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Contract Program or Project Title: Dosimetry Measurement Reference Data Base For LWR Pressure Vessel (LWR-PV) Irradiation Surveillance.

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Status Letter (for March and April): Dosimetry Measurement Reference Data Base for LWR Pressure Vessel (LWR-PV) Irradiation Surveillance.

Program Definition:

° NBS personnel gave a status presentation on March 5, 1979 for the NRC annual review of the LWR-PV Surveillance Dosimetry Program.

° Two members of NBS participated in the Third LWR-PV Surveillance Dosimetry Meeting, held at ORNL April 3-5, 1979 to review status and accomplishments and schedule activities for the remainder of CY-1979.

° NBS and CEN/SCK will participate in fission rate and neutron activation dosimetry measurements in the low-flux PCA pressure vessel simulator in early June 1979. The purpose is to confirm that a modified PSF configuration (referred to as the 4/9 configuration) for this high-flux, metallurgical irradiation, pressure vessel facility at the Oak Ridge Research Reactor will insure the availability of 2×10^{19} fluence in a one-year irradiation.

Interface Development:

° The fourth in a series of exploratory activation measurements in the cavity outside of the pressure vessel of the Arkansas Power and Light Company's Unit #1 PWR is scheduled to get underway in late May 1979. Dosimeters from the third such experiment are under analyses in a co-operative program between the University of Arkansas and the Hanford Engineering and Development Laboratory. NBS continues to be instrumental in coordination of these tests and will participate in data analysis and evaluation.

Benchmark Field Referencing:

° Status of Certified Fluence Standards: Twenty-seven nickel foils that were irradiated to a known fluence in the NBS U-235 fission spectrum Cavity Fission Source have been distributed internationally. This effort is for the purpose of establishing interlaboratory consistency among laboratories analyzing radiometric dosimeters for the LWR-PV Surveillance Dosimetry Program.

To date, ten results of analysis have been ventured. It is anticipated that 90% of the remaining foils will be in and analyzed for reported results on radioactivity, neutron fluence, and uncertainties by June 1979.

Preparation has begun on iron and fissionable counting standards, but because of increased commitments for NBS dual fission chamber measurements in the PCA facility this fall, the distribution in CY-79 will be limited.

° Benchmark Field Referencing of Dosimetry for PSF Metallurgical Irradiations: It is necessary to insure consistent international laboratory analyses of neutron dosimetry for metallurgical irradiations in the LWR-PV-PSF. This will be accomplished by using control dosimetry sets that are equivalent to those in the metallurgical irradiations (i.e., archive dosimeters). The control dosimeters will be carefully exposed in a high-fluence Benchmark Neutron Field and distributed near the time of completion of the metallurgical irradiations. Dosimetry results will only be considered certified when a laboratory has successfully analyzed at least one set of the control dosimeter sets. Dosimeter response values for the Benchmark Field, against which independent results are to be judged, will be consensus evaluations by multiple, acknowledged experts in the respective areas of dosimetry. The presently proposed Benchmark Facilities for the Certification Irradiations are either the CFRMF, a Reference Benchmark research reactor operated by EG&G Idaho Incorporated, or NIGHTMARE, an in-core benchmark facility in the NBS reactor. This latter facility is now under development for quality assurance of fast-neutron dosimetry materials.

° NBS Contribution to ASTM Uncertainty Analysis Task Force: A special task group on uncertainty analysis has been formed at the December 1978, Bal Harbour meeting of the ASTM Subcommittee E10.05 on neutron dosimetry. The goal of this group is to investigate current practices and state-of-the-art methods in uncertainty as it applies to dosimetry and to provide guidance for their implementation in ASTM standards. As a first order of business, the task group decided to make a survey on current techniques of assigning and processing uncertainties. The NBS contribution to the task group meeting in San Francisco, May 22-25, 1979 is the subject of the remainder of this report.

An NBS report entitled "Neutron Flux Measurements in the Pressure Vessel Cavity of an Operating U. S. Power Reactor" is in final draft stage. The report attempts in a simple textbook manner to address the issue of neutron fluence dosimetry based upon benchmark neutron field referencing. The focus of the report is to assess errors and, in particular, to formulate the fluence derivation in such a manner that the relative importance of the various error sources is apparent. Working with experimental data from an exploratory multiple-foil activation measurement in the pressure vessel cavity of an operating PWR, the report shows step-by-step how to determine the magnitude and uncertainty of the fast-neutron fluence above 1 MeV. In this first-cut analysis, the spectral information that is implicit in the threshold detector data is not emphasized.

Conventional analytic expressions for detector reaction rate[1/] are modified in order to make uncertainty contributions explicit and to evaluate the error reduction achieved as a consequence of benchmark field referencing. It is recognized that a rigorous treatment of error propagation, including covariance information, may eventually be desireable. However, such an analysis of the double ratios involved in benchmark referencing is a formidable task, requiring as it does correlations between spectra, cross sections, and reaction rates. The report emphasizes the following problem areas associated with integral detector neutron dosimetry.

° Dependence of Propagated Error on the Uncertainty in Calculated or Assumed Spectrum: Calculational methods that use total or effective spectrum-averaged cross sections or that employ unfolding algorithms generally do not provide an explicit indication of how much the results depend upon the calculated or assumed spectrum. This frequently turns out to be a principal source of uncertainty in the result. To improve this situation, the formulations developed in the report consider separate expressions for experimental and calculated reaction rates which are generally applicable for all types of integral detectors. On this basis there is a more consistent separation of measured integral quantities and the required input spectrum. Two important detector response parameters are involved in the development: (1) the truncated cross section defined as the spectrum-averaged cross section above the detector threshold; and (2) the spectrum coverage factor, which is the fraction of the neutron spectrum above 1 MeV to which each detector responds. A detailed description of the error analysis for these parameters shows quantitatively the relative importance of uncertainties in cross section shapes and the calculated cavity spectrum, as well as the effect of the weighting introduced by the different spectrum coverage factors of the individual detectors.

1/ As reported in the NBS section, "Compendium of Benchmark and Test Region Neutron Field for Pressure Vessel Irradiation Surveillance," in the U. S. Nuclear Regulatory Commission's Report NUREG/CR-0551 (1979).

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° The Need for Simple Intuitive Approach: Because of the integral response of neutron activation dosimeters, most calculation methods do not provide an explicit description of the relationship between the response characteristics of specific detectors and details of the energy spectrum. This is important, however, because frequently one or two detectors out of a set are almost totally responsible for the uncertainty in the quantity sought. A more explicit description of the spectral sensitivity can be achieved by reformulating spectrum-averaged cross sections in terms of their response range in the spectrum of interest and the above mentioned spectrum coverage factor. Controlling parameters are more obvious in this formulation and the contributions of their uncertainties to the overall error can be propagated by means of simple algebraic equations. This "cookbook" approach hopefully will meet the need to treat the comprehensive lists of identified errors that are to be included in the 15 ASTM standards currently under development by Subcommittee E10.05 for the LWR-PV Surveillance Dosimetry Program.

° The Need for Benchmark Referencing: The subject report not only discusses calculational procedures but also discusses experimental methods to suppress, or circumvent, uncertainties that are frequently difficult-to-measure. More important, these benchmark referencing techniques, establish a traceability of the measured quantities to the neutron source strength of NBSI, the National Standard Radium-Beryllium Neutron Source. Such referencing, or cross-calibration techniques, are of two types.

(1) Neutron flux transfer: This involves calibration of each type of detector in a benchmark neutron field of known flux intensity. Such a calibration has the distinct advantage of making the measurement of the radioactivity induced in detector foils a relative measurement, which is subject to fewer and more clearly definable uncertainties than absolute radioactivity measurements.

(2) Spectral index measurements relative to the benchmark field: Conventionally, an experimental spectral index is the ratio of the reaction probabilities of two detectors with distinguishable energy responses. These measured indexes, among threshold detectors for example, may be compared with calculated spectral indexes derived from transport computations of the spectrum. The double ratios, calculated-to-experimental, then provide a basis for evaluating the validity of the transport computation. Benchmark referenced spectral indexes are of particular value in this procedure because they are more reliable and they make it possible to carry out a complete error analysis. For example, when the ratio of the reaction probabilities of two given detectors measured in the study spectrum is divided by the comparable ratio in a benchmark neutron field, the result is independent of detection efficiencies and absolute cross section scales. Consequently, such a benchmarked spectral index is a much more accurate spectrum monitor than an index derived from the ratios of independently measured reaction probabilities.

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° A Practical Example of Error Propagation: The report provides an easy to follow example of the application of the above concepts to exploratory data from a representative PWR environment outside of the pressure vessel. In this example, it is found that the uncertainty in the cavity spectrum calculation largely governs the final error (i.e., it is more than 90% of the total error) and that nearly all of this spectrum uncertainty comes from the energy region between 1 and 1.5 MeV. The study concludes, therefore, that the two most significant isotopes for dosimetry in this type of spectrum are the ^{237}Np and ^{238}U fission reactions.

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