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EX-VESSEL WATER-LEVEL AND FISSION-PRODUCT MONITORING FOR LWR

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ABSTRACT

Given that the need for direct measurement of reactor coolant inventory under operational or abnormal conditions remains unsatisfied, a high-energy gamma-ray detection system is described for ex-vessel monitoring. The system has been modeled to predict response in a PWR, and the model has been validated with a LOFT LOCA sequence. The apparatus, situated outside the pressure vessel, would give relative water level and density over the entire vessel height and distinguish differing levels in the downcomer and core. It would also have significant sensitivity after power shutdown because of high-energy gamma rays from photoneutron capture, the photoneutrons being the result of fission-product decay in the core. Fission-products released to the coolant and accumulated in the top of a PWR vessel would also be theoretically detectable.

INTRODUCTION

Direct measurement of reactor coolant inventory under operational or abnormal conditions is a goal that potentially enhances the safety of nuclear power reactors. As a result of the Three-Mile Island incident, the U.S. Nuclear Regulatory Commission called for the establishment of a system for "unambiguous, easy-to-interpret, indication of inadequate core cooling (ICC)".[1] Although several methods that partially meet these requirements have been adopted, none are able to provide direct and unambiguous measurement under both normal and severely degraded conditions. Based on considerable test reactor experience, a high-energy gamma-ray detection system to be located outside the pressure vessel has been invented[2] to respond directly to coolant level (and to fission-product accumulation at the top of a vessel). This paper summarizes the concept and its experimental and analytical underpinnings.

From the viewpoint of enhanced power reactor safety, an ideal coolant measurement system should monitor the levels and densities directly, be independent of other instruments, and be able to function under all conceivable conditions. Normal operational power spans subcritical to full rating, as well as shutdown and decay-heat conditions. Abnormal conditions include variations in core and downcomer levels and a wide range of potential accident conditions affecting power level, coolant temperature, and detector environment. Information is also desirable on the escape of fission products from the fuel. Display units that provide information should be easy to interpret, and data should be updated on a real-time basis.

The severity of the Three-Mile Island accident can be attributed in part to indirect and interpretive means then existing for determining coolant conditions. The water level in the pressurizer was used as an indirect indication of reactor coolant inventory, but the leak occurred from a valve after the pressurizer. Although core temperature and pressure were relied upon to indicate coolant conditions, there was "no direct indication that the combination of pressure and temperature meant that the cooling water was turning to steam".[3] Misinterpretation of available plant data contributed to confusion and an incorrect understanding of actual coolant conditions in the core.

WATER-LEVEL MONITORING

Despite the research and development[4] conducted after the TMI-2 incident, questions of survivability and uniqueness of response remain, resulting in the need for continued exploration of ex-core methods. The water-level instrument reported here is situated outside the reactor vessel and is designed to give separate information on the core and downcomer levels over full vessel height, at full power and long after scram.

An axial array of gamma detectors would be used for this application (see Fig. 1).[5] High-energy (several MeV) gamma rays produced by neutron capture in hydrogen and steel are sensitive to the local coolant density. With such penetrating radiation, coolant level can be monitored from outside the pressure vessel with a detector system that is survivable under accident conditions; it would not need vessel penetrations, nor would maintenance be excessive. By concentrating on the high-energy gamma rays and by collimating the detectors, background effects would be reduced. The collimation also permits separate monitoring of downcomer and core liquid level conditions and allows vertical resolution of coolant inventory and density over the full vessel height.

COMPUTER MODEL

In order to evaluate the efficacy of this approach, a computer model[6] was developed for the expected detector response to various voiding conditions within the reactor. Although the model is designed to predict PWR response, it was configured so as to use LOFT semi-scale tests[7] for validation. Some of the LOFT simulation results have been reported.[8] A one-dimensional coupled neutron and gamma transport calculation was developed using the code ONEDANT.[9] Detector response to quasi-static water-density conditions of the core and downcomer were obtained, as a function of post-shutdown time and detector energy threshold.

RESULTS

Gamma-ray detector response was confirmed to be explicitly sensitive to voiding. Radial measurements of gamma-ray flux through the downcomer would partially alleviate misinterpretation of the resultant signal that combines core and downcomer voiding.

Peripheral coolant voiding increases the transport of neutrons while core coolant voiding also depresses the neutron source, the net result being an increase in gamma flux with loss of water. For an initial 100% theoretical density, a 1% reduction results in a few percent change in signal, depending upon the particular region voiding, with the response increasing as the void content increases.

After shutdown, the method remains sensitive to water level despite the loss of power. Because of delayed radiation, a substantial source term remains for many hours. For times long after shutdown (over 30 minutes), the predominant effective source transmitted to the reactor vessel is derived from core fission-product gamma rays, a few of which are converted to photoneutrons, which in turn produce detectable capture-gamma rays.

In a more specific analysis, the LOFT loss-of-coolant accident (LOCA) test L2-5[10] formed the basis for data input to the transport calculations. Both core and downcomer void data are available for the duration of this simulation. The break was initiated with full core uncovery and simultaneous downcomer voiding. Following reflood and complete core recovery, partial voiding (10-20 percent) existed in the inner and downcomer regions. The scenario includes a second core uncovery less severe than the first which is also followed by a later partial uncovery after reflood. The computed gamma flux at an imaginary detector tracks the LOCA sequence, reasonably coinciding with the extent and location of voiding (see Fig. 2).

SUMMARY

The computation shows that the gamma-ray flux responds uniquely and predictably to the void conditions, depending in part on the source of gammas -- core neutron or fission products. A detection system based on these principles should be able to directly monitor coolant level (and fission products) before and after cooling transients in a large reactor and follow the signal for a long time after shutdown, irrespective of core integrity.

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REFERENCES

1. U.S. Nuclear Regulatory Commission report NUREG-0737, "Clarification of TMI Action Plan Requirements (1980).

2. A. DEVOLPI, "Monitoring System for a Liquid-Cooled Nuclear Fission Reactor," U.S. patent 4,649,015 (1987).

3. J. G. KEMENY et al., "Report of the President's Commission on the Accident at Three-Mile Island," October 30, 1979.

4. A. L. HON, N. N. KONDIC, and L. E. PHILLIPS, "Summary of NRC Requirements and its Research Studies on Reactor Water Level Measurement," First Proceedings of Nuclear Thermal Hydraulics, American Nuclear Society (1983).

5. A. DEVOLPI, "Water-level and Fuel-failure External Monitoring," Proceedings, Symposium on New Technology in Nuclear Power Plant Instrumentation and Control, Instrument Society of America (1985).

6. D. MARKOFF, "Analysis of Proposed Gamma-Ray Detection System for the Monitoring of Core Water Inventory in a Pressurized Water Reactor," ANL-87-29, Argonne National Laboratory (1987).

7. D. L. REEDER, "LOFT System and Test Description (5.5 ft. Nuclear Core 1 LOCES)," NUREG/CR-0247, EG&G Idaho, Inc. (1978).

8. D. MARKOFF and A. DEVOLPI, "Ex-core Water-level Monitor: Comparison of Computations with LOFT Data," Trans. Am. Nucl. Soc., 53 (1986).

9. R. D. O'DELL, F. W. BRINKLEY, JR., and D. R. MARR, "User's Manual for ONEDANT: A Code Package for One-dimensional, Diffusion-accelerated, Neutral Particle Transport," LA-9184-M, Los Alamos National Laboratory (Revised 1982).

10. P. D. BAYLESS and J. M. DIVINE, "Experiment Data Report for LOFT Large Break Loss-of-Coolant Experiment L2-5," NUREG/CR-2826, EG&G Idaho, Inc. (1982).

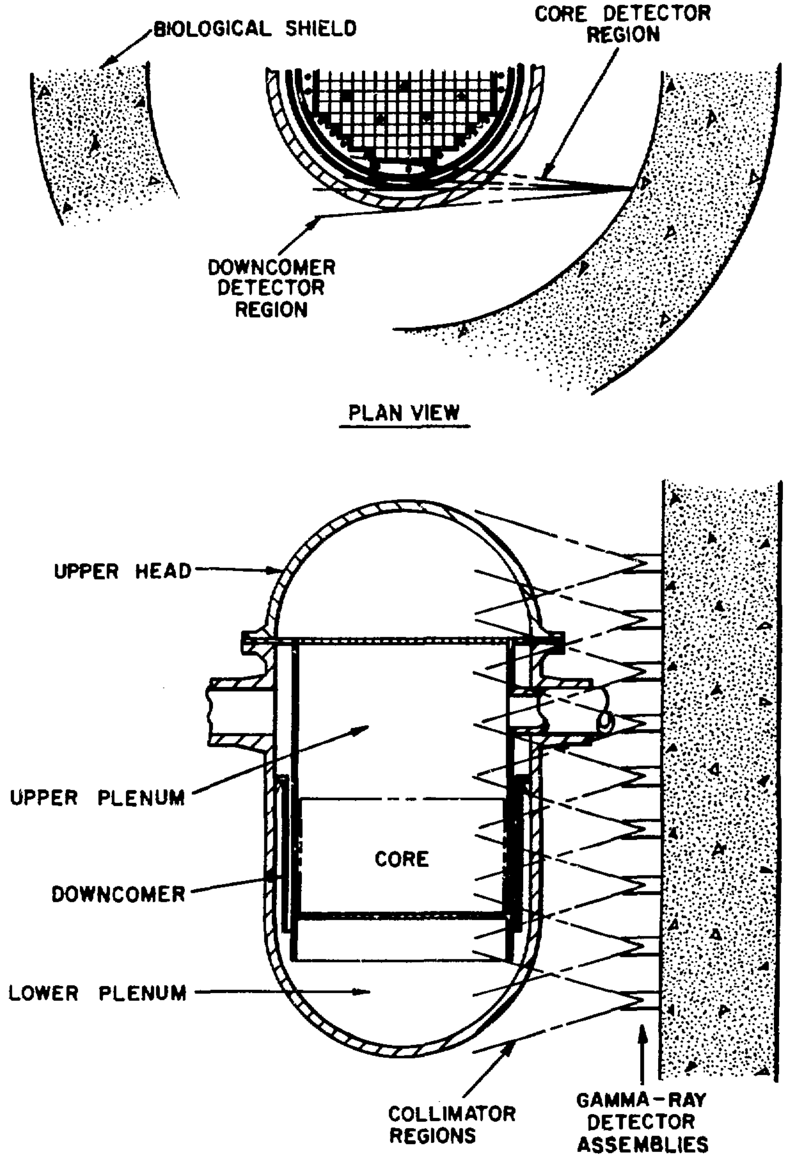

Fig. 1. Coolant Inventory Monitoring System Composed of an Axial Array of Collimated Gamma Detectors Located Outside the Pressure Vessel. Separate monitoring of core and downcomer regions is attained with collimation. A power normalized vertical distribution of coolant density can be provided during both normal operating and transient conditions.

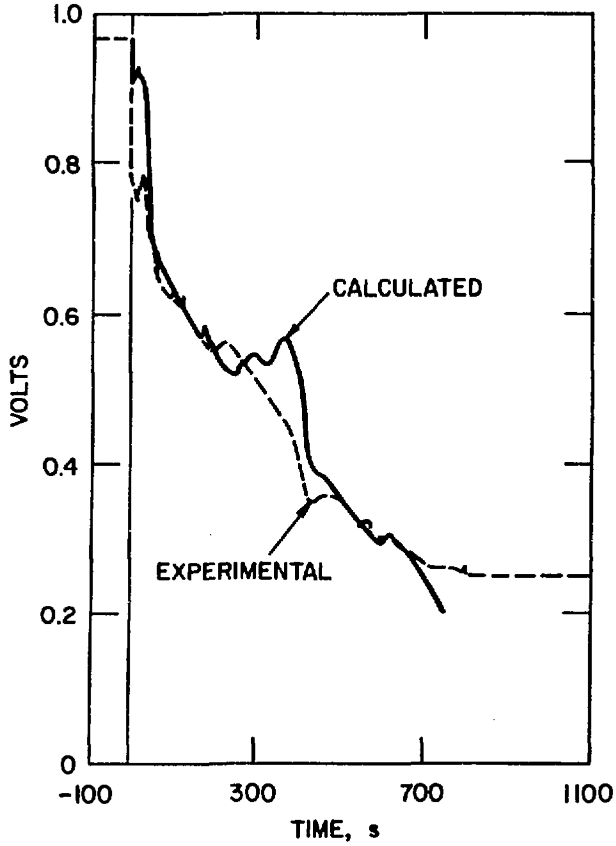

Fig. 2. Comparison of Calculated and Experimental LOFT Intermediate Range Detector normalized Response From LOCA Test L2-5. The simulated response is based on a time independent one-dimensional coupled neutron gamma transport calculation. The calculated gamma detector response follows well the actual neutron detector response with some discrepancies which are explained by the limitations of the model.