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ASSESSMENT OF RISK OF SEVERE ACCIDENTS FOR ALL MODES OF OPERATION AT NOVOVORONEZH-5 NUCLEAR POWER PLANT

A. V. Lubarsky[1]/SEC NRS, Moscow, Russia

S. O. Volkovitski/SEC NRS, Moscow, Russia

G. I.Samohine/SEC NRS, Moscow, Russia

D. Noscov/SEC NRS, Moscow, Russia

S. Chakraborty/SDC/DEZA, Switzerland

G. V. Tokmachev/ Atomenergoproekt, Moscow, Russia

M. Khatib-Rahbar/Energy Research, Inc., Maryland, USA

SUMMARY/ABSTRACT

A full-scope Probabilistic Safety Assessment (PSA) has been completed for the Novovoronezh Unit 5 Nuclear Power Plant (NVNPP-5), the first Russian VVER-1000. The analysis has been carried out within the framework of the joint Swiss-Russian PSA project (i.e., the SWISRUS). In early 2002, the SWISRUS project entered its third and final phase, involving the extension of the PSA to non-full power modes of operation (i.e., shutdown, refueling, startup, and accidents involving the spent fuel pool) and development of various regulatory guidelines for risk-informed applications.

The paper provides an overall summary of the scope, methodology, results, findings and lessons learnt from the Novovoronezh full-scope PSA study. The paper addresses the major contributors to the core/fuel damage frequency, and the insights gained with focus on the assessment of risk of severe accidents for non-full power modes of operation. Different outage types such as annual refueling and maintenance and unplanned outages are considered. The actual outage schedules and the plant records have been investigated to identify the various plant operating states and their associated duration. To enhance the completeness of the information utilized in the Shutdown Probabilistic Safety Assessment (SPSA), unplanned outages were examined. This investigation resulted in a total of 18 groups of plant operating states that were defined. The set of plant operating states modeled in the SPSA include the transition between various modes of operation.

The study has covered risks originating from damage to the reactor core, fuel handling accidents and other ex-core accidents such as loss of spent fuel pool cooling. In evaluating risk contributors internal initiating events, internal and external hazards were considered.

The SPSA addresses 62 internal initiating event groups, including heavy load drops. The initiating event frequencies have mainly been derived from VVER-1000 operational experience with plant specific updates. Event tree sequences have been developed and quantified using the SAPHIRE computer code. The existing at-power fault trees have been modified to include shutdown operational configurations. The human actions that have been modeled were identified by reviewing the various plant procedures, other industry SPSAs, and through operator interviews and surveys performed at the Novovoronezh plant. Plant-specific thermal hydraulic analyses to estimate the time to core/fuel damage have been performed to support accident modeling and human reliability analysis.

The full-scope PSA results are being actively used by the Novovoronezh unit 5 plant in their implementation of a risk management program to support the plant hardware and operational improvements.

[1] Present address: Energy Research, Inc., Rockville, Maryland

INTRODUCTION

A full-scope Probabilistic Safety Assessment (PSA) has been completed for the Novovoronezh Unit 5 Nuclear Power Plant (NVNPP-5), the first Russian VVER-1000. The analysis has been carried out within the framework of the joint Swiss-Russian PSA project (i.e., the SWISRUS). The SWISRUS project is the result of cooperation between the Swiss and the Russian Nuclear Regulatory Authorities, and is sponsored by the Swiss Government, Agency for Development and Cooperation, Division of Cooperation with Eastern Europe and the Commonwealth of Independent States (DEZA/AZO). The first two phases of the SWISRUS project covered the PSA studies performed for full power operation of NVNPP-5. Risk originated from all potential sources, such as plant system failures, internal and external hazards, was quantified. The results of studies carried out within those phases were presented in References [1-3].

In early 2002, the SWISRUS project entered its third and final phase, involving the extension of the PSA to non-full power modes of operation (i.e., shutdown, refueling, startup, and accidents involving the spent fuel pool) and development of various regulatory guidelines for risk-informed applications.

The main objective of the SWISRUS project is to assist in the training of the technical staff of the Scientific and Engineering Center for Nuclear and Radiation Safety (SEC NRS), which is the technical support organization of the Federal Nuclear and Radiation Safety Authority of Russia (i.e., Russian Federation Rostechnadzor, former Gosatomnadzor), for performance and application of PSAs in safety evaluation of Russian nuclear power plants. The PSA project was carried out under the technical direction of the Swiss Federal Nuclear Safety Inspectorate (HSK). Energy Research, Inc. (ERI) assisted HSK in project management, training, technical support and review. The technical work was performed by the members of SEC NRS and the Novovoronezh plant.

Managing this project was a complex process requiring numerous management tools, constant monitoring, and effective communication skills. The project organization was extremely complex, involving participants from different international organizations from different countries. Employing management tools to resolve unanticipated problems was one of the keys to project success.

PLANT FEATURES

The Novovoronezh Unit 5, a nuclear power plant rated at 1000 MW(e), is a water-cooled, water moderated VVER Pressurized Water Reactor (PWR) that started commercial operation on May 30, 1980. It is the first VVER-1000 type nuclear power plant that was designed and constructed in the former Soviet Union.

The NVNPP-5 reactor coolant system includes the reactor, a pressurizer, and four coolant loops, each connected to a horizontal steam generator and a main reactor coolant pump. Each coolant loop also includes two valves for isolating the steam generator from the reactor vessel. The radioactive coolant circuit equipment are enclosed in a concrete containment building, which is designed to withstand an internal pressure of 0.45 MPa.

The secondary circuit consists of four steam generators, two steam-driven main feedwater pumps, two turbine-generators and related appurtenances. There are emergency feedwater pumps that are located in the basement of the turbine building. The secondary side is also equipped with fast acting isolation valves on the main steam lines.

Safety systems consist of three trains having 100% capability each.

METHODOLOGY USED IN THE SHUTDOWN STUDY

The Shutdown PSA (SPSA) is the final stage of the Novovoronezh full-scope Level 1 PSA (NVNPP SPSA). In general, the methodology used in the NVNPP-5 SPSA follow on the guidelines as set forth by IAEA (TECDOC-1144) [4], together with other available guidelines and procedures.

The study has covered risks originating from damage to the reactor core, fuel handling accidents and other ex-core accidents such as loss of fuel pool cooling.

The information available from the Novovoronezh-5 operating experience for the period of more than 20 reactor-years was investigated to assure completeness and consistency of the shutdown study. It was found that there are basically four different types of plant outages:

- Partial refueling outages
- Lengthy complete refueling outages
- Regular maintenance outages, usually not drained to mid-loop, but not always
- Unplanned outages caused by equipment failures or other operational problems

According to usual practice plant operating states (POS) were defined to subdivide the plant operating cycle into unique states, when the plant goes from full power to shutdown and back to full power operation, such that the plant response is supposed to be the same for all initiating events. Actual outage schedules and plant documentation have been investigated to identify POS and their duration. To enhance the completeness of information used in the SPSA, unplanned outages were also examined. A total of the 30 POS were identified in the PSA for different plant outages, which were grouped into 19 groups (including two groups related to power operation) to have a manageable number of POS to be analyzed. The set of plant operating states modeled in the SPSA includes transition modes. An example of a transition is the time between intermediate shutdown and cold shutdown in which heat removal is transferred from the steam generators to the low-pressure residual heat removal system.

To ensure completeness of the SPSA initiating event list, the review of the applicability of initiating events has been performed which were identified in other sources such as:

- Other SPSAs
- Plant operating history
- Experience at similar plants
- Generic data from low power and shutdown operation
- Other sources (incident reports, failure events report, etc.)

The following categories of initiating events were considered in the SPSA study:

- Events affecting normal heat removal
- Events leading to a loss of primary coolant
- Events challenging the primary circuit integrity
- Events affecting reactivity control
- Return-to-criticality events, refueling errors or errors in fuel handling
- Heavy load drop accidents

Grouping of initiating events based on similar plant response resulted in a final list of 62 internal initiating event groups.

The PSA model is based on the small event tree/large fault tree method. The event trees and fault trees were solved using the SAPHIRE computer code. The existing at-power fault trees have been modified and enhanced to consider shutdown operation configurations. Plant-specific thermal hydraulic analyses for estimating time to core/fuel damage have been performed to support accident modeling. Success criteria were defined involving thermal-hydraulic calculations performed within at-power PSA for a large number of accident sequences using a plant-specific RELAP5 model, if applicable. Operational experience, plant procedures, and expert judgment were used for the definition of success criteria either. Additional simplified calculations were also carried out, when necessary.

The human actions that have been modeled were identified by reviewing the plant procedures, other industry SPSAs, and through an evaluation of operator interviews and surveys performed at the Novovoronezh plant. The impact of operator actions on the progression of the accident is evaluated using the Decision Tree (DT) approach, which relies on expert opinion (HRA expert and plant operators), and the judicious use of data generated in a series of simulator experiments at the Paks NPP in Hungary. Series interviews were carried out in accordance with the DT approach, in order to define the various performing shaping factors, and their ranking, and to develop the distribution of human error probabilities. The analysis of dependencies between human actions was conducted on the minimal cut set level, for cut sets containing more than one human error. The full-scope PSA results lay the basis for the decision making process at the Novovoronezh plant to implement a risk management program of plant hardware and operational improvements.

Insights gained from operational experience of NVNPP-5 and other VVER-1000 reactors were used in the PSA as the statistical basis for establishing both initiating event frequencies and reliability parameters such as failure probabilities and unavailabilities due to test and maintenance. Information on incidents and failure events that occurred during the period 1980 through 2003 was collected. The initiating event frequencies and reliability parameters have mainly been derived from VVER-1000 operational experience with plant specific updates. In addition, reliability models were developed to estimate some initiating event frequencies. The Alpha Factor Model was used for estimating common cause failure probabilities, with the exception that the β-factor method was used for several groups of breakers and relays. CCF data was extracted from NUREG-/CR-5497 [5].

The external and area event risk study involves hazard identification, data analysis, screening, and assessment using the latest accepted methods and taking into account Russian Regulatory requirements [6].

The results of the initial qualitative screening analysis of external events documented for full-power PSA have been verified for low power and shutdown conditions. It was justified that no additional externals hazards than identified for the full power conditions could be applied for low power and shutdown modes. Therefore all screened-in external hazards identified for at-power mode were analyzed in more detail in the framework of the bounding analysis.

For the external events, which could not be screened-out, the importance of various accident scenarios caused by external hazards was investigated. The associated bounding CDFs were assessed using the internal initiator PSA model developed for low power and shutdown conditions.

RESULTS AND INSIGHTS

To obtain a complete set of risk contributors for Novovoronezh 5, the shutdown risk analysis task has been integrated into the overall level-1 PSA effort. The results of the model show that the shutdown risk is lower than the full power risk for internal initiating events by a factor of two. In general, human errors dominate the fuel damage risk(~37.9%)of shutdown operations. The second significant contributor is the potential drop of heavy loads (e.g. reactor pressure vessel head) leading directly to fuel damage during a refueling outage (~31%). As a result, the POS group associated with removing and re-stalling the vessel head and the upper internals structures contributes by ~29% to the calculated fuel damage frequency, which is by far a greater contributor as compared to any other shutdown POS group.

On the contrary, the overall risk estimates from external events during full power operation and shutdown modes are comparable. Figure 1 shows the contributions to the total CDF from various external initiating events. It should be noted that the risk profile differs for the at-power versus non-power operations. The important finding is the fact that seaweeds and fish have the potential to plug the service water intake (suction) line during non-power operation modes, resulting in considerable contribution to the overall CDF (Artur: Explain if this is any different for full-power, and why].

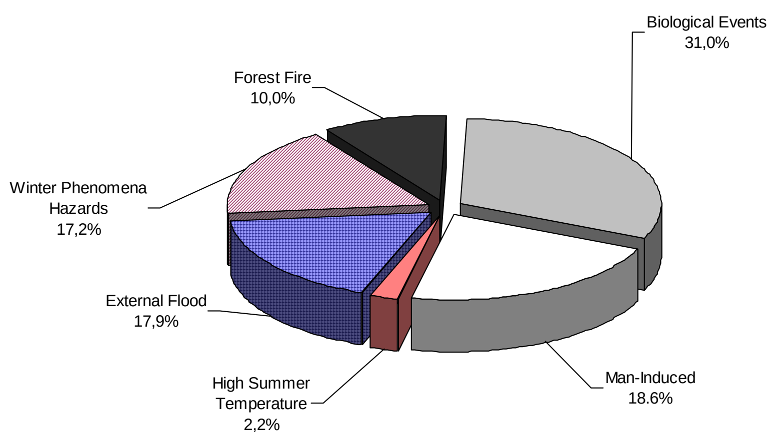

Figure 1. Contribution to core damage frequency from external hazards

The full-scope PSA results lay the basis for the decision making process at the Novovoronezh plant to implement a risk management program as part of the ongoing modernization program.

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