OPERATIONAL SAFETY
SYSTEM RELIABILITY

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ABSTRACT

This progress report describes the objectives and present status of a study concerning the operational reliability of nuclear power plants. The purpose is to develop utilitarian models for use with the Liquid-Metal-Cooled Fast Breeder Reactor; initial testing of the formalism can be carried out with LWR operational data. Methods are being directed towards (1) day-to-day operation of the nuclear plant protection system and (2) to better understand the protection system sensor characteristics in order to anticipate off-normal conditions. The initial models now underway are based on moment-matching, confidence bounding and convolution methods in the case of the protection system reliability, and for the sensor response function, a convolution of component reliability probability distributions and noise signatures.

OPERATIONAL SAFETY SYSTEM RELIABILITY

R. W. Hockenbury and M. L. Yeater

Since this is the first progress report, a few introductory statements are presented in order to outline our goals. These are followed by a summary of accomplishments to date and an outline of work in progress and future directions.

The two main objectives of this study are (1) to develop methods to calculate the reliability of the protection system of an operating nuclear power plant and (2) to develop techniques which can be used on-line to monitor the protection system sensors in such a way that off-normal behavior can be detected at an early stage possibly avoiding costly downtime. The overall goal is to maximize the safety and availability of nuclear power plants, in particular, the Liquid-Metal-Cooled Fast Breeder Reactor. The development of these methods and techniques has the added benefit of pointing out desirable modifications or additions in reactor system monitoring such as process computer data logging and also in calibration procedures and maintenance practices. The methods under development are intended to be carried out by on-line plant computers in keeping with their rapidly growing application to the operation and monitoring of nuclear power plants. At the same time, we are designing these methods so that they can be used and their results properly interpreted by on-site staff who do not necessarily have lengthy training in reliability and statistics.

Work to date has reinforced the views regarding the role and importance of both system operational reliability analysis and sensor response sensitivity analysis. In the case of sensor reliability it

seems clear that fast breeder safety systems¹ will be monitored with the support of computer algorithms, in which detailed sensor response functions (providing analysis of background) will be needed to ensure adequate sensitivity to signals which carry information about reactor conditions; it appears that more detail is required for the LMFBR than for light water reactors where minimal attention has been given so far to uncertainties in sensor and signal processor behavior. In the area of protection system maintainability, it is clear that codes which are adapted to the new generation of minicomputers and microprocessor based programmable calculators will bring reliability analysis and prediction into the reactor control room where it will be a means of improving reactor availability and economy.

In section A, current work in system reliability modeling is described. Section B describes the plans for analyzing sensor response functions. The Appendix includes a listing of personnel, publications submitted to the International Meeting for Fast Reactor Safety and Related Physics, Chicago, October, 1976 and a block diagram showing the current overall plan for this program.

A. System Reliability

The objective here is to develop a reliability analysis algorithm which can readily be tailored to a particular plant and consisting of a computer code or codes plus supplementary reference materials such as component/system reliability data manuals. This analysis system would use the best available failure data, including up-dates from plant experience to calculate the protection system reliability and its uncertainty. Part of our task is to find an expression for this uncertainty in terms of the

individual component and sub-system failure rate uncertainties. In order to accomplish the above, we have found it necessary to visit operating power plants to observe current practices in normal operations, maintenance and calibration procedures, record-keeping and component data reporting. We are also keeping in close touch with state-of-the-art reactor protection system hardware developments to assure the timeliness of our analytical methods by visiting and otherwise maintaining contact with manufacturers. We have visited Consolidated Edison, Northeast Utilities, Connecticut Yankee, Millstone I, Combustion Engineering, Nuclear Energy Liability - Property Insurance Association (N.E.L. - P.I.A.), and Brookhaven National Laboratory. In addition we have contacted the Edison Electric Institute, Electric Power Research Institute and Niagara Mohawk Power Corporation for data on operating plants to be used in testing our models. Through the courtesy of N.E.L. - P.I.A., we also expect to obtain a data file on operational performance for the Kewaunee nuclear power plant.

For model development and testing, we must use the available operating experience which is of course mostly in the L.W.R. area. Thus, we have taken a first step consisting of a reliability analysis of a BWR protection system.² A conventional reliability calculation was done in which the protection system was converted to a logic diagram. Standard boolean algebra and connection matrix techniques were used to obtain a numerical result. The mechanical system reliability was compared to the instrumental and logic reliability. The failure data were taken from various sources,³ attempting to make a realistic (less conservative) calculation than was done in Ref. 3. Our objective here is to determine

the reliability while that of the Reactor Safety Study³ was risk assessment. Sub-systems of the DWR protection system were then examined for sensitivity to their major components' failure rate data. As a next step in this part of our program, we will incorporate data available from the Nuclear Plant Reliability Data System and modify the reliability analysis in terms of efficiency and clarity. As mentioned previously, the results and conclusions developed here are intended to be carried over directly to the LMFBR.

Part of the system reliability calculation involves the propagation of component failure rate uncertainties through the analysis resulting in a probability distribution for the system reliability. Various ways to do this are being examined. These include moment-matching,⁴ confidence bounds, combination of hazard functions and the convolution method. The method of moment-matching, to obtain at least an approximate analytical form for the resultant overall distribution in system reliability, has several advantages over Monte Carlo simulation. For example, less computer time is required, a smaller computer will suffice and the relative significance of the individual contributions to the overall result can be seen. Moment-matching is also more efficient than Monte Carlo in dealing with the tails of the distribution. Proper application of the moment-matching method requires some knowledge of the individual component failure rate probability density functions and this point is presently being examined in our application. Cox and Cermak⁴ have applied this technique to obtain the maximum cladding temperature assuming various uncertainties in the system variables.

Confidence bound techniques and hazard function combinations are also under consideration. The common theme for both is that they must

be tailored to the specific system. The use of hazard functions is particularly appropriate for cases involving multi-component response times.

B. Sensor Systems Analysis

Usually the background and signal distortion originating in the sensor or signal processing components are treated as small and poorly understood corrections. In the case of fast reactors¹ it is not clear that these corrections will be relatively small. We are developing procedures which it is believed will be applicable to breeder reactor protection systems especially if a suitable computerized data logging system is included in the reactor design. One of the purposes of this study and the testing of the algorithms we are developing is to point out the specific data files which will be needed in the future in order to assure complete monitoring of sensor behavior.

Our approach is to develop methods and codes to study sensor signatures. In the usual noise analysis one seeks reactor signatures, usually on the unverified assumption that it is essentially unaffected by the sensor signature. However, one can determine a sensor and signal processor response function defined as follows: The output response probability distribution (i.e., results of a large number of repetitive measurements over a period of time) that would be measurable if there were no input fluctuations ("noise") and if the reactor power were constant.

In modeling this response we take the following steps:

1. A noise signature is generated (for the sensor and amplifier or signal converter) assuming a mixture of white noise (Fourier transform = constant) and a frequency distribution which can

be varied to simulate various degrees of sensor or processor degradation.

2. A reliability analysis is made of the sensor and processor components to determine the probability of any output in repetitive measurements given a fixed input. This response on which the frequency response of (1) preceding is superimposed is the total sensor system response function.
3. This response function is convoluted with a typical reactor signature and parameters varied to assess the sensitivity of the reactor signature analysis to sensor response variations and to determine the limits of tolerable background introduced by sensor perturbations.
4. Tests with this model will be made to evaluate the most sensitive procedure for detection of incipient sensor and processor failure.
5. In order to provide realistic input data for the preceding tests we have contacted utility nuclear plant operators, and in the third quarter will renew our series of plant visits (see comments below on previous visits) in order to expand our data file. As noted above it is expected that results of our simulations will serve to motivate additional instrumentation records in operating plants.
6. The computerization of models such as outlined above is, of course, one of the major efforts of this project and involves several students, listed below, as well as staff. Certain standard codes are used for generation of the sensor simulations including the following: Fast Fourier transform, Laplace

transform, normal distribution, random number generator
and matrix inversion. These are available on the Nuclear
Engineering Department PDP-15 and IBM 1130.