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Energy Deposition Measurements in Fast Reactor Safety Experiments with Fission Thermocouple Detectors

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The investigation of phenomena occurring in in-pile fast reactor safety experiments requires an accurate measurement of the time dependent energy depositions within the fissile material. At Sandia Laboratories thin-film fission thermocouples are being developed for this purpose.(1) These detectors have high temperature capabilities (400-500°C), are sodium compatible, and have milli-*second time response. A significant advantage of these detectors* for use as energy deposition monitors is that they produce an output voltage which is directly dependent on the temperature of a small chip of fissile material within the detectors. However, heat losses within the detector make it necessary to correct the response of the detector to determine the energy deposition. A method of correcting the detector response which uses an inverse convolution procedure has been developed and successfully tested with experimental data obtained in the Sandia Pulse Reactor (SPR-II) and in the Annular Core Research Reactor (ACRR).

The Fission Couple Detector (FCD) is fabricated by bonding a small chip of fissile material to a thin-film thermocouple junction which is plated to an electrical insulator (either glass or Al_2O_3). When fission and gamma heating occurs in the fissile chip, the heat is rapidly conducted to the thermocouple junction. An output voltage is produced in the external circuit which is proportional to the temperature difference between the junction with the fissile chip and a neighboring junction which has no chip.

To correct for the heat losses the detector output voltage is assumed to be linearly related to the energy deposition in the fissile material via the convolution integral

$$R(t) = \int_{\tau=0}^{t} F(t)H(t-\tau)d\tau \qquad (1)$$

where R(t) is the response of the detector to the energy deposition rate in the fissile material, F(t). H(t) is the impulse response of the detector. During an actual experiment the response of the detector is measured at discrete times, the impulse response function is known from previous measurement or calculations, and the objective is to determine F(t). In this case the energy deposition rate may be calculated from the discrete form of the inverse convolution integral

$$F(n) = \frac{1}{H(o)} \left[R(n) - \Delta t \sum_{i=o}^{n-1} F(i)H(n-i) \right] \qquad (2)$$

where n and i have replaced the continuous variables t and p. In practice an improved technique is used which was suggested by Beck(2) in solving similar problems. This improved method approximates F(n) for times greater than n by a power series expansion. The coefficients of the expansion are determined by minimizing the mean square error between an arbitrary number of measured future responses and the calculated responses as predicted by the power series. This method has the effect of smoothing the "unfolded" data in a realistic manner by using information contained in future data.

The impulse response function of the FCD was measured in the SPR-II reactor (pulse width of 56 μsec) and is illustrated in Figure 1. The time constant associated with the rising portion of the curve (2.6 msec) is a measure of the heat transport time from the fissile chip to the thermocouple junction. The time constant of the decaying portion of the curve (121 msec) is dependent on the heat transport times between the pairs of compensating thermocouple junctions and the heat losses to the substrate.

Figure 2 illustrates the unfolded FCD response (normalized to reactor power) during a typical reactor pulse for an ACRR Fuel Disruption Experiment.(3) The coupling factor for these experiments is 76 joules/cm^3 in the test fuel pin per MJ in the reactor. To illustrate the effectiveness of the inverse convolution procedure, the actual measured data from the fission couple is also shown. Also, for comparison the response of a cadmium self-powered detector (Cd-SPD) is given. Notice that the two curves for the SPD and the unfolded fission couple agree quite well except during the peak. This discrepancy may be caused by a nonlinearity of the SPD during rapid transients.(4)

Support for this research and development is provided by the U.S. Nuclear Regulatory Commission in conjunction with the in-core fuel motion detection program. At present several FCD's are being fabricated for use in the Sandia fuel disruption tests and in the prompt burst experiments(5). In addition an array of these detectors will also be used in the CABRI calibration experiments where the detectors will be used to monitor the time and spatially dependent energy deposition within the test fuel.

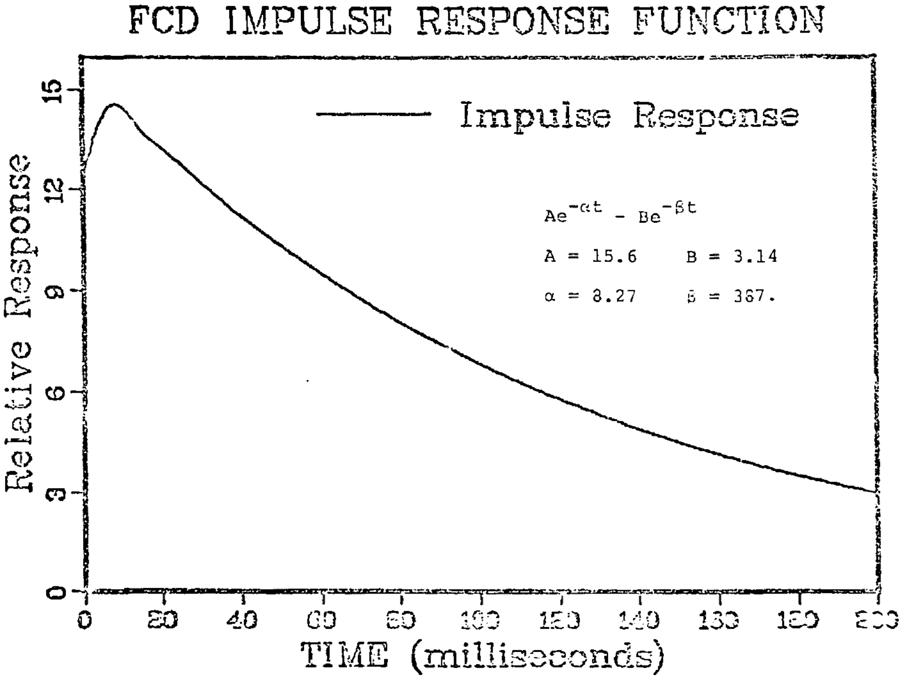

Figure 1. Impulse Response Function for a Fission Couple Detector Measured in SPR-II

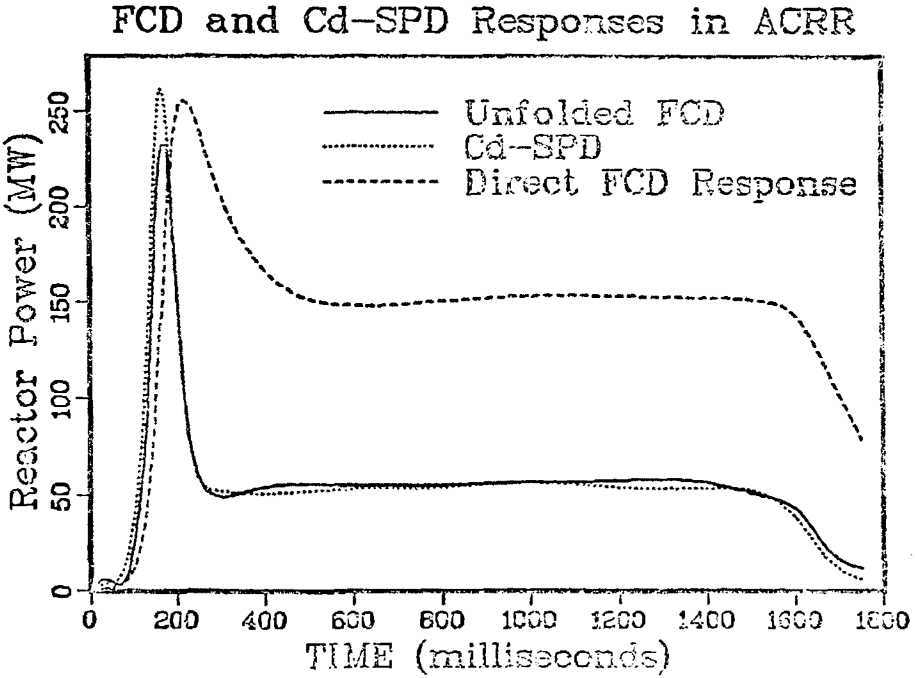

Figure 2. Inverse Convolution of a Fission Couple Response to Determine Energy Deposition Rate

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