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Theoretical Implications of Level 1 Probabilistic Risk Assessment Initiating Events Selection for Russian type of Integral SMR RITM-200N

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1. Introduction

Small modular reactors (SMRs) offer firm, low-carbon energy generation from compact units and rely on passive features that extend coping times. As Russian-type integral SMR RITM-200N has been selected in Uzbekistan for construction, alongside the plans for conventional VVER-1000 units, the safety case must explicitly address integral layouts. Probabilistic Risk Assessment (PRA), developed for large-scale PWRs (Pressurized Water Reactors), therefore requires adaptation. This paper sets out a design-led, comparative framework to define Level-1 PRA Initiating Events (IEs) for RITM-200N across full power operation, based on the experience of two advanced PWRs - VVER-1000 and APR1400. The framework underpins success-criteria specification, event- and fault-tree development, and subsequent quantification.

2. Methods and Results

2.1 Methodology

The study employs a qualitative, theoretical method that reconstructs how IEs are defined, grouped according to same success criteria or plant response basing on large scale reactors' experience, and then translates that logic to an integral SMR without simulation or quantification.

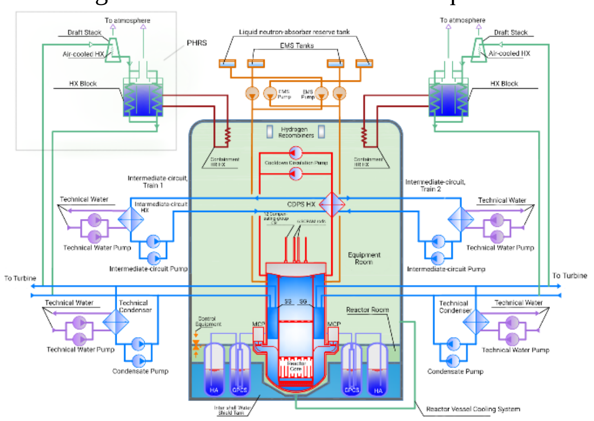

Fig 1. Schematic of RITM-200N

The VVER-1000 "Kalinin Unit 1 VVER-1000 PRA Report" [1] and APR1400 "Probabilistic Risk Assessment and Severe Accident Evaluation" [2], focusing on the structure of a Level 1 PRA, the safety systems credited, the way IEs are selected and grouped, the success criteria that govern those groups, and how accident sequences and system responses are modeled are reviewed to extract Design-based IEs. VVER-1000 is adopted as an anchor to align with Russian standards and owing to its deployment context in Uzbekistan alongside RITM-200N. Because the publicly available VVER-1000 PRA documentation is comparatively dated, APR1400 was introduced as a contemporary benchmark with a mature probabilistic framework. Although the designs differ in detail, both anchors are large, loop-type PWRs rather than integral configurations, therefore, broadly comparable IE families and success path constructs expected, enabling a controlled transfer of taxonomy and criteria. In parallel, the corresponding design documents such as "Requirements for the content of safety analysis reports for nuclear power plant units with VVER reactors" [3] and "Transient and Accident Analysis" [4] are reviewed to extract Design-based IEs.

The designs of RITM-200N and VVER-1000 are then compared to make the integral SMR features explicit and to show why a tailored approach is needed. For APR1400 and VVER-1000, a mapping is developed between DBIEs and PRA IEs to establish the logic of what is carried in both, what remains only in the deterministic set, and what is introduced only in PRA. The APR1400 precedent is used to propose a modernized IE taxonomy for VVER-1000, aligning the list with contemporary naming, grouping logic, and advanced VVER-1000 design features, consequentially, the clarified APR1400/VVER-1000 grouping logic covering LOCA classes, transient families, electrical power loss initiators, etc., is implemented for RITM-200N with design-appropriate adaptations, including delineation of a support systems failure family tailored to RITM-200N's specific systems. Thus, PRA-based list of IEs is proposed for RITM-200N for full power operation. drawing on the IAEA "Design Features to Achieve Defense in Depth in Small and Medium Sized Reactors" [5], Technical Documents and established PWR models. The approach is qualitative and design-informed; selection rules follow PRA logic, with an item carried as a headline IE when its occurrence at time zero changes the event tree topology or the minimum success path.

2.2 Results

The results include proposed lists of IEs for RITM-200N full power operation. The integral primary boundary removes loop-piping large-break LOCA; accordingly, the LOCA family is limited to vessel/penetration-credible small- and medium-break cases, typical for large-scale reactors, with explicit inclusion of a functional-LOCA mode arising from a Gas Pressure Control System (GPCS) relief valve stuck open due to its coupling with Hydroaccumulators (HAs). Primary-to-secondary pathways are differentiated as conventional Steam Generator Tube Rupture (SGTR) and a cassette header rupture (distinct failure geometry for cassette steam generators). An integral-unique primary-to-intermediate heat-exchanger tube rupture is carried to represent a primary-to-intermediate cooling circuit leakage path with no direct analogue in loop-type plants, as it propagates into the closed intermediate cooling circuit and impacts the safety heat-sink chain.

Table 1: Proposed list of PRA-based IEs for RITM-200N for full power operation

Group	IE
1. Loss of Coolant (LOCA)	#LLOCA - Large LOCA
	SLOCA - Small LOCA
	MLOCA - Medium LOCA
	*GPCS pressure relief valve stuck open
	SGTR - Steam Generator Tube Rupture
	*SG cassette header rupture
	*Primary - Intermediate Heat Exchanger (HX) tube rupture
	ISLOCA - Interfacing System LOCA
2. Secondary breaks & major transients	MSLB - Main Steam Line Break (inside/outside; isolable/not isolable)
	FWLB - Feedwater Line Break (inside/outside)
	LOFW- Loss of Feedwater
	LOCV/loss of heat sink - Loss of Condenser Vacuum/heat sink
	GTRN - General Transients
3. Reactivity/ protection	ATWS - Anticipated Transients without SCRAM
4. Electrical power	LOOP - Loss of Offsite Power (short-term)
	LOOP - Loss of Offsite Power (long-term)
	SBO Station Blackout
	Loss of DC bus
	Loss of safety-class AC bus
5. Heat sink chain/support	Partial loss of Intermediate Cooling Circuit (ICC)
	Total loss of Intermediate Cooling Circuit (ICC)
	Partial loss of Technical Water System (TWS)
	Total loss of Technical Water System (TWS)
	LOIA - Loss of Instrument Air (as applicable)

The proposed IE sets for RITM-200N keep the familiar PWR logic but recast it around an integral vessel. At full power, loop-piping large breaks drop out, marked as #LLOCA as an excluded due to the design IE; the LOCA family is limited to small and medium primary losses credible on an integral boundary. Design-specific IEs are marked with "*", as *GPCS pressure relief valve is a functional LOCA on an integral vessel. In RITM-200N (Fig.1) GPCS, unlike classical Pressurizer in VVER-1000 or APR1400, ties into Hydroaccumulators, that will inject automatically when Reactor Coolant System pressure drops and crosses their setpoint. Primary to secondary paths are carried explicitly as SGTR and *SG cassette header rupture. *Primary to Intermediate HX tube rupture (CDPS-HX tube rupture) creates primary-to-ICC leakage, degrading Intermediate loop and safety paths relying on it. PWRs transfer core heat only across the SG tubes (primary-to-secondary), in RITM-200N, by contrast, ICC is a closed safety-related circuit, that takes heat from safety Cooldown and purification System (CDPS) HXs and transfers it to TWS, hence the IE related is considered separately. An Interfacing System LOCA, or primary leak outside containment is retained. Secondary side initiators follow established practice: MSLB variants, FWLB, LOFW, LOCV or heat sink, and GTRN envelope. One reactivity outlier is kept as a separate initiator, ATWS. Electrical initiators include short- and long-term LOOP, SBO, and loss of a vital DC or safety AC bus. Support system initiators reflect the heat sink chain of an integral plant. Degradation or failure of ICC is crucial as it that serves CDPS. TWS loss implies condenser heat sink loss, ICC sink loss, Diesel Generators run time might become limited (if depend on TWS, not specified in the design information available). LOIA is included only if safety significant pneumatic actuation is credited.

3. Conclusions

This study proposes mode-specific IEs for an integral SMR, derived from a Design-based-to-PRA mapping benchmarked against APR1400 and VVER-1000 practice. The set includes design specific items that reflect the integral vessel, internal interfaces, and the plant's heat sink chain. The result is a usable foundation for PRA work in Uzbekistan: define plant specific success criteria, build event and fault trees, set data needs, and proceed to quantification and review.

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