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FUEL HANDLING EXCLUSION ZONE ESTABLISED TO PREVENT SPURIOUS ALARMS TO CAS NEUTRON DETECTORS IN THE IFSF

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ABSTRACT

An experimental and calculational study has been performed to understand and prevent inadvertent activation of the criticality alarm system (CAS) from fuel-handling operations at the Irradiated Fuel Storage Facility. In conjunction with the study, the CAS neutron detectors were tested to verify the design specifications for gamma rejection capability and zero response limit. A minimum physical restrictive boundary around the CAS location was established based on a gamma ray dose rate limit of 10 rad/hr. The canister loaded with spent nuclear fuel must be moved in the area outside the exclusion zone so as not to trigger a false alarm from the CAS detectors.

I. INTRODUCTION

The purpose of a criticality alarm system (CAS) is to reduce risk to personnel by detecting a criticality event (neutron radiation) and actuating an alarm system to initiate emergency response. Inadvertent criticality alarms from non-critical events, such as spurious voltage spikes or intense gamma radiation fields can result in work cessation, time-consuming and costly event assessments, and potential harm to personnel during a false evacuation. It therefore becomes a major concern to ensure inadvertent or false criticality alarms do not occur or at least are minimized. Minimization of inadvertent criticality alarms due to intense gamma radiation emitted from spent nuclear fuel elements as opposed to neutron radiation from an actual criticality event is the primary focus of this calculational and experimental study.

The Irradiated Fuel Storage Facility (IFSF) is a government-owned, contractor-operated facility located at the Idaho National Engineering and Environmental Laboratory (INEEL), within the Idaho Nuclear Technology and Engineering Center (INTEC). The mission of the facility is to provide safe dry storage for various types of spent nuclear fuels. Some of the fuel types stored in the facility include high burnup elements from the Advanced Test Reactor (ATR), High Flux Beam Reactor (HFBR), Experimental Breeder Reactor, Fort St. Vrain and Peach Bottom commercial reactors, and TRIGA reactors. Although other fuel types (lower burnup) are stored in the IFSF, it is these high-burnup elements with the associated intense gamma radiation fields that have the potential to inadvertently set off the criticality alarms in the fuel-handling area adjacent to the storage vault.

Fuels requiring dry storage are received at the IFSF in fuel shipping casks. At the facility's receiving dock, the casks are removed from the transport vehicle, positioned in a cask transport car, and moved into the fuel-handling cave. Typically, in the fuel-handling cave, the cask lid is removed, and individual fuel elements are extracted from the cask and placed in special storage canisters. It is during the time period when fuel elements are extracted from their casks or when fully loaded canisters are moved in the cave that the CAS detectors are exposed to the intense gamma radiation fields from the spent fuel.

II. CAS NEUTRON DETECTORS

The IFSF fuel-handling cave is rectangular in shape with 4.5 ft thick concrete walls. On the north wall is a leaded-glass-viewing window with two manipulator ports on each side of the window that penetrate the concrete wall. The manipulators are no longer in service and have been removed, leaving one of the two cylindrical tube penetrations in the concrete wall available for the placement of the neutron detector cluster, which is part of the CAS. The other penetration is filled with lead shot to prevent radiation streaming through the wall. The neutron detectors are designed such that fast neutrons from a criticality event are thermalized by a polyethylene moderator, strike the scintillator detector material, and generate a light pulse. The cluster is composed of three scintillator tubes bound tightly together in a lead sheath as shown in Figure 1. The lead plug and sheath provide gamma radiation shielding, but does not fully shield the tube axial length circumferentially. The top of the sheath is open and can allow buildup of scattered gamma rays that penetrate the concrete wall and strike the scintillator material. The CAS detector is designed with a 10000:1 gamma rejection ratio and zero response above background in gamma radiation fields of $\leq$ 10 rad/hr.

III. DETECTOR GAMMA RESPONSE

The three neutron detectors of the CAS cluster were first individually tested to verify the design specifications for gamma rejection capability and test the zero response limit. The detectors were subjected to two different gamma-ray-emitting sources of known strength, Ir-192 and Cs-137. The Ir-192 source emits gamma rays in the range of 0.296-0.468 MeV and the Cs-137 source has a gamma ray peak at 0.662 MeV. The local gamma dose rates experienced by the detectors were varied by carefully changing the distance between the source and the detector. For the Cs-137 tests, all three detectors passed the zero response to gamma fields exceeding 10 rad/hr. One detector did not register a response until subjected to a field of greater than 40 rad/hr. Another detector responded just over 10 rad/hr. This indicates some variation in the individual detector gamma rejection capability, but all three met the vendor specification.

The second test source, Ir-192, is not a vendor specified gamma ray source. One detector was tested and found to respond to a field intensity in the 3-5 rad/hr range. The background radiation level consistently registered 3-4 mrad/hr and when the Ir-192 produced a 3.85 rad/hr field in the vicinity of the detector, the detector registered a 34 mrad/hr response. The neutron detector did not pass the vendor specification limits at this gamma ray energy indicating some nonlinear response as a function of energy. Also, it is important to note that the CAS detector with a set point of 20 mrad/hr would have inadvertently alarmed for this situation.

In addition, the Ir-192 source test indicated extreme non-linearity in the gamma rejection ratio as shown in Figure 2. (Distance between the source and the detector is given in inches.) At high external gamma field intensities, the gamma rejection was approximately 10:1. At 6 rad/hr, the gamma rejection increased to approximately 100:1. At 5 rad/hr, the ratio increased to 1000:1. Beyond this point, an accurate calculation of the ratio was not possible because the Data Acquisition System (DAS) reading was a steady background count rate. The measured ratio was considerably less than the 10,000:1 gamma rejection ratio.

IV. ANALYSIS

In order to evaluate the gamma-ray intensity and spectrum that the CAS neutron detector cluster is exposed to, two separate calculational studies were performed. The first calculation involved the determination of a bounding spent fuel gamma-ray source term. The second calculation was a parametric study involving gamma-ray transport from a canister loaded with spent fuel elements to the CAS detectors and determine the dose rate at the detectors as a function of distance and angle between the canister and the CAS concrete wall. From the second calculation, an exclusion zone was established. (i.e., calculated dose rate had to be $\leq$ 10 rad/hr).

A variety of spent nuclear fuel elements that have varying magnitude of burnup and decay time are expected during the course of fuel movement into the fuel-handling cave. Gamma ray source spectrum for each fuel type is calculated using ORIGEN2 based on detailed burnup history of the fuel.[1] The gamma flux-to-dose conversion factors are based on ANSI/ANS-6.1.1-1977. In order to encompass all spent nuclear fuels, a hypothetical ATR maximum burnup fuel element was used in the calculations. ORIGEN2 was used to perform the fuel depletion calculation for the single ATR fuel element. The ATR fuel element was assumed to have a burnup of 367.2 MWD (megawatt-days) followed by 11.5-year ex-core decay. The resulting gamma-ray source spectrum from this calculation was then used as the source term for gamma transport calculations.

The individual fuel and the canister were modeled using the three-dimensional Monte Carlo code, MCNP.[2] The single spent ATR fuel element and a canister loaded with eight ATR elements were explicitly modeled using MCNP.

A third calculation was also performed in order to add confidence in the analytical methodology. Gamma-ray dose rates from previously measured spent fuel elements were available for this verification check. Four Advanced Reactivity Measurement Facility (ARMF) spent fuel elements had measured surface dose rates of 1.18, 2.0, 2.0, and 1.5 rad/hr. Using detailed MCNP geometry models of the ARMF element and a detailed power history, the calculated dose rate values ranged from 1.3 to 1.7 rad/hr, indicating good agreement between the measured data and the calculated dose rate values.

V. EXCLUSION ZONE

A solution to prevent inadvertent activation of criticality alarms involves setting up an exclusion zone around the CAS detectors. Centered about the CAS and extending from the north wall into the fuel-handling cave and from the cave ceiling to an elevation below the detector level, the exclusion zone boundaries and dimensions were determined analytically. Individual elements or loaded canisters would be prohibited from entering the exclusion zone.

Based on the Ir-192 gamma source test, a limit of 4 rad/hr at the detectors was initially used as a basis for determining the exclusion zone boundary. This limit was later increased to the vendor specified 10 rad/hr considering that the gamma ray spectra of the spent nuclear fuels are similar to that of Cs-137 rather than Ir-192.

An experimental test of the exclusion zone was actually performed in the IFSF fuel-handling cave with a canister loaded with two ATR fuel buckets and one HFBR fuel bucket. The CAS was not activated for the canister placed adjacent to the north concrete wall of the fuel-handling cave. The calculated dose rate, 17.9 ± 0.8 rad/hr, was higher than the limiting dose rate, 10 rad/hr, but still did not cause any false alarm to the CAS detectors. The dose rate obtained from an independent calculation was 18.4 ± 1.5 rad/hr, which gave further confidence in the analytical modeling and calculational method.

The parametric dose rate calculations were performed by varying the spacing between the concrete wall and the canister, and by varying the height relative to the canister position and the CAS elevation. A minimum physical boundary was established to envelop all of the fuel types moved through the fuel- handling cave. The exclusion zone is 8 ft from the concrete wall and 8 ft wide on both sides of the CAS detector position as shown in Figure 3. The calculated gamma ray dose rate at the CAS detectors is less than 10 rad/hr for spent fuel outside the exclusion zone, and within the exclusion zone, the dose rates would be greater than 10 rad/hr. The canister must be moved in the area outside this exclusion boundary so as not to trigger a false alarm from the CAS detectors.

VI. CONCLUSION

The minimum physical boundary, 8 ft from the concrete wall and 8 ft on both sides of the CAS detector position, enveloped all of the fuel types moved through the fuel-handling cave.

ACKNOWLEDGEMENT

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2. J. F. Briesmeister, Editor, MCNP4A: Monte Carlo N-Particle Transport Code System, LA-12625-M, Los Alamos National Laboratory (1993).

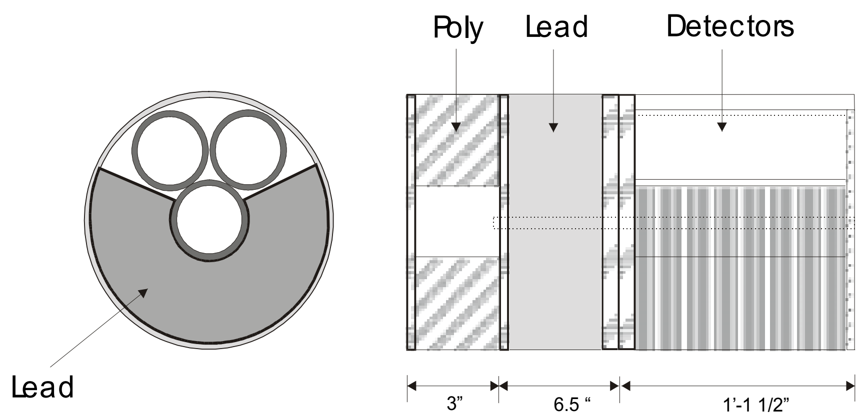

Figure 1. CAS Neutron Detector Assembly

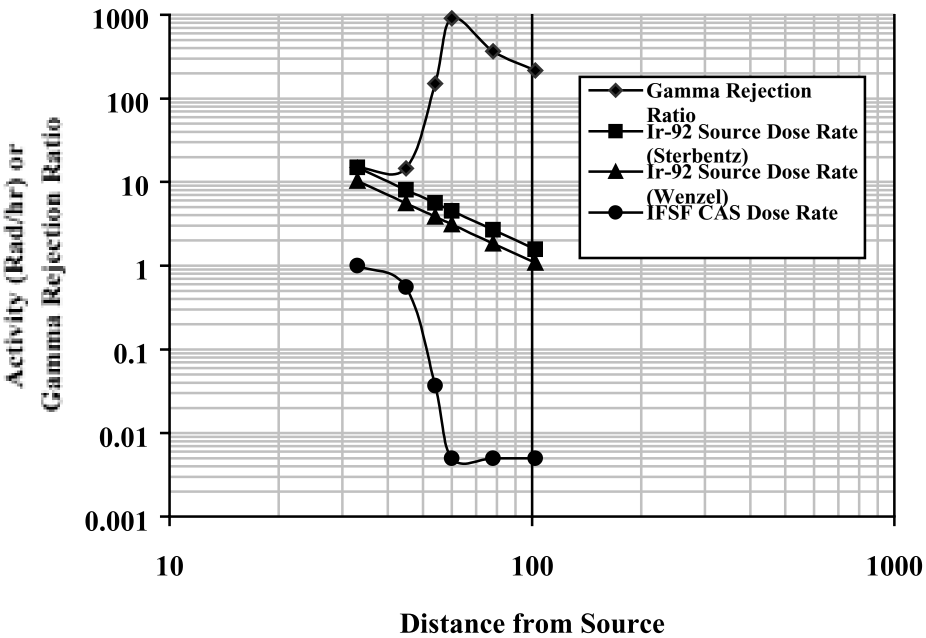

Figure 2. Gamma Rejection Ratio for Ir-192

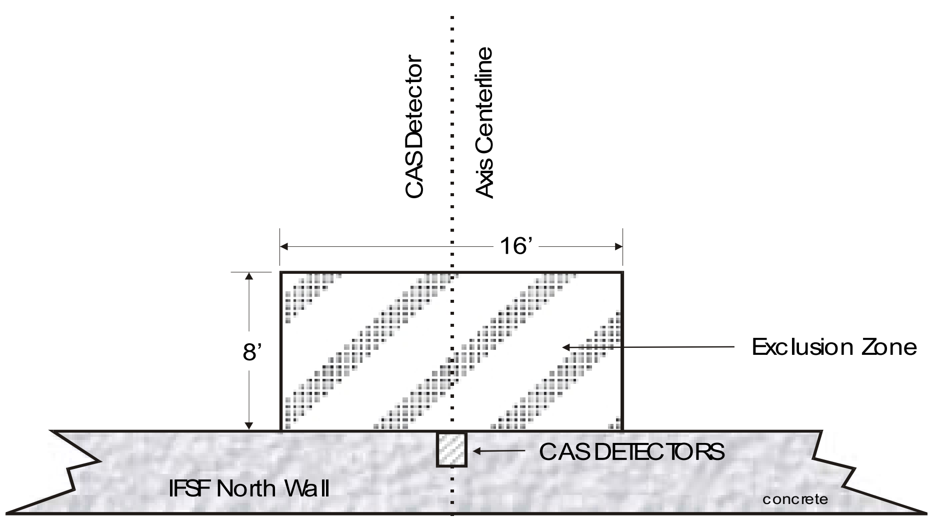

Figure 3. Exclusion Zone Boundary