

# Success Criteria Definition and Accident Sequence Analysis Tasks for VVER-440 PSA

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# BACKGROUND OF REVIEW

(1)

1. **Level 1 PSA studies of NVNPP Unit 3 accomplished within the scope of the project of the in-depth safety analysis of Novovoronezh NPP, Units 3&4, (NOVISA) was completed in 1998.**
2. **Work was performed by NV NPP, AEP, OKB “Gidropress” and Russian Research Centre “Kurchatov Institute”**
3. **Peer Review of NOVISA Project was performed by SEC NRS GAN of Russia in March 2002.**
4. **Work was sponsored by United States Department of Energy**

# BACKGROUND OF REVIEW

(2)

1. **IAEA C3.RER/9/068 Regional Workshop for PSA Specialists and Practitioners on Harmonization of PSA Methodology Approaches for VVER 440 Reactors and Comparison of PSA Results, Bratislava, Slovakia, 4-8 March 2002**
2. **Level 1 PSA studies for Unit 3 (V-179) of NvNPP (NOVISA Project, 1998)**
3. **Level 1 PSA studies for Unit 3 (V-230) of Kozloduy NPP (Riskengineering, 1995)**
4. **Level 1 PSA studies for Unit 1 (V-230) of J.Bohunice NPP (RELCO, 1999)**

# **SUBJECT OF REVIEW**

## **for NOVISA**

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**Success Criteria Definition and  
Accident Sequences Modeling  
Element of the Novovoronezh Unit 3  
Level-1 Probabilistic Safety  
Analysis.**

# **REVIEWED WORK PACKAGES for NOVISA**

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- 1. Input deck developed for code RELAP5 and plant design information [1,2] Novovoronezh Nuclear Plant. NOVISA Project. Hand Book for Unit 3 and 4 of Novovoronezh NPP for Relap5 code.**
- 2. List of calculations for TH analysis [3].**
- 3. Calculations to support success criteria [4,5].**
- 4. Success criteria analysis [6,7,8,12].**
- 5. Accident sequence analysis [9,10,11,12].**
- 6. Integral probabilistic model of NVNPP Unit 3 in SAPHIRE format.**

# REVIEWED DOCUMENTS for NOVISA

1. **Novovoronezh Nuclear Plant. NOVIZA Project. Final verified Input Deck for code RELAP5 and supporting documentation. 5BW010XR**
2. **Novovoronezh Nuclear Plant. NOVIZA Project. Hand Book for Unit 3 and 4 of Novovoronezh NPP for Relap5 code.**
3. **Novovoronezh Nuclear Plant. NOVIZA Project. NOVIZA Project. List of T/H Analysis to Support Success Criteria Analysis. 6BW020XR.**
4. **Novovoronezh Nuclear Plant. NOVIZA Project. NOVIZA Project. Calculations To Support Success Criteria-I. 5CW010XE.**
5. **Novovoronezh Nuclear Plant. NOVIZA Project. NOVIZA Project. Calculations To Support Success Criteria-II. 5CW020XE.**
6. **Novovoronezh Nuclear Plant. NOVIZA Project. NOVIZA Project. Success Criteria Guideline (NPG-2).**
7. **Novovoronezh Nuclear Plant. NOVIZA Project. Analysis of Success Criteria. Preliminary Success Criteria. 6BW01BXR.**
8. **Novovoronezh Nuclear Plant. NOVIZA. Project. Final Success Criteria: LOCA, ILOCA, SGTR. 6BW03AXR.**
9. **Novovoronezh Nuclear Plant. NOVIZA Project. NOVIZA Project. Accident sequence analysis Guideline (NPG-4).**
10. **Novovoronezh Nuclear Plant. NOVIZA Project. Final Event Trees-I: LOCA, ILOCA, SGTR. 6DW030XE.**
11. **Novovoronezh Nuclear Plant. NOVIZA Project. Final Event Trees for General Transients. 6DW02CXE.**
12. **Novovoronezh Nuclear Plant. NOVIZA Project. PSA level 1 final report. 6JW01AXE.**

# THE OBJECTIVES OBJECTIVES OF THE REVIEW FOR NOVISA

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1. Evaluation of the clarity, completeness and traceability of the documentation associated with definition of the safety functions, safety systems and success criteria
2. Evaluation of the completeness of the list of safety functions, and of the front-line systems that directly perform the safety functions
3. Evaluation of the validity of the system success criteria
4. Evaluation of the clarity, completeness and traceability of the report and supporting documentation associated with definition of the accident sequences and development of the event trees
5. Evaluation of adequacy and completeness of the summary list of Event tree top events, and of the front-line system fault trees
6. Evaluation of adequacy and completeness of descriptions of the event trees for each initiating-event group
7. Evaluation of adequacy and completeness of descriptions of event trees structure, success criteria, and grouping of accident sequences
8. Evaluation of the correctness of usage of TH analysis results in the success criteria definition and accident modeling process

## CRITERIA OF REVIEW

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- ✓ Procedure for Conducting Probabilistic Safety Assessment of Nuclear Power Plants (Level-1), Safety Series #50-P-4, IAEA, Vienna, 1992.
- ✓ Regulatory review of probabilistic safety assessment (PSA) Level 1, IAEA-TECDOC-1135, IAEA, Vienna, 2000.
- ✓ IPERS guidelines for the international peer review service. Second Edition, IAEA-TECDOC-832, IAEA, Vienna, 1995.

# USED FOR REVIEW EVALUATION QUESTIONS for NOVISA (1)

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## Success Criteria Definition and Accident Sequence Modeling Documentation

1. **Is the documentation clearly written, adequate and traceable?**
2. **Are lists of front-line systems and safety functions clearly presented, adequately documented and do they refer to the reference status of NVNPP with account for upgrading measures?**
3. **Are dependency matrices (or another formats with similar information) clearly presented and adequately documented?**
4. **Are success criteria clearly presented and adequately documented?**
5. **Is list of the event tree for each initiating event group clearly presented and adequately documented?**
6. **Is list of summary of the event tree top events and sequence naming, clearly presented and adequately documented and corresponds to the ETs in PRA computer model?**
7. **Are computer files (event tree) for IRRAS code and their analyses clearly presented and adequately documented?**
8. **Are the thermalhydraulic analysis results available complete and clearly documented?**

# USED FOR REVIEW EVALUATION QUESTIONS for NOVISA (2)

## Evaluation of Safety Functions and Front-line Systems

1. Do safety functions correspond to similar plant PRAs?
2. Do safety functions correspond to other literature?
3. Is list of safety functions and associated front-line systems presented?
4. Are descriptions of front-line and support systems reasonably complete, are they based upon as-built P&IDs, and are they reflective the referenced status of NVNPP with account for upgrading measures?

## Evaluation of Success Criteria

1. Are all assumption listed?
2. Are all assumptions adequate and supported with analysis and/or reasonable judgment?
3. Are the procedures involved in the success criteria analysis precisely formulated, and are have the specific references to the primary sources where these procedures are established?
4. Were the success criteria for each system based upon documented analysis and realistic criteria?
5. If engineering or expert judgment is used for any success criteria, was the basis for the judgment stated; is the judgment reasonable?
6. If plant transient calculations were performed, are all the supporting documentation adequate for review?
7. Is each success criterion accurate, reproducible and documented?

# USED FOR REVIEW EVALUATION QUESTIONS for NOVISA (3)

## Evaluation of Success Criteria

8. If operator action is required, is time constraint presented along with its technical basis?
9. If any system recovery is modeled (including power recovery) is time constraint presented along with its technical basis?
10. If mission times presented along with their technical basis?
11. Is the time constraint accurate and reproducible?
12. Were the success criteria for a system checked to determine whether it depends on success or failure of some other safety system?
13. Were the success criteria defined with account for associated effects of IEs (i.e. “steaming of turbine hall”, “sump clogging”, “compartment heating”, etc)?
14. Were success criteria for systems required in each event tree (accident sequence) explicitly defined and justified?
15. Were the success criteria for front-line and support systems expressed in terms of performance criteria?
16. Were mission time requirements justified from functional and operational standpoints?
17. Were success criteria based on realistic assumptions which are justified by appropriate analyses?
18. Were all possible dependencies influencing support criteria identified and documented (shared equipment, equipment operation conditions affected by the IE, etc)?

# USED FOR REVIEW EVALUATION QUESTIONS for NOVISA (4)

## Assessment of Adequacy and Completeness of Accident Sequence Modeling

1. Were criteria for what constitutes core damage clearly stated?
2. Are basis and procedure for assuring completeness of accident sequence analysis adequately described; are all assumptions presented?
3. Are all assumptions adequate and supported with analysis and/or reasonable judgment?
4. Are top events consistent with accident sequence descriptions (with success criteria, system recovery times, operator procedures, automatic actuation logic)?
5. Do event trees correspond to similar plant PRAs?
6. Were event trees developed based upon plant-specific design specifications, normal and emergency operating procedures?
7. Were plant-specific procedures used in defining event trees?
8. Were sequences, depended on interaction between operators and system, evaluated?
9. Were dependencies accurately represented and modeled (dependencies caused by environmental impact associated with the originated IE; functional dependencies; shared component; system interactions; subtle interactions)?
10. Are all procedures properly accounted in accident sequence models (i.e. requirements of symptom based procedures, etc.)?
11. Were the accident models developed with account for all effects of IEs on mitigating systems (including support systems) and operator actions (i.e. steaming of turbine hall for FWB/SLB, high temperature and humidity in the compartments for leaks outside confinement, pipe wiping, sump clogging, etc)?

# **USED FOR REVIEW EVALUATION QUESTIONS for NOVISA (5)**

## **Assessment of Adequacy and Completeness of Accident Sequence Modeling**

12. **Was the timing for system actions and operator actions explicitly identified for each event sequence?**
13. **If time frames were derived from thermal hydraulic analysis, are all the supporting documentation adequate for review?**
14. **Was the accident sequence logic organized in such a way that any dependencies missed (sequencing of top events, IE effects on mitigating systems, system dependencies)?**
15. **Was the influence of the other units properly accounted in the accident sequence model?**

## **Evaluation of Grouping of Accident Sequences**

1. **Were endpoint outcomes for the event sequences that lead to core damage consistent with the defined criteria for core damage?**
2. **Were the event sequences that are identified for transfer to other event trees accurately represented and modeled?**
3. **Do all transferring ETs developed?**
4. **Do transferring ETs account for bounding conditions in originated ETs?**
5. **Were the success criteria and event trees task performed in a complete and correct manner?**

# GENERAL CONCLUSIONS FOR INPUT DECK DEVELOPING TASK FOR NOVISA (1)

- ✓ Generally, Input Deck is developed on enough high level in boundary of selected for modeling systems.
- ✓ The information about Input Deck development [1] is presented in a very compressed form.
- ✓ Insufficiency of information about algorithms of operation of active components and their realizations in an Input Deck. In most cases it is not possible to identify how various elements and functions of systems in an Input Deck are realized and its connection with the data in [2].
- ✓ Insufficiency (simplification) of modeling of feed water system, pressurizer spray system, primary circuit makeup and blowdown systems, primary circuit emergency injection system and loss of SDS-TN system.

# GENERAL CONCLUSIONS FOR TH SUPPORT OF PSA FOR NOVISA (1)

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- ✓ **Some results of TH calculations were useful for PSA.**
- ✓ **Generally, thermalhydraulic support analyses are poor, incomplete and inconsistent in the NOVISA PSA.**
- ✓ **There is no either specific section or any other information with the reasons and specific goals of performance of each of calculation.**
- ✓ **There is no section or the information about the analysis of calculations already existing and executed within the framework of another studies for this or similar units and applicable for use in given PSA.**
- ✓ **Formulations of the purposes for many of calculations have the very general character. For example - " The substantiation of criteria of success " or " Specification of boundary conditions for IE ". I.e. it is not underlined, which systems and what their criteria of success will be investigated.**

## GENERAL CONCLUSIONS FOR TH SUPPORT OF PSA FOR NOVISA (2)

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- ✓ Based on the presented documentation it is impossible to trace how the results of thermohydraulic calculation meet the needs of the PSA. This connection especially should be defined at the stage of performance of the additional calculations after the preliminary quantification for PSA model.
- ✓ Initial and boundary conditions for many of calculations are insufficiently identified.
- ✓ Generalizations and conclusions are absent for the results of specific calculations and series of calculations, which could be used for formation of success criteria.
- ✓ Results of some calculations can not be used, as they are not adequate either because of restrictions of modeling of an input deck for code Relap 5 or usage of incorrect boundary conditions.
- ✓ 17 calculations are not performed, though they are requested and included into the list of thermalhydraulic calculations in [3].

## **GENERAL CONCLUSIONS FOR FOR SUCCESS CRITERIA DEFINITION FOR NOVISA (1)**

- ✓ **Generally the task of Success Criteria Definition is performed with high quality level.**
- ✓ **The list of selected Success Criteria includes the most impotent equipments and operator actions for accident sequences modeling of unit.**
- ✓ **The presented documentation has enough good quality.**
- ✓ **Definitions of Success Criteria are precise enough.**
- ✓ **Declared Success Criteria are in accordance with PSA model.**
- ✓ **The reference status of NVNPP on 2000 year conforms to developed PSA model.**

## GENERAL CONCLUSIONS FOR FOR SUCCESS CRITERIA DEFINITION FOR NOVISA (2)

- ✓ There is no specific information on the analysis used for the justification of each success criteria, (TH calculations, expert judgment, reference to other analysis, etc.).
- ✓ There is no information on the success criteria for support systems.
- ✓ In the success criteria definition the mission time or available time for operator actions in the majority is stated in the form "During short time " without concrete information.
- ✓ In success criteria the operation of a number of important systems (for example SDS\_EN, spray injection into PR) is not taken into account.
- ✓ A number of success criteria non-justified.

## GENERAL CONCLUSIONS FOR ACCIDENT SEQUENCES MODELING FOR NOVISA (1)

- ✓ Generally the subtask of Accident Sequence Analysis is performed on high word level.
- ✓ The modeled event trees have good realistic conformation with accident sequences progress.
- ✓ The list of the event trees for each initiating event group is clearly presented and adequately documented.
- ✓ Descriptions of modeled in accident sequences have enough volume and quality.
- ✓ Declared event trees are correspond to Sapphire computer PSA model.

## GENERAL CONCLUSIONS FOR ACCIDENT SEQUENCES MODELING FOR NOVISA (2)

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- ✓ The operation of a some important systems, witch are influences to a development of emergency successions, such as SDS-EN, spray injection into PR, MCPs is not taken into account.
- ✓ The some of the important dependences (for example, such as dependence of serviceability of secondary circuit systems from steaming and flooding effects due to leaks of secondary circuits, dependence of operation of the PR SV from operation of EIPs, isolation of steam leaks, switching off of MCPs and losses of serviceability of an spray injection into PR) is not taken into account.

## GENERAL CONCLUSIONS FOR ACCIDENT SEQUENCES MODELING FOR NOVISA (3)

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- ✓ The some IEs are not taken into account and the emergency successions for them are not developed (such IEs, as spurious switching off of feed water superheaters, spurious opening of regulators of SGs levels, spurious spray injection into PR, small leaks of secondary circuits).
- ✓ The requests of emergency procedures for stable “cold” end state of unit weren’t taken into account.

# GENERAL RESULTS OF REVIEW

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- ✓ As a whole high quality of performance reviewed tasks of PSA and documentation.
- ✓ Incompleteness of analyses separate problems of PSA.
- ✓ Poor quality of deterministic support of the PSA, insufficient quality of the documentation of this subtask.
- ✓ Presence of separate mistakes of the Success Criteria Definition and Accident Sequences Modeling, resulted to not significant understating of overall estimation of CDF.

# COMPARISON OF DIFFERENT PSA

## (1)

Item	Novovoronezh NPP, Unit 3	Kozloduy NPP, Unit 3	J.Bohunice NPP, Unit 1
1. Recover of normal heat removal through the turbine condensers after loss of this heat removal	The possibility of restoration of heat removal through the turbine condensers for IE with loss of normal heat removal through the turbine condensers is not considered.	Recover of normal heat removal on not affected loops through the turbine condensers after loss of this heat removal is considered.	It wasn't considered.
2. Taking into account the impact of steaming or flooding effects of the turbine hall with secondary leaks	The impact of steaming or flooding effects of the turbine hall with secondary leaks upon generation of such events the dependent failures of equipments and components of the heat removal system via the secondary circuit was not taken into account..	It wasn't considered. But was used of modeling of supper emergency feed water system.	It was considered, detail modeling is performed. After reconstruction of the plant only the MFW and AFW system can be affected by the IE. The EFW system piping was replaced from the affected area.
3. Modeling of IEs with spurious SDA opening	In modeling of initiating events with spurious SDA opening, the events related to non-implementation of power decrease and stabilization of the primary and secondary parameters at the initial stage were not considered since these actions are performed automatically by the normal operation systems which are serviceable till the moment of initiating event arise.	It wasn't considered. These IEs were impacted to secondary side leaks IE group.	These events are excluded from the analyses. Spurious opening and not closing of a single SG SV, steam dump station to the atmosphere or steam dump station to the condenser can be compensated by MFW pumps without need to scram the reactor.
4. Taking into account the possibility of primary coolant loss outside the confinement through tightness or ventilation system	It was assumed that for the group of LOCA's (with the spray system in operation) under review no obvious cause exists for loss of water from the emergency make up system due to large leaks outside the confinement. Therefore, in the ET development the events caused by the loss of tightness of the containment, were not considered.	ET development the events caused by the loss of tightness or ventilation system of the containment, were not considered.	Not considered. This contribution to the risk is negligible.
5. Taking into account the possibility of reactor vessel overcooling for not isolable steam line leakage	It's conservatively defined that not isolable leakage of steam line of 2 and more SGs lead to core damage due to reactor vessel overcooling  It's conservatively defined that not isolation of affected SG from feed water line in case of not isolable steam line leakage lead to core damage due to reactor vessel overcooling	In the past PSAs SHIVER event was defined in the event trees as consequence of unheated water feed or excessive cooling down of primary side by secondary side on SG integrity. Better understanding of the event phenomena and the performed thermal-hydraulic analysis have shown negligible impact of SHIVER on the plant safety. So, it is not involved in the event trees of this study.	It wasn't considered.

# COMPARISON OF DIFFERENT PSA

## (2)

Item	Novovoronezh NPP, Unit 3	Kozloduy NPP, Unit 3	J.Bohunice NPP, Unit 1
6. Using of procedures for modeling of END States	For the most successful sequences were used hot stable unit states. Only for IEs with unisolable primary circuit LOCAs, SGCR and SGTR were used successful cold end states.	For definition of successful end states was used information from procedures. In all cases where procedures required of removal of unit into cold state, it was modeled.	All successful sequences are carried out to the point where stable hot shutdown conditions or stable long term cooling conditions are established. For success cold shutdown is required only for SGTR, SGTM and interfacing LOCA.
7. Taking into account the operation of SDS-EN	It wasn't considered	It wasn't considered	It wasn't considered
8. Using of positive features of units interconnection for secondary feed water supply	No credit was given to feed and bleed procedure	In case of loss of all feed water supply into secondary side it was considered of the using feed water reserve of unit 4.	The AFWS of unit 2 is modeled in the unit 1 PSA.
9. Modeling of failure to open of PR SVs	Failure to open of all safety valves were considered if there was demand for opening.	The failure to open of PR SVs is not considerate due to negligible probability.	The failure mode is modeled for loss of offsite power and for seismic event.
10. Modeling of the operation of normal primary circuit makeup system	Operation of a normal primary circuit makeup system was not considered in the PSA. However, interfacing LOCA via the normal primary circuit makeup system was considered as an initiator.	The modeling of normal primary circuit makeup system is not considered.	RCS inventory makeup is not required if RCS integrity is maintained. Normal pressurizer water level is sufficient to accommodate RCS inventory shrinkage from full power to hot shutdown. The normal makeup system is not considered for compensation of losses in case of LOCA (only in case of very small LOCA where the losses are compensated).

# COMPARISON OF DIFFERENT PSA

## (3)

Item	Novovoronezh NPP, Unit 3	Kozloduy NPP, Unit 3	J.Bohunice NPP, Unit 1
11. Modeling of ATWS accident sequences	Failure to trip the reactor (ATWS) was considered as the core damage end state.	ATWS subtree wasn't developed. The overall frequency of ATWS events was conservatively added to the CD frequency.	ATWS subtree wasn't developed. The overall frequency of ATWS events was conservatively added to the CD frequency.
12. Modeling of minimal number of available SGs for successful heat removal for accident sequences with secondary circuit using	For all sequences that require primary to secondary side heat removal, the success criteria were assumed to be cooled through one steam generator available.	For all sequences that require primary to secondary side heat removal, the success criteria were assumed to be cooled through two steam generator available.	For all sequences that require primary to secondary side heat removal, the success criteria were assumed to be cooled through 1/6 SGs during pumped circulation or 2/6 SGs during natural circulation.
13. Modeling of primary bleed and feed operation	No credit was given to feed and bleed procedure	Modeling of primary feed and bleed operation was considered.	Modeling of primary feed and bleed operation was considered.
14. Definition of boundary primary LOCA size for sufficient post LOCA heat removal without secondary circuit	It was supposed that leak through diameter of 32 mm and more would be enough for heat removal without secondary side involvement.	It was supposed that secondary circuit is required for long term heat removal for leak through diameter less then 32 mm. For leaks through diameter between 32 - 100 mm the secondary circuit is required without of feed water supplying. For leaks through diameter more 100 mm the secondary circuit isn't required.	For LOCAs > 32 mm where blowdown of the primary circuit is relatively quick, it is assumed that the core cooling can be maintained by post LOCA circulation via the break using HPIS or LPIS system. LOCAs < 32 mm are too small to afford sufficient primary heat removal during post LOCA recirculation via break, therefore secondary side heat removal is required.
15. Modeling of possibility of primary circuit break isolation by MIVs prior pressure decrease and core damage	It was considered for small and medium LOCAs	It was considered only for interface LOCAs. Maximal leaks diameter not more 13 mm.	For LOCAs < 32 mm it is assumed that successful isolation of the break is achievable (if the break is isolable) prior to core damage. Successful isolation of LOCAs > 32 mm is conservatively not assumed due to the pressure difference across the main isolating valves which can prevent to close them.
16. Modeling of the passive systems of the confinement overpressure protection	Passive systems of the confinement overpressure protection were not modeled.	Passive systems of the confinement overpressure protection were not considered.	Passive systems of the confinement overpressure protection were not considered.