

## DOSIMETRY OF CRITICALITY ACCIDENTS USING ACTIVATIONS OF THE BLOOD AND HAIR\*

Dale E. Hankins

Hazards Control Department, Lawrence Livermore Laboratory, P. O.  
Box 808, Livermore, California, U.S.A.

### INTRODUCTION

The evaluation of the dose that a person received in a criticality accident can be difficult. Most accidents have occurred when the person was not wearing nuclear accident dosimetry and since the NRC no longer requires these dosimeters, future dose evaluations may have to be based on body activations and gamma-to-neutron dose ratios. To aid in a dose evaluation we have compiled in a table (available from the author) the results from numerous criticality accident studies using 10 different critical assemblies, each with different neutron leakage spectra. There are several problems involved in applying these results accurately, the most significant problem being the determination of the configuration of the fissile material at the time of the accident. Other problems include a lack of information concerning the location, orientation, and possible shielding between the person and the accident assembly.

### DOSIMETRY STUDIES

The literature contains a number of criticality accident dosimeter studies,<sup>(1)</sup> including a mock-up study of the accident which occurred in the Y-12 facility at Oak Ridge, Tennessee and four studies sponsored by the International Atomic Energy Agency. Also studied were the Health Physics Research Reactor (HPRR) at the Oak Ridge National Laboratory and five different types of critical assemblies at the Los Alamos Scientific Laboratory.

These dosimetry studies were made with reactors and critical assemblies having extremely diverse configurations. Schematics of these assemblies, drawn to scale in Fig. 1, show major features that are important in modifying the neutron leakage spectrum. Leakage spectra vary greatly, and as a result the blood or hair activations for the same neutron dose will be very different from each assembly.

### SODIUM ACTIVATION OF BLOOD AND $^{32}\text{P}$ ACTIVATION OF THE HAIR

The most useful activations of the body for dose estimation following a criticality accident are those of the blood and the hair.

Activation of  $^{23}\text{Na}$  in the body is determined by counting the  $^{24}\text{Na}$  produced in about 20-cm<sup>3</sup> of blood with a NaI or GeLi detector. The 1.369-MeV gamma ray is used to determine the  $^{24}\text{Na}$  activity in  $\mu\text{Ci}$  of  $^{24}\text{Na}$  per mg of  $^{23}\text{Na}$ . The probability of neutron capture by sodium in the human body is fairly constant for neutron energies from thermal to 5 MeV,<sup>(2)</sup> but the kerma dose delivered by

\*Work performed under the auspices of the U. S. Department of Energy by the Lawrence Livermore Laboratory under contract No. W-7405-ENG-48.

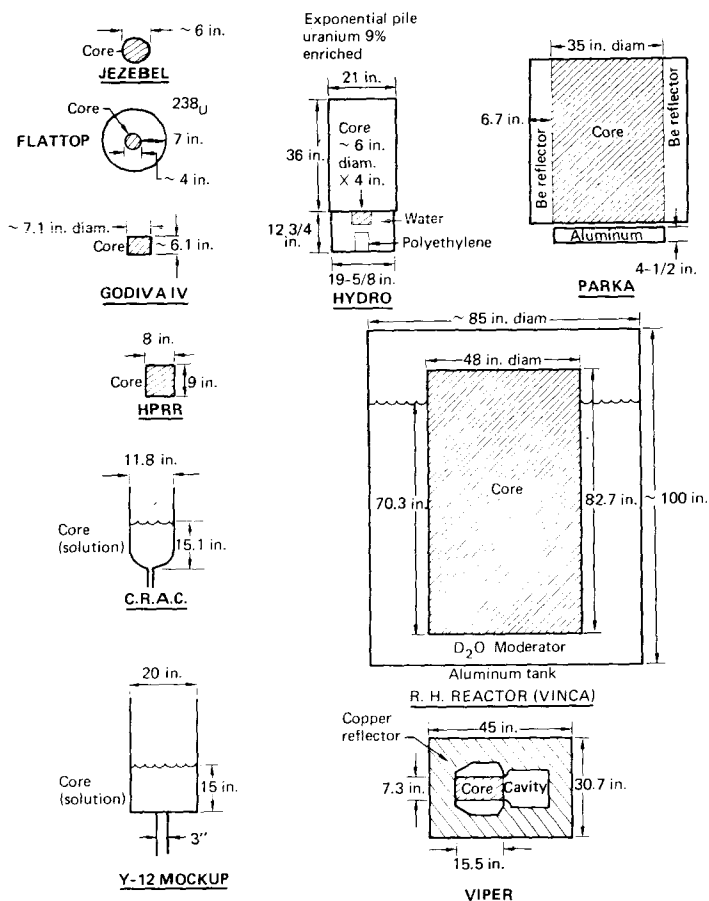


Figure 1. Schematic of the critical assemblies and reactors used in dosimetry studies (drawn to scale), showing the core configuration and components that affect the leakage neutron spectrum.

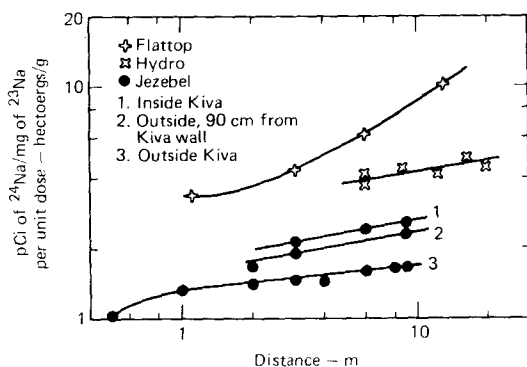


Figure 2. Blood sodium activation per hct of neutron dose as a function of distance from the assembly. Jezebel results with assembly located inside, outside, and near the outside wall of a building are given.

neutrons is predominantly from fast neutrons. Consequently,  $^{24}\text{Na}$  activation in the blood is not proportional to the neutron dose.

Figure 2 shows blood sodium activation from the Jezebel assembly as a function of the distance from the assembly, when the assembly is (1) in a building (kiva), (2) outside, and (3) near a concrete wall. Increases in activations are caused by scattered, low energy neutrons, which activate the blood but contribute little to the neutron dose. Similar curves for the Hydro and Flattop assemblies are shown.

Sodium activation in the body can be detected by placing a G-M instrument in the abdomen. The G-M reading is proportional to the Na activation and the resulting curves (available from the author) are very similar in shape to the curves given in Fig. 2.

Activation of the sulfur in the hair by fast neutrons ( $>2.9$  MeV) produces the beta emitter  $^{32}\text{P}$ . If the individual has not been contaminated, the technique preferred, because of accuracy and simplicity, is the direct counting of the hair with a beta counter following the procedure described in detail by Hankins.<sup>(3)</sup> The counter is calibrated using a  $^{90}\text{Sr}$ - $^{90}\text{Y}$  source, and the count rate of the hair in counts/min/g is determined and divided by 1.77 to obtain the fast neutron dose in rads (above the 2.9 MeV threshold for sulfur). Unfortunately, the percent of the neutron kerma dose that is from neutrons having energies of 2.9 MeV varies from 2.1 to 48%.

## RELATIVE GAMMA AND NEUTRON DOSES

The ratio of gamma-to-neutron doses can be used to determine the total dose if either the gamma or the neutron dose is known. Unfortunately, the estimation of dose based on gamma-to-neutron ratios may not be accurate since this ratio for the various critical assemblies varied from around 0.09 to 2.9. The effect of shielding material is also significant. For example, the HPRR ratios vary from 0.19 for a bare assembly to 1.9 for a polyethylene-shielded assembly.

## EVALUATION OF THE DOSE

Following an accident the configuration of the fissile material at the time of the excursion is established, if possible. This configuration can then be compared with those shown in Fig. 1, and if it is similar to one of them, the experimental results (available from the author) obtained with the assembly most closely resembling the excursion can be applied to evaluate the doses.

The neutron leakage spectrum and subsequent activations of hair and blood are also affected by other factors which include: shielding the exposed person; whether the exposed person was indoors or outdoors; where he was with respect to walls or floors; his orientation; the angle of exposure; and his distance from the assembly. Several of the assemblies shown in Fig. 1 have been used to evaluate the effect of many of these factors.

## DOSE EVALUATION USING A COMBINATION OF THE BLOOD AND HAIR ACTIVATIONS

The most serious problem following an accident is a lack of information on the configuration of the fissile material which makes it impossible to find in Fig. 1 an appropriate critical assembly. Furthermore, there is often a lack of other information necessary to

accurately assess the dose. The dose can still be evaluated by using a combination of blood and hair activations.

The activation of the blood and hair is determined as described previously and the ratio of the sulfur fluence to the blood sodium activation is calculated. In Fig. 3, we have plotted the ratio of sulfur fluence to blood sodium activation as a function of blood sodium activation and have drawn two curves.

To evaluate the dose using this procedure we first read the blood activation (in  $\text{pCi } ^{24}\text{Na}/\text{mg } ^{23}\text{Na}$  per rad of fast neutrons) from the curve at the point corresponding to the measured sulfur-fluence/blood-sodium-activation ratio. Then, we divide the blood sodium activation by that quantity to obtain the neutron dose that the individual received.

This procedure is independent of the neutron spectrum, hydrogenous shielding, victim orientation and distance, and room scatter. Where there were thick metal shields ( $>10$  cm) either associated with the assembly or between the person and the assembly, the curve on the left must be used. Fortunately, thick metal shields are not commonly used. A dose estimate accurate to within  $\pm 20$ -30% should be obtainable using this procedure.

## REFERENCES

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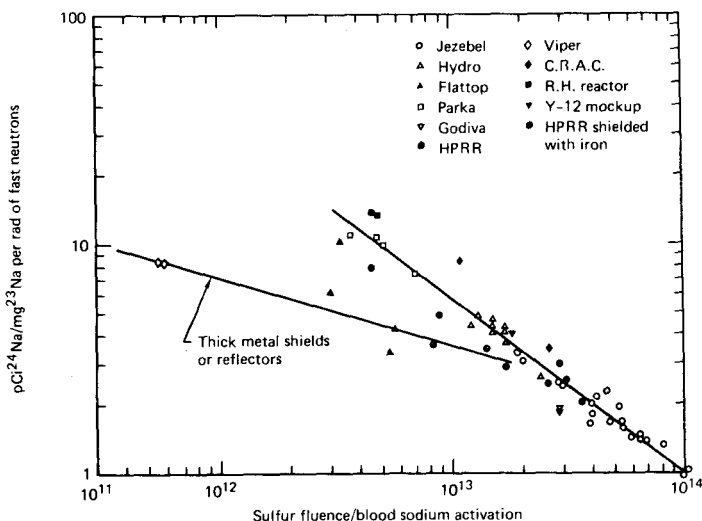


Fig. 3. Curve used to determine the neutron dose using a combination of blood and hair-activation data.