DERIVATION OF FREQUENCY AND RECOVERY PROBABILITIES FOR LOSS OF OFF-SITE POWER ACCIDENT

V.B.Morozov[1] and G.V.Tokmachev[1]

[1]Atomenergoproekt, Moscow, Russia

In: C. Guedes Soares (Ed.), Proceedings of the ESREL'97 International Conference on Safety and Reliability, 17-20 June, 1997, Lisbon Portugal, Volume 3, pages 1889-1894, Elsevier Science, 1997.

ABSTRACT

The paper discusses frequency and recovery probability derivation for loss of off-site power (LOOP) at VVER NPPs based on operating experience from the countries of the former Soviet Union. The period used for initiating event frequency derivation was from 1985 through 1994. The data base covers more than 400 reactor years including 130 reactor years from VVER-1000 operating experience. Loss of off-site power frequency has been derived assuming Poisson hypothesis based on VVER-1000 operating experience. To estimate recovery probabilities, 29 losses of off-site power were classified according to their duration based on the total operating experience from SU NPPs. Five distribution low families which reflect probability of recovery versus duration were defined on statistical basis. Parameters of low were obtained for each family by either maximum likelihood method or moment method. Resulting distributions were examined by χ^2 criterion.

KEYWORDS

VVER reactors, loss of off-site power, operating experience, frequency, restoration probability.

INTRODUCTION

Atomenergoproekt institute has performed a number of preliminary level 1 probabilistic safety assessments (PSA) for different types of VVER-1000 reactors from advanced VVER in design to operational VVERs (Shviryaev *et al*, 1994). These studies were done in co-operation with almost all Russian institutions working in the field of PSA. PSA results are used for NPP's safety level evaluation as well as for the identification of design and procedure improvements needed.

LOOP event tree developed within the framework of PSA study includes several nodal events which refer to the total LOOP frequency as well as to probability of off-site power restoration for different time points. These time points reflect plant specific features such as capacity of station batteries, steam generator water inventory, etc.

Accident sequences resulting from long-term LOOP have been recognised to be significant contributors to core damage frequency for all VVERs (Shviryaev *et al*, 1992 and Hohn *et al*, 1996). Therefore, among the areas to be investigated the following which would impose on plant safety were selected as a result of PSA:

- The reliability of the off-site power grid.
- The ability to restore off-site power supply to the station loads.

Thus, to eliminate conservative estimation of core damage frequency, best-estimate values for both frequency and recovery probability should be used for such initiating event as LOOP. However, frequencies of LOOP within PSA already performed had been estimated based on use of not directly applicable foreign experience or limited amount of specific data. A number of problems also arise in estimating the duration of LOOP. As a rule, probabilities of recovery from LOOP were often estimated in a very pessimistic manner.

The objectives of this study are as follows:

- To support PSA being performed for NPP with VVER-1000 with best-estimate numerical values related to LOOP initiating event.
- To investigate plant behaviour, followed by such an accident thoroughly reviewing an operating experience available from all types of NPPs.

ANALYSIS OF OPERATING EXPERIENCE

The derivation of LOOP frequencies and recovery probabilities is based on operating experience from VVER and other type NPPs of Russia, Ukraine, Armenia and Lithuania. The period used for initiating event frequency derivation was from 1985 through 1994.

Frequency of LOOP as well as recovery probabilities is estimated by reviewing all the event reports that national data base on plant occurrences had kept. The event descriptions in accident reports are quite detailed and give enough information to categorise the event. These data are supplemented by data extracted from internal NPP reports, thereby assuring quality of information accordingly.

Frequency estimation was performed based on operating experience from NPPs with VVER-1000. There are 17 Units with VVER-1000 reactors which operate in the region. For all those Units, initiating event data have been collated and were used an aid in the frequency derivation.

A more substantial amount of operating experience accumulated in the last ten years from all types of NPPs has been used to obtain best estimate values for restoration of off-site power (i.e. 88 reactor-years of type VVER-440; 130 reactor-years of type VVER-1000 and about 190 reactor-years of other types). Thus, the complete data base covers more than 400 reactor years. Twenty nine events of interest were identified.

Among root causes of the LOOPs there were floods and moisture impacts, transformator failures, C & I faults, personnel errors, hurricane. It is highlighted that redundancy reduction of grid distribution lines during unit shutdown can increase dramatically frequency of LOOP. For example, two accidents were initiated by line disconnection caused by single impact of a boom of either the pipe laying crane or the crane truck. This has to be taken into account within shutdown PSA study being performed for VVER-1000 NPPs.

LOOP FREQUENCY AND RESTORATION TIME ESTIMATIONS

An estimation of LOOP frequency has been derived assuming Poisson hypothesis based on VVER-1000 operating experience. The total occurrences in all operation modes of VVER-1000 NPPs were taken explicitly providing 0.12 events per year. It should be noted that LOOPs occurred in Unit shutdown period have significant impact on the mean frequency. Therefore, this value can be considered as conservative if a power operation mode is only analysed for which the mean frequency is estimated as 0.09 events per year.

To estimate recovery probabilities, LOOP events were classified according to their duration. Cumulative distributions for recovery time for NPPs in the former USSR region were developed based on review of all the event reports that SU data base on plant occurrences had kept since 1985 through 1994. Twenty nine unit's LOOPs were extracted from this operating experience. It was found that the longest restoration had been accomplished in approximately a three hour period from the time started. This is considerably shorter than the longest duration of 11 hours extracted from US operating experience (Baranowsky *et al*, 1989).

The insights from a qualitative review of LOOPs are that all recovery events can be divided into a number of groups which seem to include homogeneous data. At least, two groups can be clearly identified. A short-term group includes events for which no repair is required to restore off-site power, for example, LOOPs caused by spurious unit switching off. In this case, off-site power can be easy restored by operator by reconnecting to available power sources. A long-term group contains events for which complex operator actions or repair are required to restore off-site power.

As a result of the above, a mean recovery time for the long-term group should be greater than for the short-term one. It is reasonably to assume based on sample that restoration time exceeds an hour for the long-term group, vice versa for the short-term group. The further group splitting is also possible as there are no arguments in a favour of two groups against a multigroup model. However, as amount of specific data is limited there is no way to estimate properly a proportion for each of them.

To predict non-recovery probabilities for wide range of time periods a parametric statistical approach was applied (Borovkov, 1984). Five distribution low families which reflect probability of recovery versus duration were defined on the statistical basis as follows: Gamma, exponential, mixture of two exponents, log-normal and Weibull. Parameters of low were obtained for each family by either maximum likelihood method or moment method. Resulting distributions presented in Fig. 1 were examined by χ^2 criterion.

Non-recovery probabilities were calculated for the following timings:
- up to 30 minutes;
- from 30 minutes to 10 hours;
- from 10 to 24 hours.

These three timings depend on a plant specific coping time and emergency feedwater inventory according to accident sequence modelling as well as mission time usually modelled in PSA. Corresponding numerical values for probabilities of recovery/non-recovery from LOOP can be applied to PSA VVER-1000 model for the LOOP initiating event.

The coping time is defined as the time period that the plant can withstand prolonged unavailability of on-site and off-site power without severe core damage. About 30 minutes necessary for operator recovery actions should be additionally taken into account. There are three competing effects, followed by diesel generator failure which determine the coping time:
- Depletion of the Station batteries. Station battery capacity is necessary to restart key components in the AC power system, e.g. to reclose circuit breakers.
- Degradation of the reactor coolant pump sealings.
- Loss of steam generator water inventory.

Based on analysis of the above effects the coping time of 0.5 hours was obtained for a station blackout.

Following a LOOP, the availability of the emergency feed water system supplied by diesel generators is also critical in preventing severe core damage. Emergency feedwater inventory is sufficient to remove residual heat from the reactor coolant circuit through evaporation of feedwater within 10 hours. After that, residual heat removal in recirculation mode has to be available either through ECCS heat exchangers or through normal heat removal system. In the latter case, off-site power should be restored.

Having developed a distribution function describing LOOP times, the probabilities of off-site power not being restored for time periods up to 0.5 hours, 10 hours and 24 hours are derived and given in Table 1.

TABLE 1.
NON-RECOVERY PROBABILITIES OF LOOP

Distribution	χ^2	Non-recovery probability		
		0.5 hrs	10 hrs	24 hrs
Exponential	14.3	0.39	6.4-9	<1.E-18
Gamma	5.09	0.36	3.7E-7	1.1E-15
Mixture of two exponents	7.72	0.22	9.6E-4	5.8E-7
Weibull	6.49	0.36	1.6E-6	4.7E-13
Log-normal	3.79	0.27	4.8E-3	7.7E-4

RESULT OVERVIEW

Frequency estimation for VVER-1000 is more conservative compared with both US (Baranowsky *et al*, 1989) and FR Germany (Simon, 1987) operating data. Frequency of LOOPs at US NPPs for all years through 1988 is 0.07 1/year. Moreover, five occurrences have only occurred in 112 years operating in FR Germany, that is 0.045 events per year. Nevertheless, from the standpoint of shutdown PSA, VVER frequency obtained is optimistic. Therefore, an operation mode specific value should be definitely used for shutdown PSA.

Off-site power non-restoration probability curves for examined distributions are given in Figure 1. Based on statistical calculations all distributions of off-site power restoration time except for single exponent distribution have decreasing recovery rate (for log-normal distribution it is true for $t > 1$ minute). It should be underlined that the only single exponent distribution do not meet χ^2 criterion for significance level α = 0.1 (Phi-square critical value is 10.6 for six degrees of freedom). This distribution has a constant recovery rate of 1.88 1/hrs. Hence, it can not describe as short-term ($t < 0.1$ hrs) so long-term ($t > 1$ hour) restoration effects.

Other distributions do not contradict to data sampling. However, those distributions provide significantly different results in evaluation of non-recovery probabilities for $t>2$ hrs. The most conservative estimations could be obtained by application of log-normal law, whereas the most optimistic estimations by application of Gamma distribution. These differences arise from model limitations. They could be mainly explained by lack of occurrences of long-term LOOPs. Nevertheless, the results of analysis seem to be satisfactory for PSA needs.

There are several arguments to use for PSA quantification the recovery probability values based on a log-normal assumption. These arguments are as follows:

- log-normal distribution is usually used for multi-group sample;
- non-recovery probabilities derived by using log-normal distribution are the most conservative;
- the value of Phi-square statistic for this distribution is a minimum;
- taking into account the total frequency of LOOP of 0.12 1/year, the probabilities of non-recovery for long-term periods ($t>24$ hrs) seem to be reasonable in comparison with the LOOP design basis frequency of 1E-4 1/year. Such LOOPs are supposed to be caused by external events corresponding to safe shutdown design conditions.

REFERENCES

Borovkov, A.A. (1984). *Mathematical statistics.* Nauka, Moscow, Russia.

Hohn, J. (Ed) (1996). *Insights from PSA Results on the Programmes for Safety Upgrading of WWER NPPs.* International Atomic Energy Agency, WWER-SC-152, Vienna, Austria.

Baranowsky, P.W., Kolachzkowski, A.M., and Fedele, MN.A. (1989). *Losses of Off-Site Power at US Nuclear Power Plants. All Years Through 1988.* Electric Power Research Institute, NSAC-144, Palo Alto, CA, USA.

Shviryaev, Ju., Morozov, V., Barsukov, A., Derevyankin, A., and Tokmachev, G. (1994). The state and problems of PSA for VVER plants*. Proceedings of IAEA Technical Committee on Advances in Reliability and Probabilistic Safety Assessment held in Budapest, Hungary, September 7-11, 1992, IAEA-TECDOC-737, International Atomic Energy Agancy,* 72-80.

Simon, N. (1987). Redundancy proves its worth in FR Germany. *Nuclear Engineering International* **32:394,** 57.

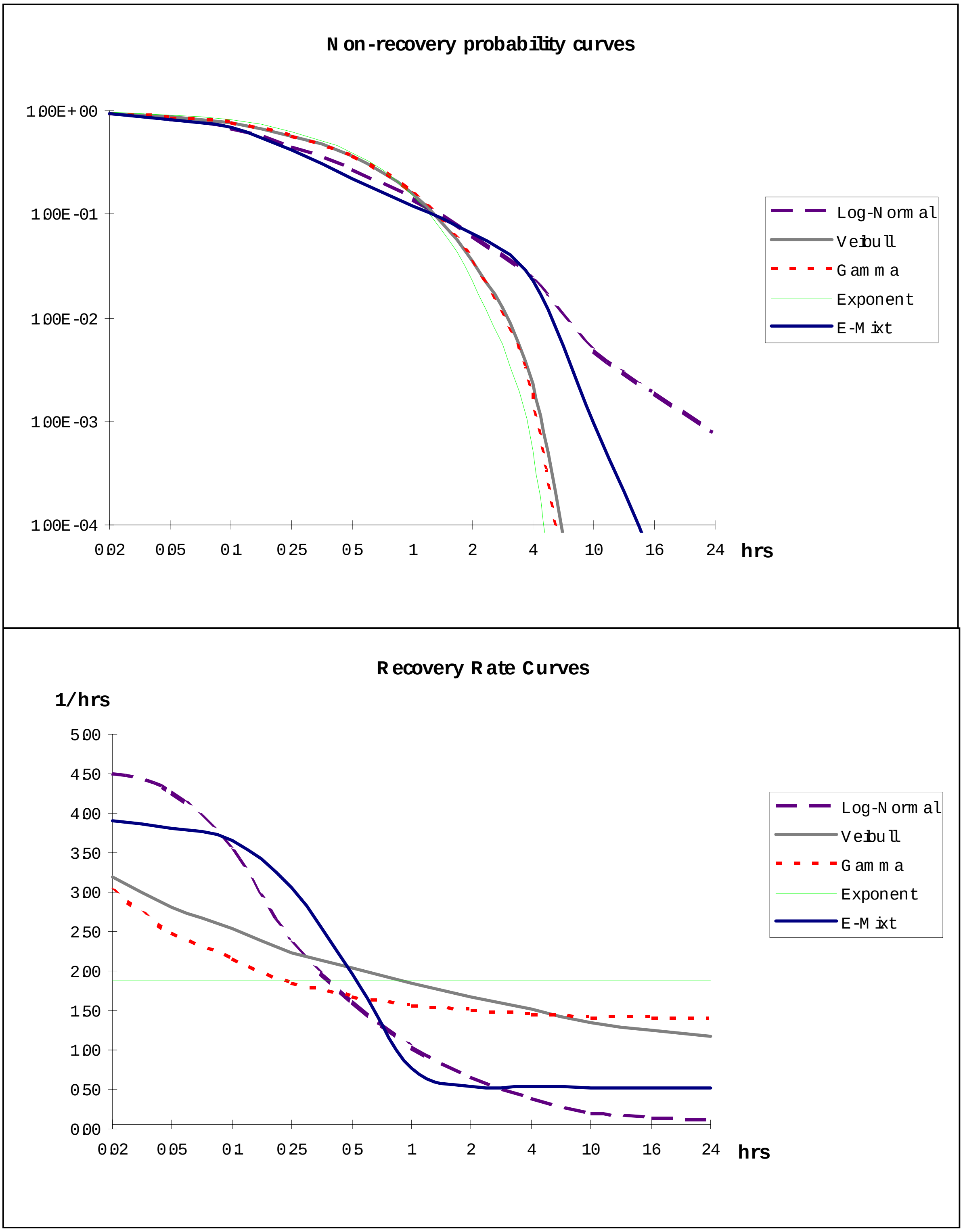

Figure 1: Off-site power non-recovery probabilities and recovery rates for different distributions