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SEISMIC PROBABILISTIC SAFETY ANALYSIS OF LOVIISA NPP UNIT 1

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ABSTRACT

The seismic probabilistic safety assessment consists of five phases. In the seismic hazard analysis the seismicity of the plant site is quantified. In the second phase, the structural response of plant buildings is evaluated. On the basis of structural response, the seismic fragilities of selected plant components are developed. In the fourth phase, the plant logic in form of fault trees and event trees is established. In the last step, the quantification of core damage risk on the basis of above information is carried out. For the median value of the annual core damage frequency, the value of 4.4.E–7 was determined.

1. INTRODUCTION

In the following, the methods used to assess the seismic core damage risk during full power operation of the unit 1 of Loviisa NPP are described. The scope and accuracy of the seismic PSA–analysis depend on the level of seismicity of the plant site. In the case of the Loviisa plant, the level of seismicity was expected to be low and in this case it was judged to be sufficient to determine the frequency of seismically induced core damage and to compare this frequency with the core damage frequencies caused by internal initiating events or by the other external initiating events. Thus the results of the Level 1 seismic probabilistic risk assessment can be presented as the cumulative probability distribution of the annual core damage frequency.

2. SEISMICITY OF THE PLANT SITE

The mathematical hazard model used in this study is due to Cornell /1/ and its computer application was set up by McGuire /2/. The detailed steps of the method are the following. Source area delineation is defined first followed with the development of the magnitude occurrence relationship. Maybe the most important step in hazard analysis is the determination of the attenuation function. This function describes the ground motion intensity which depends on magnitude of the event and on the distance between the site and the epicenter. The contribution of each source area to the site seismicity is determined by numerical integration and the seismicity of the site is described in the form of a hazard curve, where the annual exceedance probability of certain peak ground acceleration is given. The hazard analysis for the Loviisa site was based on the Fennoscandian seismic records and the resulting family of hazard curves is given in Fig. 1.

3. THE SELECTION OF COMPONENTS FOR FRAGILITY EVALUATION

The scope of the detailed fragility study was determined with the aid of the plant review and walkdown. The plant components were grouped to three different categories with the aid of so called high (95%) confidence of low (5%) probability of failure (HCLPF) capacity. Components with rating of low (L) have HCLPF capacities that were judged to be lower than 100 cm/sec^2. The components with rating high (H) were judged to have HCLPF capacities higher than 100 cm/sec^2. For certain components, information was not sufficient to rate them either for L nor for H category and these components were given rating medium (M). Components with ratings L or M were selected for specific fragility evaluation. In Loviisa plant, the number of such component types were thirty.

4. STRUCTURAL RESPONSE CALCULATIONS

In order to calculate the fragilities of the plant equipment, it is necessary to obtain seismic responses of structures which support this equipment. The scope of the response analysis depends on the information existing on analyses performed during the design stage and on the method used to develop component fragilities. For Loviisa plant, there is no seismic analysis performed during the design stage so that the structural response analyses had to be set up from scratch. The seismic response calculations were carried out for the most important structures with regard to the seismic safety and, in case of Loviisa plant, the reactor building and turbine/control building were chosen for the response analysis. In order to account for uncertainties in ground motion and structural properties, the structural response was computed in form of probabilistic floor response spectra. The procedure for generating probabilistic floor response spectra follows the methodology developed under the seismic safety margins research program (SSMRP) conducted in the early eighties in the U.S. /3/.

The final result of the spectra generation were the mean and mean + one standard deviation spectra for selected in–structure locations calculated from the sample of thirty spectra generated using Latin Hypercube sampling. The control motion characteristics used in above analysis are given in /4/. An example of the probabilistic floor spectra is given in Fig. 2.

5. SEISMIC FRAGILITIES OF SELECTED COMPONENTS

The seismic fragility of a structure or equipment is defined here as a conditional probability of its failure at a given value of peak ground acceleration.

Seismic fragility is expressed in terms of the ground acceleration capacity of the component. Typically, three parameters are used in describing this capacity: Median ground acceleration capacity A_m, and logarithmic standard deviations β_R and β_U reflecting the randomness in capacity and the uncertainty in the median capacity, respectively. For critical failure modes identified for the component, these three parameters are estimated using plant design information, walkdown findings and probabilistic floor response analysis results. Knowing these parameters, a family of curves could be obtained based on the double lognormal model for the fragility as follows:

$$f' = \Phi\left[\frac{\ln\dfrac{A}{A_m} + \beta_U\,\Phi^{-1}(Q)}{\beta_R}\right] \qquad (1)$$

where f' = conditional probability of failure at any acceleration A for a given non–exceedance probability level Q (confidence), $\Phi(.)$ = standard Gaussian cumulative distribution function.

Table 1 shows the seismic fragilities of 30 selected components

TABLE 1 SEISMIC FRAGILITIES OF SELECTED COMPONENTS

	COMPONENT	ID	$A_m(g)$	β_R	β_U
1.	Steam generator	YB11	0.40	0.28	0.53
2.	Reactor internals	YA	---	---	---
3.	Diesel control panels	EY01	0.59	0.38	0.35
4.	Diesel field flash batt.	1EC20	0.47	0.38	0.35
5.	Diesel fuel oil st. tank	UP02	1.00	0.25	0.25
6.	Station emerg. batteries	IEC03	0.47	0.38	0.35
7.	Motor control centers	0FH, 0FJ	0.84	0.38	0.35
8.	Motor control centers	1EH	0.92	0.38	0.35
9.	Motor control centers	1FV	0.59	0.38	0.35
10.	Battery chargers	1EK01	0.64	0.38	0.35
11.	Battery chargers	1EC05	0.54	0.38	0.35
12.	Battery chargers	0EK33,34	0.64	0.38	0.35
13.	Transformers	0AT01	0.40	0.22	0.20
14.	Transformers	0BT01	0.40	0.22	0.20
15.	Relay cabinets	0RT03	0.53	0.38	0.35
16.	Relay cabinets	0HH16	0.94	0.38	0.35
17.	Relay cabinets	0BA09	0.53	0.38	0.35
18.	Reactor prot. cabinets	PAN, UN0	0.73	0.33	0.38
19.	Ceramic insulators	AC, AE	0.30	0.22	0.20
20.	Main cont. benchboard	GA	1.40	0.33	0.38
21.	Monitor on benchboard	GA	0.50	0.38	0.35
22.	Main operator panels	CA, CB	1.40	0.33	0.38
23.	Heat exchanger	PR21W001	0.30	0.44	0.44
24.	Feed water tank	RL10B001	0.15	0.28	0.38
25.	Boron water tank	TB10B003	0.38	0.22	0.27
26.	Comp. cool. exp. tank	TF60B001	0.45	0.38	0.35
27.	EFW–pumps lub. tank	VT20B001	0.31	0.27	0.39
28.	Deionization tank	RV01B001	0.16	0.25	0.25
29.	Demineral water tank	TD51B001	0.16	0.25	0.25
30.	Control room chiller	UV21B002	0.58	0.23	0.36

As an example of the fragility curves generated with the aid of equation (1), the family of fragility curves for the feedwater tank (RL10B001) is presented in Figure 3.

6. THE QUANTIFICATION OF SEISMIC CORE DAMAGE RISK

The identification of seismic initiating events was based on modeled internal initiating events. Altogether twelve seismic initiating events were identified. The risk quantification was made with the aid of the SEISM–computer program which was developed on the Duke

Power Company. Using the SEISM–computer code with the proper input values for the hazard of the site, for the fragilities of the components and for the Boolean cut set equations of the fault trees of the seismic initiating events, the following mean frequencies for the initiating events can be computed (Table 2):

TABLE 2 MEAN FREQUENCIES OF SEISMIC INITIATING EVENTS

AT09_L	(LMFW)	2.21E–7
AT10_L	(LOSS OF CONDENSATE PUMPS)	2.15E–7
AT18_L	(PART. LOSS OF ACT. INTERM. CIRC.)	9.14E–8
AT19_L	(TOT. LOSS OF ACT. SEA WATER CIRC.)	1.26E–7
AT20_L	(PART. LOSS OF AUX. SEA WATER CIRC.)	5.01E–8
AT22_L	(TOT. LOSS OF CONVENT. COOL SYSTEM)	6.50E–8
AT23_L	(TOT. LOSS OF CON. AUX. COOL. CIRC.)	2.06E–7
AT35_L	(LOOP)	1.03E–7
AT36_L	(FAILURE OF STEAM GEN. SUPPORTS)	4.45E–7
AT42_L	(LOSS OF EMERGENCY FEED WATER)	1.89E–6
AT70_L	(SEAL LEAK OF PCP)	8.20E–8
AT71	(LDCP)	1.00E–7

The total core damage frequency was estimated by assuming that each initial event leads directly to the seismic core damage. Thus the individual cumulative probability distributions for seismic initial events were summed up and as a result the cumulative probability distribution of seismic annual core–melt frequency was obtained. The curve for this distribution is depicted in Fig. 4.

7. CONCLUSION

In summarizing the work done the following remarks seem to be warranted. Concerning the seismic hazard, the level of seismicity in Finland is low as expected. Commenting the results of structural response and fragility analyses it turned out that the lowest capacities were found in large tanks like the feed water tank. In risk quantification it was assumed that every initiating event leads directly to core damage. From the graphical presentation of core damage probability distribution it can be observed that the curve is quite flat, which indicates that there is considerable uncertainty in core damage estimate. The median value of core damage is 4.4E–7.

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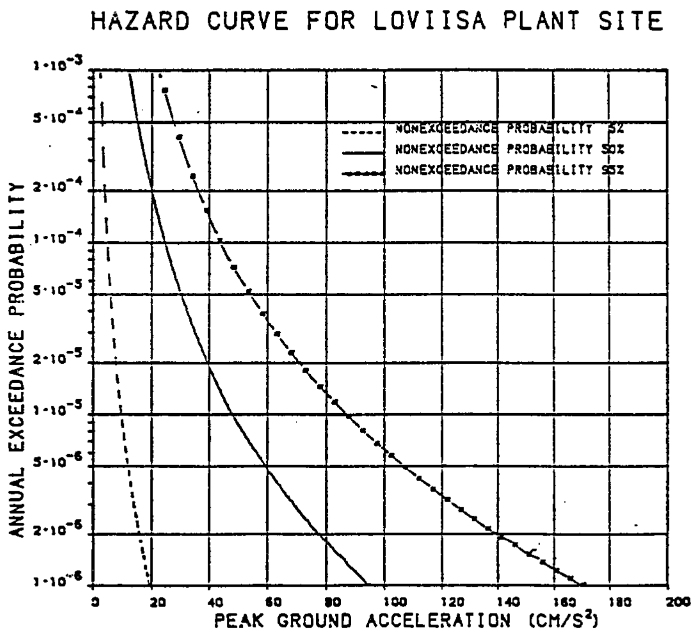

Fig. 1 Hazard curves for Loviisa plant site.

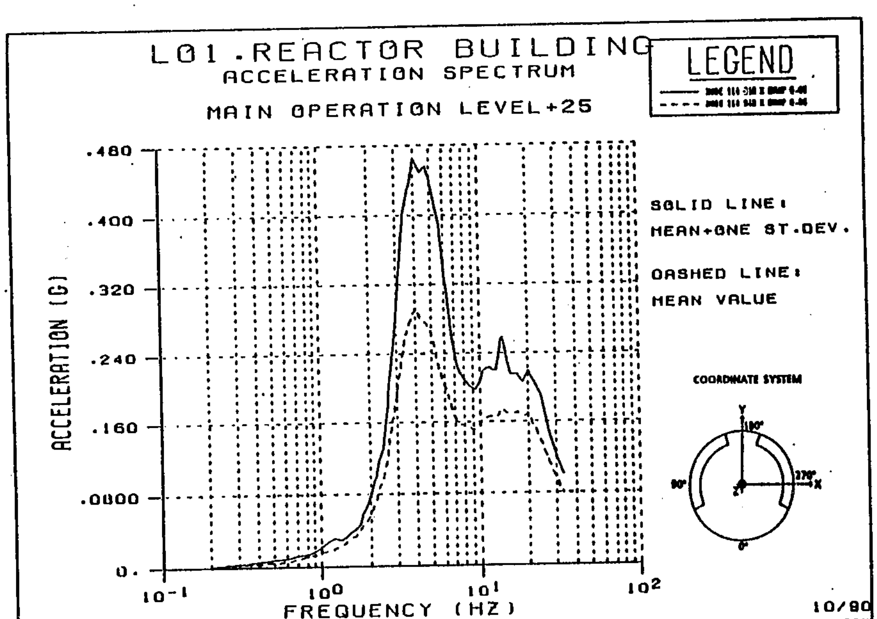

Fig. 2 Reactor building, the horizontal response spectrum of the acceleration on the floor level of 25 m at 5% damping in the direction x.

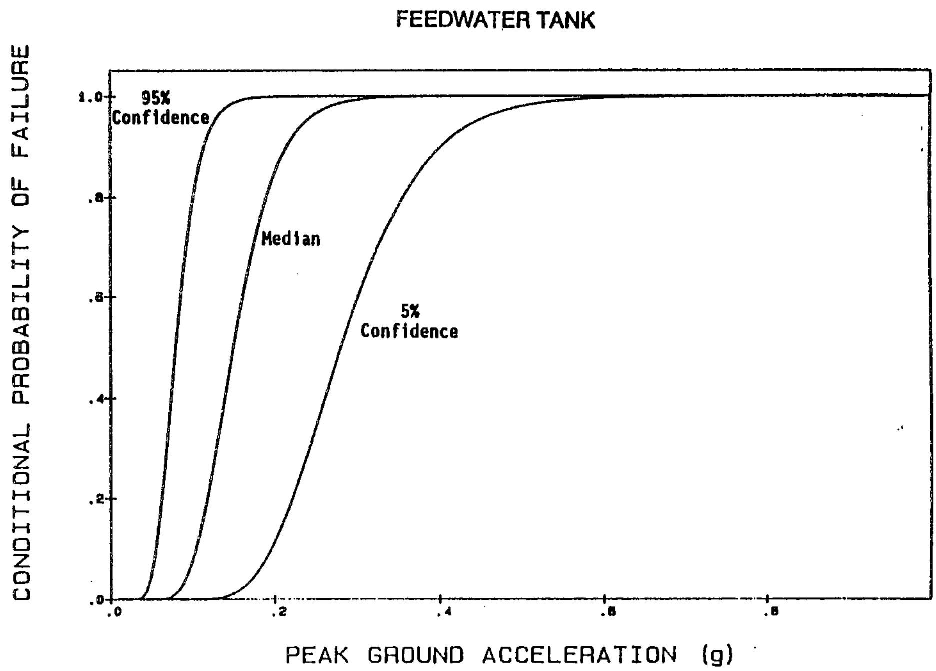

Fig. 3 The family of fragility curves for feedwater tank (RL10B001).

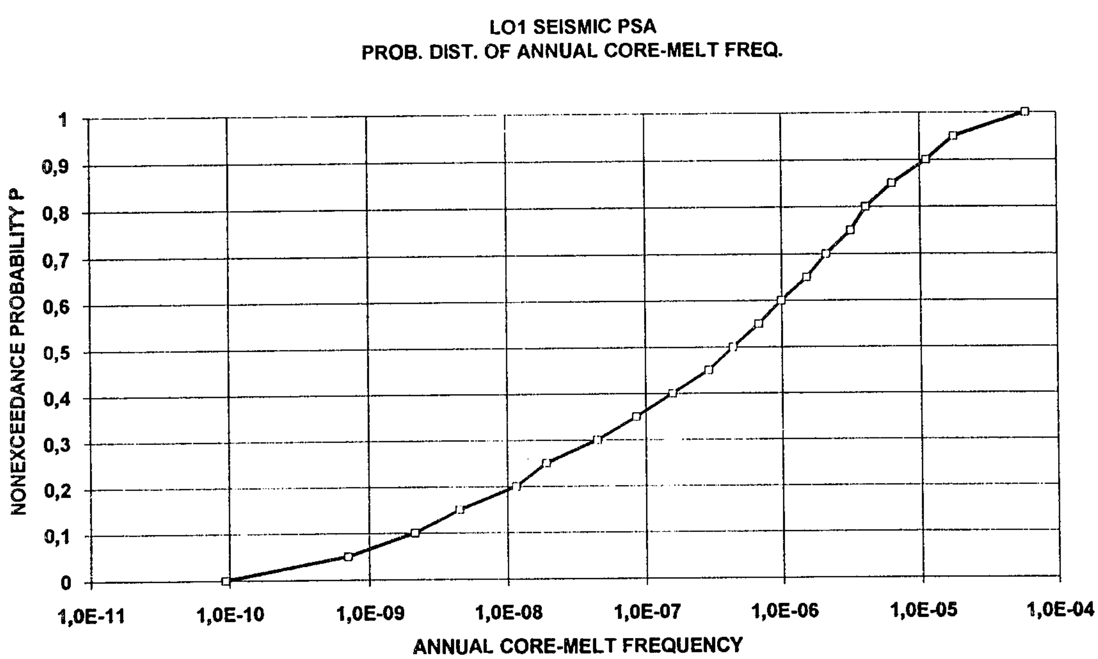

Fig. 4 Probability distribution of annual core–melt frequency of Loviisa NPP unit 1.