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Preliminary Investigation of Electromagnetic Pulse Effects on Commercial Nuclear Power Plant Systems

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Sandia National Laboratories and its subcontractors have been engaged since October 1980 in a study of the potential interaction of the electromagnetic pulse (EMP) from a high altitude nuclear burst with commercial nuclear power plant (NPP) systems. This study, which is being conducted for the U. S. Nuclear Regulatory Commission, addresses some concerns about our ability to safely shut down plants exposed to EMP.

The effort, which is a scoping study, is designed to address the question: "Could EMP cause failure of critical systems in nuclear power plants and does it warrant further study in this context?" Therefore, this study has three objectives:

1. Determine the EMP vulnerability of selected safe shutdown systems for an example plant.

2. If vulnerable systems are identified, make recommendations as to how such vulnerabilities may be reduced or eliminated.

3. Generalize and extend the results for the example plant to nuclear plants in general.

This paper discusses initial results obtained pursuing the first two objectives.

Three functions must be accomplished to safely shut down a NPP: (1) the fission process must be terminated; (2) the coolant inventory must be maintained so that the core remains covered;

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and (3) the heat generated by the radioactive decay of fission products must be removed. A number of systems are required to carry out these functions and they include the reactor protection system, the AC/DC emergency power systems, the auxiliary feedwater system, the chemical and volume control system, the component cooling water system, the essential service water system, the instrument air system, and portions of the heating, ventilating and air conditioning systems. There is a "common denominator" present in these systems and that is a dependency upon electrical circuitry. Therefore, our initial efforts were directed toward the potential interaction of EMP with the power, control and instrumentation portions of these systems.

The EMP, being a broad band RF signal, can interact with a variety of electrical networks which are designed as antennas or which act like antennas when exposed to such signals. For nuclear power plants we identified and examined three potential interaction paths. The EMP signal may penetrate directly into the plant interior creating diffused fields, which then couple with the interior plant cabling to induce current on those cables. The EMP can interact with the external power grid to which the plant is connected, and currents induced there could penetrate into the plant on the power lines feeding plant systems. Finally, the EMP might induce currents on power and instrumentation lines which interconnect various plant buildings and systems.

The Watts Bar Nuclear Plant of the Tennessee Valley Authority was selected as the example plant for study because of the availability of previous systems studies, and also because it was sufficiently far along in construction that the final configuration is available, but at the same time it was "open enough" that details could be observed visually.

Penetration of diffuse fields into the facility was examined analytically and experimentally. The construction drawings were reviewed with particular emphasis upon the amount and placement of rebar in the walls and roof and upon grounding techniques. Following this review and a physical inspection, it was concluded that the structures offered shielding of at least 30 dB, and probably more. Subsequent tests using MIL STD 285 shielding effectiveness techniques indicate that the shielding is 40 dB or greater. Therefore, diffuse fields were not considered further, given the signal levels available from other sources, as discussed below.

Coupling with the power grid and site cables was examined as follows. The various cable routings and potential signal penetration points were identified and examined. The currents induced by EMP were estimated and their penetration into the plant interior traced. The estimates account for other cables in duct banks and cable trays, grounding systems and other paths for signal propagation such as fluid piping in the immediate vicinity. Inside the plant, the penetration currents were reduced by attenuation along cable runs and by ohmic losses, multi-moding and breakout distribution.

The penetration currents are distributed to the loads at various busses and the value of the individual current on any outgoing cable was assumed to be bounded by $1/N$ and $1/\sqrt{N}$ of the incoming current when N is the number of loads. The currents are interpreted as a short circuit current at the critical equipment. The analysis then used estimates of the cable and load impedances and the predicted current to estimate voltages at the critical equipment. The nominal response is estimated from the $1/N$ and $1/\sqrt{N}$ bounds. The study includes current and voltage predictions for nearly 100 points on safety-related loads such as motor operated valves, heaters, battery chargers, inverters, system controls, and instrumentation power.

Our predictions suggest that EMP-induced signals would be well below nominal operating voltages for the heavy duty equipment (AC motors, transformers, etc.) so the main effort in estimating damage thresholds was directed toward equipment containing solid state devices. This decision was also based upon experience which indicates that semiconductor devices are usually the most susceptible components. This led to consideration of the battery chargers, inverters, regulated power supplies, process instrumentation, and controls. In general, the estimated thresholds are well above anticipated signal levels. The ranges of the EMP signal and damage threshold predictions are summarized in the following table.

Summary of Analytical Predictions

Items	Predicted EM Signals (V_R)	Predicted Damage Threshold (V_T)
6.9 kV Equipment	50-500 V	69 kV*
480V Equipment	2-100 V	4.8 kV*
125 VDC/120 VAC Equipment	2-100 V	70 V-40 MV
Instrumentation	≤10 V	50 V-30 MV Megavolts

*Damage threshold assumed (conservatively) at 10X operating voltage.

When the individual response predictions and damage threshold estimates are combined, the minimum safety margin (SM) observed is 44 dB, where SM = 20 log V_T/V_R.

As with any analytical program, there was strong interest in "verifying" the predictions by experiments. In this study, the shielding effectiveness of the buildings was established as described earlier. In addition, selected cables in the facility were driven by inductively coupling an RF signal to the cable by a current transformer. The induced currents were observed at the points of interest and a transfer function between the drive point and measurement point obtained. When this transfer function is used with the appropriate driving function, the induced current amplitude in the time domain can be established. The peak amplitudes thus derived were compared with predictions to establish confidence in the basic analytical procedures. For this study, the results indicate that on the average the predicted EMP signals are modestly conservative (1-2 dB) when compared to measurements. Additional tests were conducted to search for inadvertent or unexpected cable penetrations; none were located.

Based upon our efforts, we have arrived at the following conclusions.

1. Diffused fields inside Seismic Class I buildings are negligible.

2. EMP signal entry points are identifiable.

3. Signal attenuation and distribution can be reasonably modeled.

4. Damage thresholds are substantial for the components ~~[illegible]~~ examined.

5. Predicted EMP signals at the critical equipment are less than, or equal to, nominal operating levels.

6. The selected systems examined will not be damaged by EMP.

We must emphasize that these conclusions are preliminary and are restricted to the systems and components studied. Additional efforts are now underway to extend our results to other plants.