kyiv (2008).

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[3] IAEA "Integrated Regulatory Review Service (IRRS) to Ukraine" (2008).