Application of PSA to resolve design and operational issues for VVER plants in Russia

G.V.Tokmachev

In: PSA Applications, Report of a Technical Committee Meeting, Madrid 23-27 February 1998, Vol. II, pages 104-110, IAEA, IAEA-J4-98-TC-1066, 1998.

ABSTRACT

Since 1988 AEP has performed a number of probabilistic risk studies for different VVER type NPPs in design and operation. These studies were carried out in cooperation with Russian and Western institutions as well as NPPs within both national and international programs. The scope of probabilistic risk studies varies from reliability analyses to PSAs including both internal and external initiating events. PSA results are used for NPP's safety level evaluation as well as for the identification of design/procedure improvements needed.

The paper presents the state-of-the-art information on developments related to PSA applications that can have the largest impact on NPP safety. PSA tools are also used to assist utility in resolving operation issues within safety margins. As a rule, PSA results are used to support deterministic methods for decision making in safety related matters.

Introduction.

Since 1988 Atomenergoproekt institute has performed a number of probabilistic risk studies for different types of VVER reactors from advanced VVER-1000 in design to the first VVER-440 operated at Unit 3 of Novovoronezh NPP. These studies were carried out in cooperation with Russian and Western institutions working in the field of PSA as well as NPPs. They were done within both national and international TACIS programs. The scope of probabilistic risk studies varies from reliability analyses to PSAs including both internal and external initiating events.

The results of PSAs have been used for the following purposes:

- development of design basis for the new generation VVER-1000 reactor
- justification that advanced NPP with VVER-1000 meets probabilistic safety criteria established in national safety rules
- identification of weaknesses in design and procedures of operational VVERs where improvement needs
- support of modifications implemented in operating plants with VVER-440 and VVER-1000 reactors by evaluating of risk reduction

- validation of allowable outage times and surveillance test intervals as well as testing strategy for safety systems of operating NPPs with VVER type reactors
- development of the list of beyond design basis accidents to support accident management for VVER-1000 according to requirements of national rules
- support of safe shutdown analysis for fires at Balakovo NPP

Some areas where PSA results have been implemented are discussed below.

Identification of safety improvement for advanced VVER based on lessons learned from PSA

To achieve improved safety level of a new generation of VVER-1000 by reinforcing the defense-in-depth principle, integration of deterministic and probabilistic approaches is used [1,2]. To design advanced VVER-1000, the results of PSAs performed for present operating VVER-1000 were taken into account. As a matter of fact, insights from PSA were used to complement deterministic analysis.

Technical design criteria aimed to achieve significant improvements in safety level of advanced VVER-1000 which are supposed to be applied to Novovoronezh NPP Unit 6 have been developed using as experience feedback and results of safety research programs so PSA conclusions. For example, it was found that almost all the contribution into core damage frequency for operating VVER-1000 was the result of either human errors or common cause failures. This raises an important problem of inherent defensive measures against both human errors and common cause failures which should be applied to the advanced NPP design. Undoubtedly such problem should be solved to improve safety of NPPs. It is unlikely, of course, that root causes of all human errors and dependent failures will be eliminated by the inherent protection, but the ultimate aim is to ensure that such factors are not dominant contribution into the overall risk from severe accidents.

The concept of advanced VVER is realized based on two fundamentals:

- to remain the important features of the existing VVER-1000;
- to add passive features in such a way that all important safety functions are fulfilled by two diversified redundant systems, one of which is operated in passive mode.

Comparison of results of PSA performed for advanced design with those of PSA of operating VVER-1000 were used to analyze an impact which design improvements have on frequencies of both core damage frequency and uncontrolled radioactive release from containment. It should be noted that PSA was integrated into design process in early stages of the project, i.e. both conceptual and detail design phases. In some cases step-by-step PSA feedback makes it possible to resolve issues concerned with design vulnerabilities and alternatives and to find optimum design solution by iterative process.

Finally, PSA was used to show the compliance with the required quantitative goals. It should be noted that Russian Regulatory Body adopted two quantitative safety goals for nuclear power plants in design [3]. According to the first quantitative safety objective, nuclear plants to be designed should meet the criterion that a probability of core damage should not be greater than $1x10^{-5}$ per year. The second numerical safety objective is met if the probability of a severe accident with containment failure is less than approximately $1x10^{-7}$ per year. PSA including Level 1 and 2 was used to compare the safety level of the advanced VVER against these criteria. PSA results demonstrate that frequency of unplanned radiological consequences derived does not exceed the corresponding target value of $1x10^{-7}$ per reactor year given in regulating requirements. It has been also demonstrated that core damage frequency obtained does not exceed the target value of $1x10^{-5}$ per reactor year established by regulating requirements. With regard to quantitative criteria, we believe that PSA methods cannot be used to settle absolutely the question of adequate safety of a particular NPP because PSA still cannot give an accurate results, but probabilistic analysis must be added to deterministic to reach an overall conclusion and to identify weaknesses that might undermine the safety of a specific NPP.

Support of modifications implemented in operational plants with VVER

PSAs for two units of present operating VVERs were carried out within the framework of the European Commission TACIS programme. Both Novovoronezh Unit 3 referred to as VVER-440 model 179 (in the family of 440/230 reactors) and Balakovo Unit 4 referred to as VVER-1000 model 320 were under consideration.

Several benefits were obtained from the analysis of PSA results.

Design improvement. PSAs performed give an indication of the areas of relative concern at each specific nuclear power plant. As an example, Novovoronezh PSA results for internal events are dominated by a certain number of design weaknesses identified. The risk to the plant can be significantly reduced by the upgrading measures recommended by PSAs. These recommendations include [4]:

- Provision of an additional long-term decay heat removal path. An additional technological condenser needs to be implemented to make the cooldown system single failure proof

- Provision of additional reliable means for supplying feedwater to the steam generators. A supplementary independent emergency feedwater system needs to be implemented which should have its own dedicated feedwater source
- Provision of heat removal capability by primary bleed-and-feed. A complete set of engineering analyses are required to provide this capability
- Provision of reliable isolation of charging lines to reduce interfacing LOCA risks
- Provision of motor-operated valves to automatically isolate an affected steam generator from the auxiliary feedwater system. Modification of the feedwater isolation actuation system is also required
- Provision of isolating capability in case of BRUV relief valve failure to close in the secondary side
- Provision of an automatic connection from diesel generators to essential buses in case two diesel generators fail to start
- Provision of additional emergency batteries to extend heat removal capacity in case of station blackout
- Provision to improve reliability of isolation of confinement ventilation lines
- Provision of an automatic actuation of a demineralised water pump following a trip in an operating pump

Majority of the upgrading measures supported by PSA results is implemented in the Novovoronezh plant specific programme for safety upgrading. In spite of PSA results make it possible to quantify the impact the modifications have on safety improvement and to rank the possible options in operating NPP, it should be noted that PSA only one input to the decision making. Cost evaluation of design modification alternatives is another important input because it is more difficult to implement high cost modifications.

Implementation of additional tests. PSA of Novovoronezh NPP also identified that implementation of additional testing procedure would be necessary. There were some motor-operated valves belonging to cooldown system which were estimated to be dominant contributors to core damage frequency. It was associated with the fact that those components were only tested during plant shutdown. Modification of procedures for periodical testing of cooldown system valves had already been applied in Novovoronezh NPP when PSA was finished.

Accident management. Based on dominant accident sequences identified, the list of significant beyond design basis accidents for VVER-1000 are being developed within Rosenergoatom Utility's Programme for safety upgrading. For those scenarios, more detailed thermohydraulic analyses have to be performed. After that, severe accident guidelines for operators would be developed or modified, if necessary. The plant-specific PSA seems to be the most appropriate tool for the selection of credible scenarios since it models the plant design and operation in an integrated way.

Changes in Technical Specifications. PSA tools were also used for optimisation and validation of Technical Specifications (TS). Paper [5] presents the brief review of submissions to changes applied in TSs for NPPs with VVER type reactors which were issued by Atomenergoproekt PSA team in the early 90's. Those included changes associated with limiting conditions for operation (surveillance requirements, allowed outage time, etc.). Changes were based on risk results obtained by performing probabilistic studies for specific NPP units. Atomenergoproekt performed those studies for Kola Unit 3,4 at safety function level evaluation and Kalinin Unit 1,2 at the limited Level 1 PSA using plant specific data. Surveillance test intervals and allowed outage time as well as repair strategies were under consideration. For decision making regarding TS optimisation an acceptance of risk increase over 10% of nominal level for the TS changes was assumed. However, regarding Kalinin NPP, the risk level was demonstrated even to improve. Such results were achieved by extending of allowed outage times in exchange for reducing a number of long-term surveillance test intervals as well as implementing staggered testing strategy.

Following a request of Balakovo NPP associated with mitigation of some TS requirements, a risk based evaluation of surveillance test intervals is being performed now. To reduce the burden of TS requirements without compromising safety during the power operation of NPP, the risk impact of all types of surveillance tests applied in NPP is evaluated at the core damage frequency level based on time dependent PSA model. Both test independent and test dependent contributions to core damage frequency were quantified. The test independent risk contribution is associated with failures of components untested during Unit power operation, human errors, etc.. It was found that the test dependent fraction is only 10-30% of the test independent one depending on test intervals considered up to two months. PSA results are used to support qualitative evaluations such as test caused degradation and transients. Possibility of test interval increase is now under consideration based on qualitative and quantitative evaluations.

Support of safe shutdown analysis for fires

A systematic fire hazard analysis should be performed for every operating VVER plant in Russia according to regulation requirements [6]. It is necessary for license extension. It was supposed that fire hazard analysis should be mainly based on a deterministic study of safe shutdown following recommendations of US DOE guidelines [7]. The main objective of deterministic analysis is to prove the availability of sufficient plant equipment, called safe shutdown path, to reach and maintain a safe shutdown state of the reactor given a fire in any location. In the beginning, probabilistic approach was not supposed to use due to the uncertainties related to the PSA. However, a fire PSA for operating Unit 4 of Balakovo plant is currently being carried out to support safe shutdown analysis [8]. As for uncertainty, the advantage of probabilistic techniques is that PSA makes it explicitly transparent, where as deterministic analysis keeps it latent.

The fire PSA has two main objectives:

- to estimate VVER fire frequencies and frequency of core damage resulting from a fire in a manner that makes the maximum possible use of plant specific data, and
- to identify the relative weaknesses in a defence in depth which could affect plant safe shutdown capability as a result of a fire event.

There are several benefits of PSA in safe shutdown analysis for fires. On the one side, a fire PSA makes it more easy to perform deterministic analysis. For example, input probabilistic model for internal events pre-developed within TACIS project facilitates the identification of the safety related components which are necessary for plant safe shutdown. Besides, probabilistic screening makes it possible to reduce the number of fire zones to be analyzed.

On the other side, PSA based technique allows to identify significant vulnerabilities of the plant missed in deterministic analysis of safe shutdown. For example, PSA can identify possible beyond design accidents such as multiple opening of relief valves which are supposed to lead to reactor core damage directly in spite of the availability of safe shutdown paths.

The fire PSA for Balakovo Unit 4 is going to be finished. Based on results of qualitative and probabilistic analysis plant vulnerabilities have been defined and prioritised depending on their safety significance. Plant modifications based on fire PSA are now under development.

References

1. J.A.Carretero, Y.Shvyryaev, and J.M.Lanore "Item 8: Analysis of accident initiating events, including incidents during shutdown, fire and flooding. Comparative analysis of various PSAs." Final Report. Ciemat, 082503-F-CI-EC-0001, 1997.

2. G.V.Tokmachev and Y.V.Shvyryaev. "Lessons learned in applying PSA methods to VVER-1000 design." In: Proceedings of the International Conference on Probabilistic Safety Assessment Methodology and Applications PSA'95. November 26-30, 1995, Seoul, Korea, Volume 2, pages 783-787, Korea Atomic Energy Research Institute, Seoul, 1995.

3. "General Rules of Ensuring Nuclear Power Plant Safety." OPB-88/97. Gosatomnadzor of RF. PNAE G-01-011-97. Moscow, 1997 (available in Russian). Госатомнадзор России. "Общие положения обеспечения безопасности атомных станций." ОПБ-88/97. ПНАЭ Г-01-011-97. Москва 1997.

4. J.A.Carretero, Y.Shvyryaev, G.Tokmachev, V.Morozov, and P.Fernández "Results of Novovoronezh-3 PSA Performed within TACIS-91 Programme." To be presented at TOP SAFE '98 International Conference, Valencia - Spain, April 15-17, 1998.

5. V.Morozov and G.Tokmachev "Risk based definition of TS requirements for NPPs with VVER type reactor." IAEA Technical Committee Meeting on "Advances in Safety Related Maintenance", 15-19 September 1997, Vienna, Austria.

6. V.Pogorelov "Regulation activity in the area of NPP fire safety in Russia - legislation basis and experience of licensing." IAEA-SM-345/13. International Atomic Energy Agency Symposium on Upgrading the Fire Safety of Operating Nuclear Power Plants. Vienna, November 1997 (available in Russian). В.И.Погорелов "Регулирующая деятельность в области пожарной безопасности АЭС в Российской Федерации - законодательная база и опыт лицензирования."

7. G.Soldatov, V.Morozov, and G.Tokmachev "Safe shutdown analysis for fires at NPP with VVER-1000." IAEA-SM-345/9. International Atomic Energy Agency Symposium on Upgrading the Fire Safety of Operating Nuclear Power Plants. Vienna, November 1997 (available in Russian). Г.Е.Солдатов, В.Б.Морозов, Г.В.Токмачев. "Анализ безопасного останова АЭС с ВВЭР-1000 при пожаре."

8. "US Department of Energy Reactor Core Protection Evaluation Methodology for Fires at Soviet-Designed RBMK and VVER Nuclear Power Plants." US Department of Energy, Washington, DC, December 1996.