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KRŠKO SEISMIC LEVEL II PRA

by

P. N. Shah, R. Prior, F. P. Wolvaardt, R. Bastien
Westinghouse Energy Europe S.A.
Boulevard Paepsem, 20
1070 Brussels, Belgium

Abstract

The analysis of seismic risk has been receiving increased attention in recent years. It is recognized that seismic excitation has the potential of simultaneously damaging several redundant components in a nuclear power plant. The basis for the conclusion in the Reactor Safety Study (U.S. NRC 1975) that earthquakes are not major contributors to nuclear power plant risk has been questioned by several experts in the fields of seismology, earthquake engineering, and probabilistic risk analysis. Seismic risk studies performed since the Reactor Safety Study have indicated that the contribution of seismic risk to the overall plant risk may be significant.

The evaluation of seismic risk requires information concerning the seismologic and geographic characteristics of the region, the capacities of structures and components to withstand earthquakes beyond design basis, and interactions between the various systems and components of a nuclear power plant.

A level 1 analysis, plant damage state bridge trees, and a level 2 analysis were performed for the Krško Nuclear Power Plant. This paper focuses on the level 2 seismic analysis since relatively few level 2 seismic analyses have been performed to date.

Conceptually, the seismic level 2 study covers the same scope as the level 2 study performed for the internal events analysis. The containment performance was assessed by evaluating, for each plant damage state, the conditional probability that the damage state would result in each of the fission product release categories.

Krško has a seismic core melt frequency similar to western plants located in high seismic areas. Over half the core melt frequency is attributed to the station blackout initiating event. Approximately 66% of the seismic core damage frequency falls into the long term overpressurization with core concrete attack release category. This relatively large contribution was due to the station blackout type events resulting from a seismic initiator.

Although, intact containment sequences account for only 6% of the seismic core damage frequency, most sequences lead to a very late failure.

Introduction

This paper summarizes the level 2 Seismic Individual Plant External Event Examination (IPEEE) study performed for the Krško plant in Slovenia. The level 2 study is an integral part of the Krško Seismic IPEEE. The level 2 study takes as input the results of the level 1 system analysis, in the form of grouped accident sequences leading to core damage, and their frequencies, and evaluates the consequences of these severe accidents in terms of the plant's (and particularly the containment's) response. The result of level 2 is a quantified plant specific risk profile, describing the magnitude, frequency, and characteristics of fission product releases to the environment which can result from the core damaging events.

Plant Models and Methods for Assessment of Physical Processes

The Krško seismic level 2 IPEEE includes a detailed evaluation of the response of the Krško plant to severe accident conditions. These investigations take various forms:

a. Phenomenological Evaluations: Nine phenomenological evaluations have been performed. The purpose of phenomenological evaluations is to provide detailed investigation of the plant specific response to important severe accident phenomena. The results provide a primary source of information for the quantification of phenomenological issues in the containment event tree, in particular in defining ranges of possible behavior for uncertain phenomena. The phenomenological evaluations presented are:

- Hydrogen Generation
- Hydrogen Behavior in Containment
- Creep Failure of Primary System or SG Tubes
- Reactor Vessel Failure Modes
- Vessel Thrust at Vessel Failure
- Direct Containment Heating
- Debris Transport, Quench and Coolability
- Steam Explosions
- Containment Failure Mechanisms

The evaluations make extensive use of information on severe accident phenomenology from numerous sources, including previous and ongoing experimental programs, previously performed PSA/IPE and severe accident management studies for other plants and Krško-specific analyses. One advantage of investigating severe accident response in this way is that it allows many different sources of information to be taken into consideration and does not rely entirely on a single model or view.

b. Plant specific severe accident analysis has been performed using the MAAP 3.0B code. All the dominant accident sequences have been analyzed, providing many useful insights into plant response, and also assisting in quantification of the containment event tree.

Bins and Damage States - the Interface with Level 1

The level 1 study has identified the accident sequences, and their frequency, leading to core damage. In addition, in the containment systems tree analysis, these accident sequences have been assigned into "plant damage states". The plant damage state (PDS) groups accident sequences leading to core damage which have similar containment response characteristics, and can therefore reasonably be represented in the subsequent level 2 analysis by a representative accident sequence. The PDS contains the necessary containment system information - in this way, the level 2 analysis concentrates on the phenomenological aspects of containment response to each PDS. For the Krško level 2 IPE, core damage sequences are grouped into plant damage states for further consideration in the containment event tree.

Containment Failure Characterization

The level 2 study includes an analysis of the Krško containment structural capability, which has identified the dominant structural failure modes, the expected failure pressure as a function of temperature, and the associated uncertainties. A composite containment fragility curve, developed from these Krško-specific results, is used in the level 2 study to calculate the expected probability of containment failure for the many different potential loads (also described using probability distributions) on containment during the severe accident progression.

Containment Event Tree, Accident Progression and CET Quantification

The containment event tree (CET) approach is used to provide the framework for identifying, displaying and quantifying severe accident sequences. The Krško CET contains top events related to the severe accident phenomenology. CET split fractions are developed using detailed event decomposition and describing uncertainties in physical phenomena by means of probability distributions. Containment failure probabilities are evaluated using "stress-strength interference" combinations of the specific derived load distribution with the calculated containment structural capacity distribution. In this way, the CET provides the mechanism for the expression and consideration of phenomenological uncertainty in the level 2 study, and also the structure for developing the overall plant risk profile.

Release Categories and Radionuclide Release Characterization

Release categories are defined which provide a means to group severe accident sequences with similar fission product source terms. Accident analysis, using MAAP 3.0B, has been performed to quantify the source term (the magnitude, timing and content of the fission product release from the plant due to the severe accident) associated with each release category by investigating a representative accident sequence.

Release Category Definitions

Each endpoint of the CET represents a single path through the tree, and therefore a unique accident sequence progression. There are many thousands of possible accident progressions, and in order to present and use the results of the seismic level 2 IPEEE in a manageable fashion, the endpoints are grouped into bins termed release categories. A given release category (RC) contains a number of possible accident sequences, which fission product release characteristics (source terms) are similar enough that they can all be reasonably characterized by a single representative accident sequence. The source term of all the accidents within a given release category is then characterized by the source term of the representative sequence.

The definition of release categories must then consider the key sequence progression characteristics which influence the release spectrum. The key characteristics chosen to define the Krško release categories are:

a. Containment status: intact, bypassed, isolation failure or failure in one of four time frames;

b. whether molten core concrete attack (and associated increased fission product release) occurs;

c. whether a release is scrubbed by overlying water (for bypass releases); and

d. whether the core is recovered in-vessel.

Use of these key accident characteristics with the necessary consideration of dependencies, leads to the release categories listed in table 1. The Krško IPE and IPEEE considers 12 release categories, of which three (1, 2 and 4) may be considered as representing very small releases, four (3A, 3B, 5A, 5B) as representing small releases, and five (6, 7A, 7B, 8A, 8B) as representing potentially large releases.

Quantification of Level 2 External Event Analysis

The external event analysis may be regarded as an extension of the main (internal event) analysis to consider potential accident initiators resulting from external influences on the power plant. Conceptually, the level 2 study covers the same scope as before, for an extended set of initiators. In practice, the level 2 external events study makes use of evaluations and analogies with the existing internal events information in order to assess likely containment performance for the new set of initiators. The level 2 external events evaluations have the following characteristics:

a. The scheme used to define the plant damage states is maintained the same as for the internal events.

b. The general containment event tree structure is maintained the same, as are the definitions of the fission product release categories.

c. The source terms corresponding to each release category are maintained.

The inputs for the external event level 2 are the new set of damage states calculated in the level 1 study for external events. The containment performance is assessed by evaluating, for each plant damage state, the conditional probability that the damage state will result in each of the fission product release categories. Where a damage state is present for external events which is also present for internal events, then the conditional probabilities used are taken directly from the internal event study. Where the damage state has not already been quantified in the internal event study, it is quantified by analogy with other damage states, using the knowledge gained during the internal event analysis.

Results of Level 2 Quantification for Seismic Events

Figures 1 and 2 show the results (the release categories and their associated frequencies) of the seismic level 2 analysis. *These figures show contributions to release category frequency from both internal and seismic events.* Figure 1 shows the frequency associated with each release category. A breakdown by initiator can be seen in figure 2. As can be seen from the figure, the transient initiator which is dominated by the station blackout event is by far has the largest initiator frequency.

Seismic events contribute 5.96×10^{-5} /year to the core damage frequency of Krško. This value is above that due to internal events (5.103×10^{-5}/yr).

66% of seismic core damage frequency falls into release category 3B (long term overpressurization with concrete attack). This relatively large contribution to RC3B is due to the importance of station blackout type events resulting from a seismic initiator.

Seismic events with a peak ground acceleration greater than 1.1g were not quantified at level 1 (i.e., detailed systems analysis was not performed), and thus the consequences in terms of accident sequence are not presented. This fraction of the contribution to core damage from seismic events (about 2.3%) has been assigned to a new damage state labeled "UXXXXB". The consequences of these events are unknown, but could in principle result in containment bypass events. The UXXXXB damage state has therefore been assigned to release category 8B with conditional probability 1.0.

Conclusions

Examining the level 2 output for both the internal events and seismic events shows that:

1. Approximately 80 % of the frequency of core damage events lead to a fission product release which can be described as very small or small. This result demonstrates the ruggedness of the Krško plant and its resistance to severe accident challenges.

2. Very small releases result from core damaging events where the containment is not damaged (release categories 1 and 2) and where concrete attack occurs leading to very long term (many days) basemat failure (release category 4). These events make up approximately 25% of the core damage frequency.

3. Small releases result from late containment overpressure failure events (release categories 3 and 5), and these make up a further 59% of the core damage frequency.

4. 17% of core damage frequency represents "large releases". Large releases include early containment failures (RC6), containment isolation failures (RC7A and RC7B) and containment bypass events (RC8A and RC8B).

5. However, early containment failure contributes a negligible 0.05 % (of CDF). This demonstrates that the Krško containment is very resistant to early failure challenges including those due to high pressure melt ejection and that the frequency of such challenges is low.

6. Containment isolation failure events with approximately 9.5 % and bypass events with approximately 7.1% both contribute significantly to the large release frequency, and are important contributors to total risk.

7. The dry reactor cavity design influences significantly the risk profile, leading to the relatively large fraction of long term concrete attack and basemat penetration sequences. A change to a wet cavity could decrease basemat penetration sequences

and long term concrete attack cases (RC 4 and 3B), and increase the "no containment failure" frequency correspondingly.

8. Formalized guidance for recovery actions after core damage has occurred, for example in the form of Westinghouse Owners Group Severe Accident Management Guidelines, but is not credited in the study since it is currently not implemented. Implementation of such guidance could bring significant benefit in overall risk. For example, strategies addressing the minimization of fission product releases, recovery of containment isolation, and recovery of key equipment could significantly reduce the frequency and consequences of all release categories 3 to 8.

9. The base case results indicate that the frequency of recovery of the damaged core in vessel is very small. However, as noted above, the study does not credit accident management strategies not currently implemented. A strategy to flood the outside of the reactor vessel and thereby prevent vessel failure could lead to a significant risk benefit. Such a strategy, being implemented at other plants, is addressed in the WOG SAMG and would be investigated as part of the SAMG implementation.

10. The impact of a typical severe accident filtered vent system in terms of its effect on frequency of containment failure could also have a significant impact on the release frequency. The system basically converts small release events (late overpressure failures in RC3 and RC5) to very small releases (no containment failure, filtered release). The most benefit can be obtained from the system if it is used in combination with a wet cavity modification.

11. The importance of station blackout events caused by seismic initiators is clear when the internal and seismic event analysis results are considered together.

12. The level 2 study has provided a valuable, plant-specific, severe accident analysis database, which has contributed to a greatly improved understanding of the likely response of the Krško plant to a severe accident, and of the accident sequences which dominate the risk profile.

References

1. WENX-95-25, “Krško Individual Plant Examination, Level 2, Summary Report”.

2. WENX-95-24, Krško Individual Plant Examination, Level 2 Report, Volume 4, "Containment Event Tree Notebook Part 4".

3. “Probabilistic Safety Assessment of Nuclear Power Plant Krško, External Event Report,” Section 1.A IPEEE Seismic PRA.

Table 1
Krško Release Categories

RC no.	Release Category Definition
1	Core recovered in-vessel, no containment failure
2	No containment failure
3A	Late (time frame IV) containment failure, no molten core-concrete attack
3B	Late (time frame IV) containment failure, molten core-concrete attack
4	Basemat penetration (no overpressure failure)
5A	Intermediate (time frame III) containment failure, no molten core-concrete attack
5B	Intermediate (time frame III) containment failure, molten core-concrete attack
6	Early (time frame I or II) containment failure
7A	Isolation failure, no molten core-concrete attack
7B	Isolation failure, molten core-concrete attack
8A	Bypass, scrubbed
8B	Bypass, unscrubbed

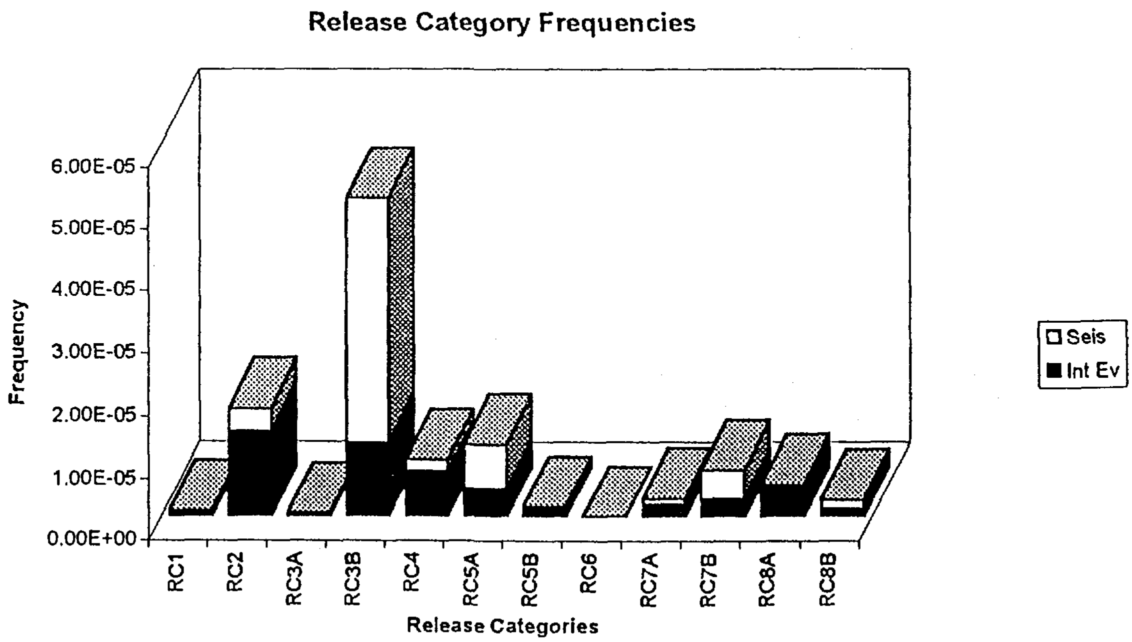

Figure 1
Krško Level 2: Release Category Frequencies

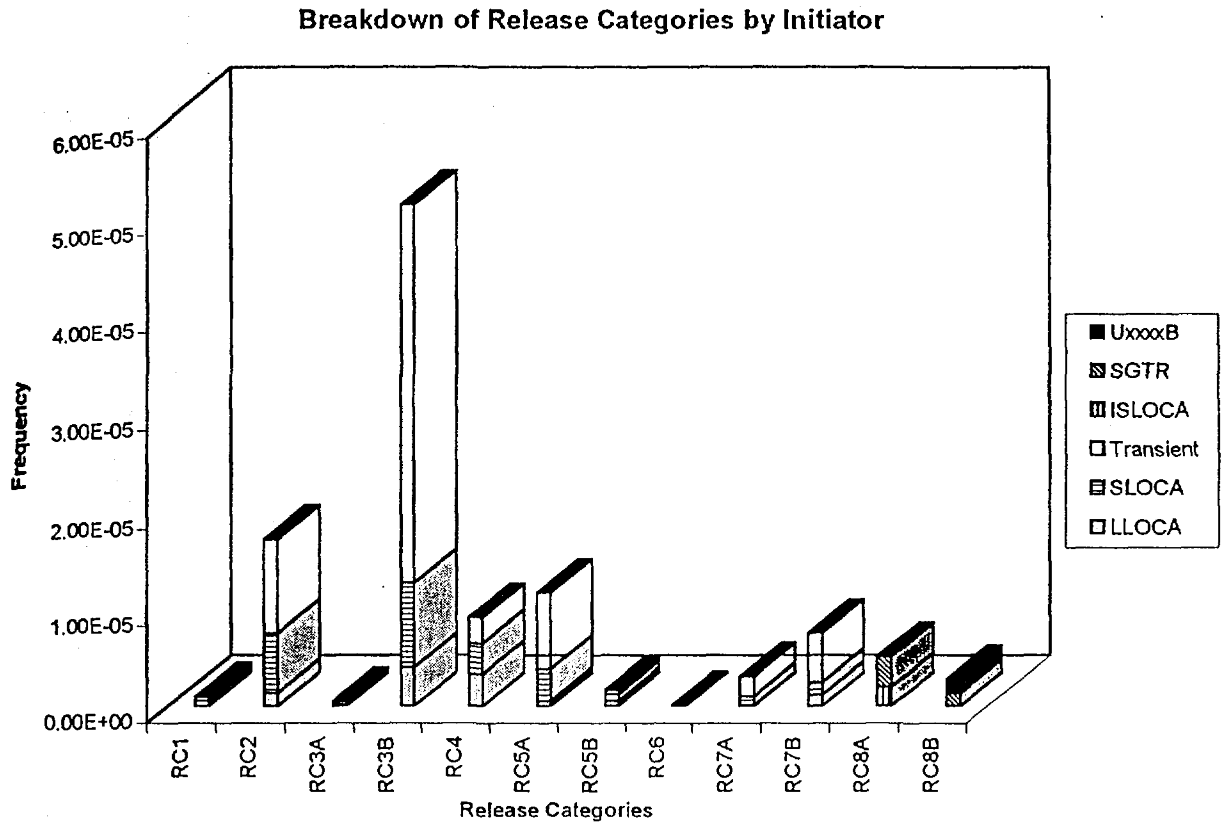

Figure 2
Krško Level 2: Breakdown of Release Categories by Initiator