# LOS ALAMOS SCIENTIFIC LABORATORY
## of the
## University of California

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# Revised Dose Estimates for the Criticality Excursion at Los Alamos Scientific Laboratory May 21, 1946



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by

Dale E. Hankins
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ABSTRACT

This report presents revised estimates of the dose received by personnel exposed in the Los Alamos criticality excursion that occurred May 21, 1946. The revised doses are based on a calculation of the leakage neutron spectrum from the critical system and the results obtained from a recent study of blood-sodium activation.

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## Introduction

The $^{24}Na$ activation induced in a person's blood can be used to determine the neutron dose he received in a criticality excursion. Measurements were made of the blood-sodium activity of the eight people exposed in the Los Alamos criticality excursion (LA Accident No. 2) that occurred May 21, 1946. To determine the neutron dose by measuring blood-sodium activation, one must know the neutron spectrum incident on the body or, if this is unavailable, make a dosimetry study using the critical system involved in the excursion. Such a study was made with the reactor involved in the accident at the Boris Kidric Institute in Yugoslavia.[1] When the critical system involved in the excursion cannot be reproduced, a mockup, such as the Y-12 critical assembly mockup used to investigate the Y-12 criticality accident,[2] can be made. No mockup of LA Accident No. 2 has been performed; the need for a mockup assembly has been largely eliminated by a recent study involving five critical assemblies at the Los Alamos Scientific Laboratory. The information obtained during this study allows much more accurate use of the $^{24}Na$ activation of blood than was previously possible. The revision in this report of the neutron dose received by personnel involved in LA Accident No. 2 uses information obtained with two of the five critical assemblies (Flattop and Jezebel).

During the 22 years since LA Accident No. 2, calculations have been developed to obtain the leakage neutron spectra from critical assemblies, and these calculations have recently been used to determine the leakage neutron spectrum from the critical assembly involved in LA Accident No. 2. The results from the Y-12 assembly mockup and the information obtained from the new blood-sodium activation study are applied to the calculated leakage neutron spectrum to obtain revised neutron dose estimates from the blood-sodium activity measurements made following the excursion.

## Calculated Leakage Neutron Spectra

The critical assembly involved in LA Accident No. 2 was a 6.19-kg sphere of δ-phase plutonium alloy reflected on top by a 9-in.-o.d. hemisphere of beryllium and on the bottom by a 13-in.-o.d. hemisphere of beryllium. A screwdriver was used as a wedge between the upper and lower hemispheres to adjust them to the desired critical configuration. The excursion resulted from an unexpected movement of the screwdriver which allowed the upper beryllium shell to fall into place.

The neutron leakage for the assembly has been calculated by Hansen, and is given in Table I. A detailed description of the calculation is given in the Appendix.

The data in Table I are plotted in Fig. 1 relative to the calculated spectra of four critical assemblies used in a recent study of blood-sodium activation.[3] The spectrum in LA Accident No. 2 does not agree well with any of the spectra of the critical assemblies studied. It has a peak at about 2.5 MeV and a steady decrease in neutrons as the energy decreases.

TABLE I

COMPUTED NEUTRON LEAKAGE PER FISSION NEUTRON FOR THE LA ACCIDENT No. 2 CRITICAL ASSEMBLY

| Group | Energy | Neutrons |
|---|---|---|
| 1 | 3 MeV-∞ | 0.0404 |
| 2 | 1.4-3 MeV | 0.1259 |
| 3 | 0.9-1.4 MeV | 0.0606 |
| 4 | 0.4-0.9 MeV | 0.0884 |
| 5 | 0.1-0.4 MeV | 0.1109 |
| 6 | 17-100 keV | 0.0763 |
| 7 | 3-17 keV | 0.0561 |
| 8 | 0.55-3 keV | 0.0398 |
| 9 | 100-550 eV | 0.0288 |
| 10 | 30-100 eV | 0.0158 |
| 11 | 10-30 eV | 0.0115 |
| 12 | 3-10 eV | 0.0098 |
| 13 | 1-3 eV | 0.0071 |
| 14 | 0.4-1 eV | 0.0048 |
| 15 | 0.1-0.4 eV | 0.0055 |
| 16 | Thermal | 0.0176 |
| Sum | | 0.6993 |

In Fig. 2, the calculated leakage neutron spectrum for LA Accident No. 2 is compared to that for the Y-12 accident assembly mockup. Since these spectra agree reasonably well, the blood-sodium activation obtained in the Y-12 assembly mockup studies can be used. The small differences between the spectra would result in calculation of only a slightly higher dose (<2%) than that actually delivered.

## Blood-Sodium Activation

The blood-sodium activation as a function of distance has been obtained for several critical assemblies.[3] As shown in Fig. 3, the blood-sodium activation from 1 rad of fast neutrons varies from 1 pCi for a near-fission spectrum (Jezebel) to 12.5 pCi for a heavily moderated fission spectrum (Yugoslav). The amount of $^{24}$Na produced per rad of fast neutrons varies because high energy neutrons deliver more dose per neutron than do low energy neutrons although the blood-sodium activation

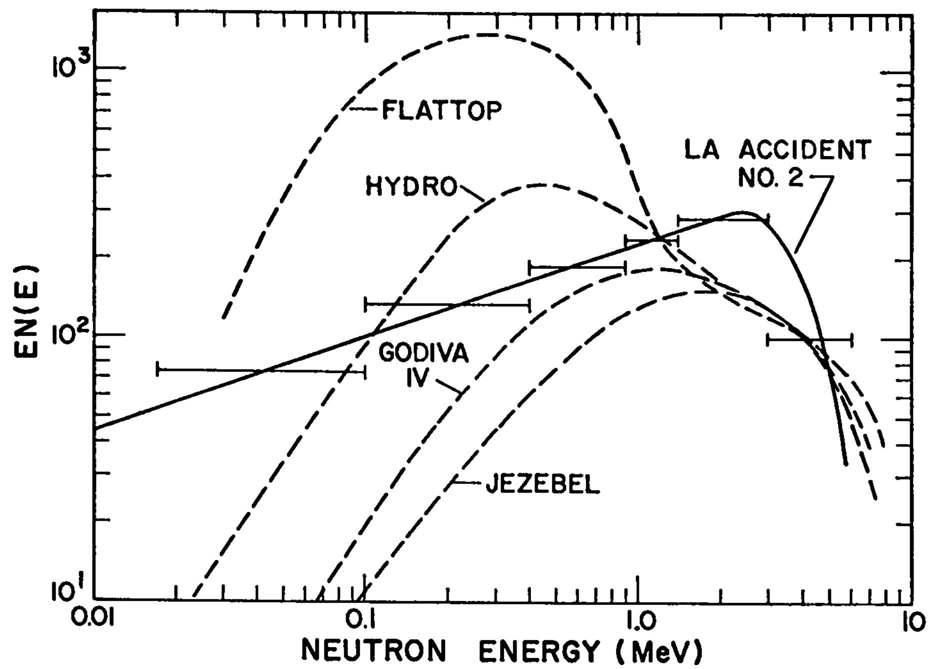


Fig. 1. The calculated leakage neutron spectrum for LA Accident No. 2 vs calculated leakage neutron spectra of other critical assemblies.

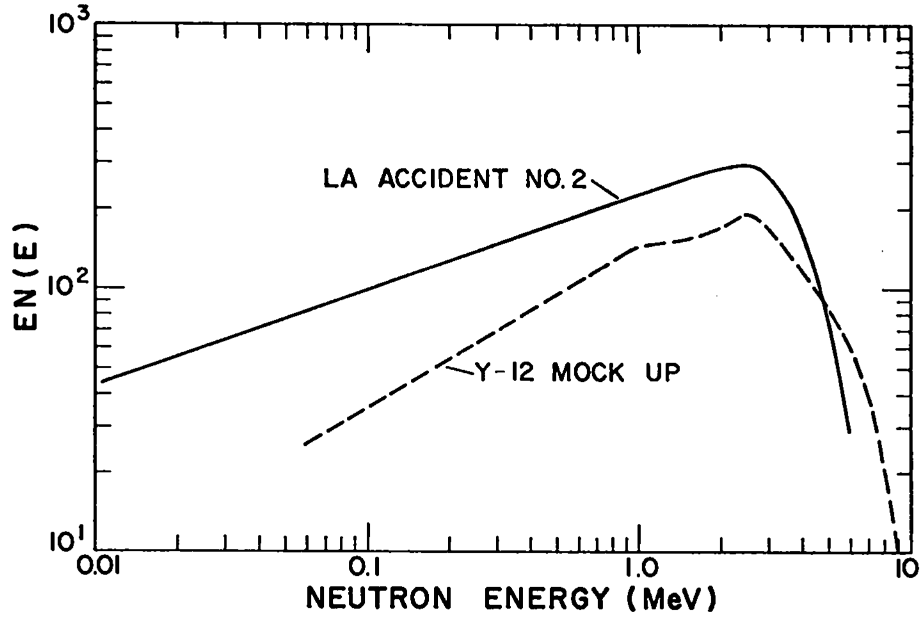


Fig. 2. The calculated leakage neutron spectrum for LA Accident No. 2 vs the leakage neutron spectra of the Y-12 assembly mockup.

per incident neutron remains fairly constant.[3] Consequently, as the average energy of the neutrons in the leakage spectrum of the assembly becomes lower, more activation results from a given neutron dose.

Also, Fig. 3 shows the blood-sodium activation data obtained with the Jezebel assembly in various locations relative to the kiva (kiva is the name given to the buildings which house the Los Alamos criti-

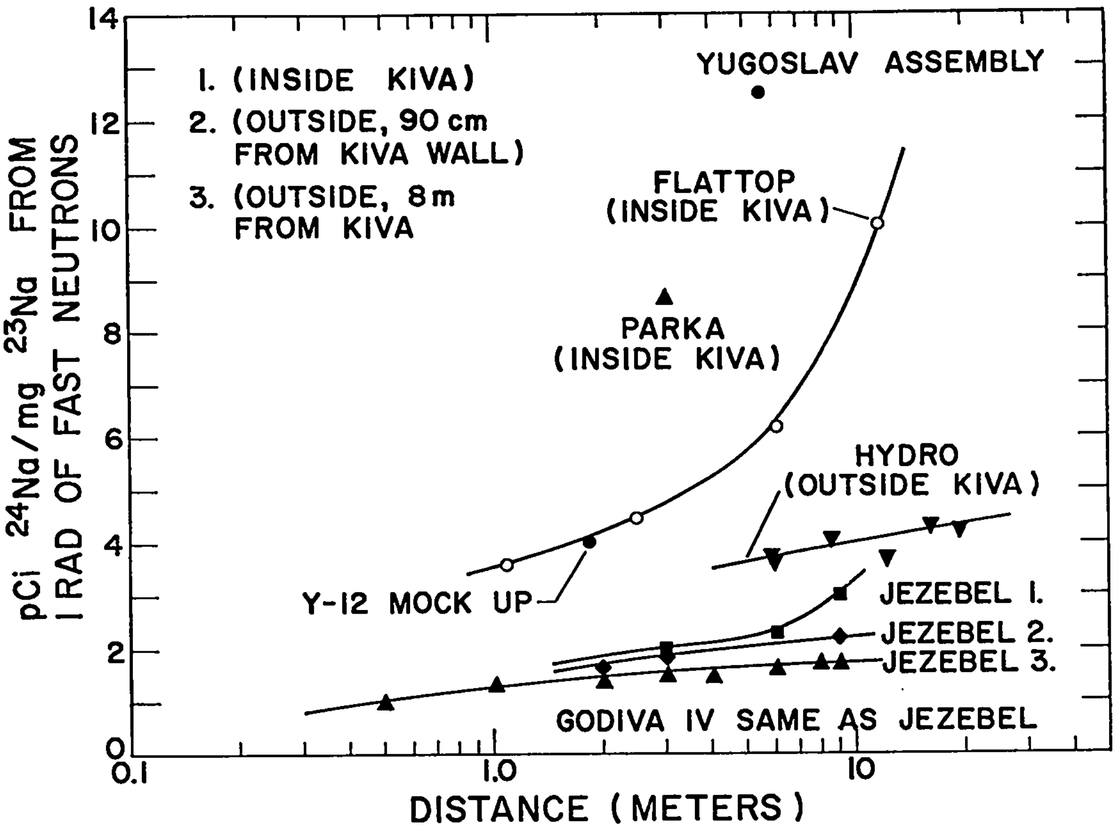


Fig. 3. Blood-sodium activation as a function of distance from the assembly, normalized to 1 rad of fast neutrons measured with the Hurst threshold detector unit.

cal assemblies). Blood-sodium activation is given with the Jezebel assembly outside the kiva at ~8 m and 90 cm from the kiva wall, and inside the kiva. The blood-sodium activation is lowest when the assembly is outside the kiva, increases at it is moved near the kiva wall, and increases further inside the kiva.

The Y-12 mockup data are also shown in Fig. 3. These data were obtained 1.83 m from the assembly and 2 m above the floor inside the ORNL critical assembly building, which is similar to the Los Alamos kivas. To apply the Y-12 mockup data to LA Accident No. 2, one must correct for the difference in neutron scattering geometry caused by the building and the distance of the assembly above the floor.

LA Accident No. 2 occurred with the critical assembly 84 cm above the concrete floor of a wood-frame building which had one concrete wall backed by an earth berm. Positioning the Jezebel assembly 90 cm from the kiva wall and 2 m above the ground very closely approximates the neutron scattering geometry of LA Accident No. 2.

Referring to Fig. 3, we find that, although the leakage neutron spectra are not the same, the Y-12 blood-sodium-activation data fall just slightly below the curve drawn for the Flattop critical assembly (permanently located inside a kiva). Since the blood-sodium activations are nearly the same, we can consider the Y-12 and Flattop assemblies to be similar for studies of blood-sodium activation. The

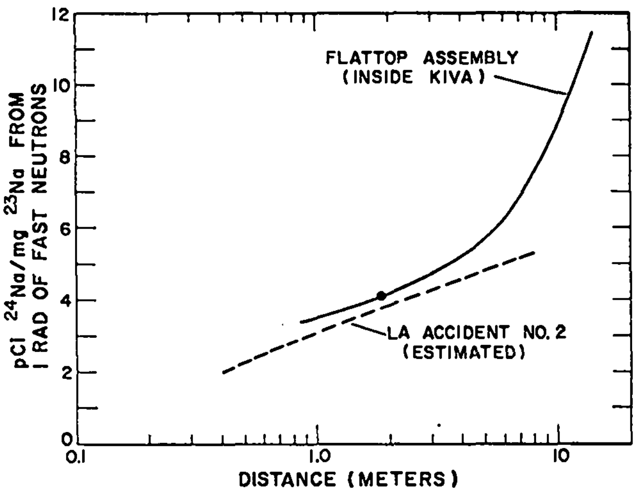


Fig. 4. Blood-Sodium activation as a function of distance from the assembly.

Flattop assembly blood-sodium-activation curve has the same general shape as the curve obtained with the Jezebel assembly inside a kiva. The similarity of these two curves indicates that there should be a similarity between the curves that would be obtained if both the Flattop and Jezebel assemblies could be moved outside 90 cm from the kiva wall. In Fig. 4, the "LA Accident No. 2" curve is the blood-sodium-activation curve drawn by adjusting the Flattop curve by the ratio between the curves for the Jezebel assembly inside the kiva and the Jezebel assembly 90 cm outside the kiva wall. The "LA Accident No. 2" curve will be used later to determine the blood-sodium activation from 1 rad of fast neutrons received by the personnel involved in the excursion.

<u>Determination of Distance from the Excursion</u>

To apply the blood-sodium activation curve shown in Fig. 4 to an excursion, one must know how far the exposed persons were from the assembly. A review of the interviews obtained and measurements made after LA Accident No. 2 enables us to definitely establish the location of only three of the eight persons involved. Case 3* was holding the screwdriver and reflector, and Cases 9 and 10 were standing next to a table at the far side of the room. All other personnel were standing around the assembly in an open area with no definite points of reference from which to determine their positions.

The blood-sodium activation as a function of distance for the Flattop assembly could not be obtained outside the kiva since the assembly is not portable, but such a curve is shown in Fig. 5 for the Jezebel assembly. The curves were obtained with the Jezebel assembly at ~8 m and at 90 cm outside the kiva wall, and inside the kiva. The results obtained ~8 m outside the kiva give a curve with slightly less slope than is obtained from the inverse square relationship. A deviation from this curve was found for the 50-cm position. The 50-cm location was measured from the

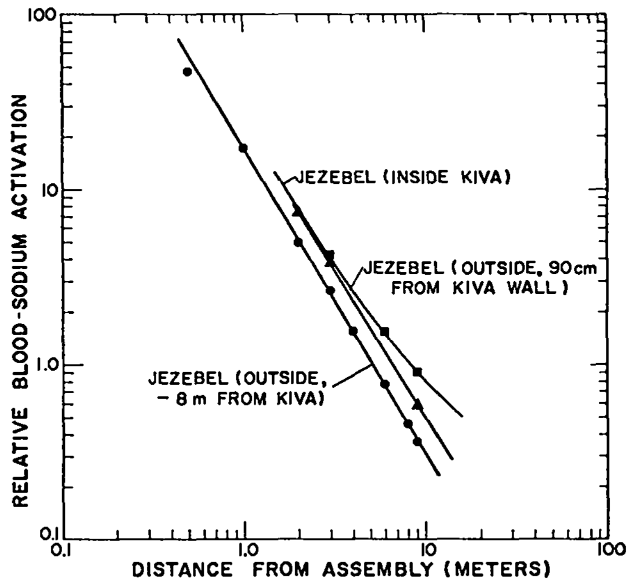


Fig. 5. Blood-sodium activation in man as a function of distance from the Jezebel critical assembly.

*The personnel involved in this accident have been referred to in earlier reports as Cases 3 through 10. That nomenclature is retained in this report.

center of the assembly to the center of a man's abdominal region. This causes the head and feet to be more than 50 cm from the assembly, resulting in a total blood-sodium activation ~20% less than would be predicted from the curve in Fig. 5. This effect is found later for Case 3 in LA Accident No. 2.

The curve obtained outside near the kiva wall is a straight line with a slope only slightly different from the curve obtained ~8 m outside the kiva. The curve obtained outside near the kiva wall most nearly approximates the situation existing in LA Accident No. 2, and, although it was obtained with the Jezebel assembly, it can be used without introducing any error for the LA Accident No. 2 discussion to follow.

The positions of Cases 9 and 10 can be accurately established. The sodium activation found in their blood and their distances from the excursion are given in Table II. These data were plotted in Fig. 6, and a curve with the same slope as that in Fig. 5 for the Jezebel assembly near the kiva wall was drawn. The blood-sodium

TABLE II

NEUTRON DOSE RECEIVED BY PERSONNEL IN LA ACCIDENT No. 2 (Revised January 1968)

| Case No. | Distance from Assembly (m) | $^{24}Na$ in Serum (μCi/mg) | pCi $^{24}Na$/mg $^{23}Na$ from 1 Rad of Fast Neutrons | First Collision Neutron Dose (rads) |
|---|---|---|---|---|
| 3 | 0.4 | $2.0 \times 10^{-3}$ | $2.0 \times 10^{-6}$ | 1000[a] |
| 4 | 1.0[b] | $3.6 \times 10^{-4}$ | $3.1 \times 10^{-6}$ | 166[c] |
| 5 | 1.5 | $2.7 \times 10^{-4}$ | $3.5 \times 10^{-6}$ | 77 |
| 6 | 1.8 | $1.9 \times 10^{-4}$ | $3.7 \times 10^{-6}$ | 51 |
| 7 | 2.4 | $8.1 \times 10^{-5}$ | $4.0 \times 10^{-6}$ | 20 |
| 8 | 2.4[d] | $5.5 \times 10^{-5}$ | $7.0 \times 10^{-6}$[e] | 7.9 |
| | 4.0[f] | | $4.5 \times 10^{-6}$ | 12 |
| | 2.4[g] | | $4.0 \times 10^{-6}$ | 20[h] |
| 9 | 5.0 | $4.2 \times 10^{-5}$ | $4.8 \times 10^{-6}$ | 8.8 |
| 10 | 5.0 | $3.3 \times 10^{-5}$ | $4.8 \times 10^{-6}$ | 6.9 |

a. This dose is for the abdominal region. The dose to the hands, which were closer to the assembly, would be much greater, and that to the head and feet, which were farther from the assembly, would be smaller.

b. This man was side-on to the assembly at the time of the excursion.

c. The decrease in blood-sodium activation for side irradiations is ~30%.[3] The value given above has been increased from 116.

d. Assuming that Case 8 was shielded by Case 3.

e. At 2.4 m this value is $4.0 \times 10^{-6}$, but it has been increased to correct for the 74% increase in blood-sodium activation which occurs because of shielding by another person.[3]

f. Distance greater than that initially estimated following the excursion (see text).

g. Assuming that Case 8 was side-on to the excursion.

h. This value has been increased from 13.8 (see footnote c).

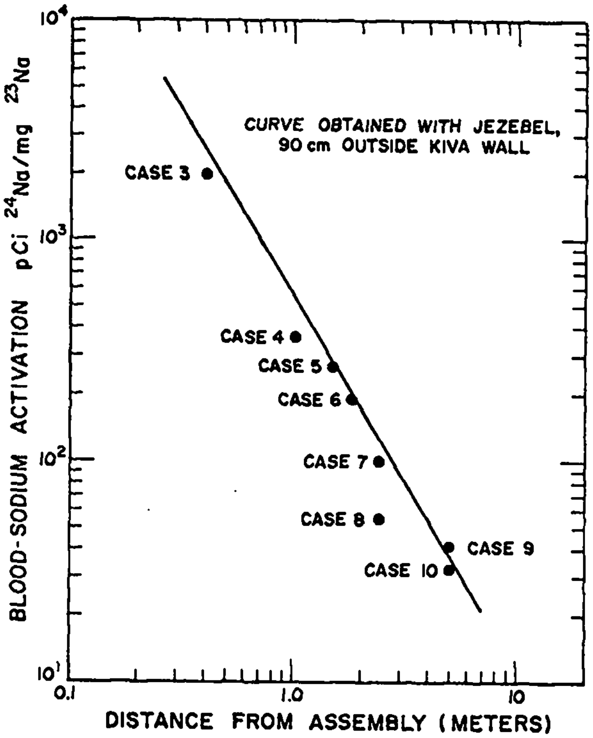


Fig. 6. Blood-sodium activation as a function of distance from LA Accident No. 2 critical assembly.

activations for Cases 3 to 8 were then plotted in Fig. 6. The distances from the assembly indicated in Table II were obtained from a recent review of the statements of the exposed personnel and of the investigation conducted after the excursion.

Figure 6 indicates that Case 3 has less blood-sodium activation than the curve predicts. This agrees with the results given in Fig. 5 in which the exposure occurring 50 cm from the Jezebel assembly resulted in less than the expected blood-sodium activation. Case 4 was known to be side-on to the assembly at the time of the excursion. When the side is exposed to the assembly, the blood-sodium activation is ~70% of that found for a full-face position.[3] A correction of this magnitude places the blood-sodium activation for Case 4 essentially on the curve. Figure 6 confirms that the estimated distances from the assembly were quite accurate except for that of Case 8.

The location of Case 8 at the time of the excursion can not be definitely established. This individual gave no statement following the accident that would establish where he was or what he was doing at the time of the excursion. The fact that he did see the blue glow indicated that he was probably watching the procedure, but the initial estimate of his location placed him behind Case 3 where he could not have seen the assembly (see Fig. 7). If he was watching the work, he must have been farther away than the originally estimated 2.4 m because there was a table at that position. The blood-sodium activity indicates that he was ~4 m from the assembly. Radioanalysis

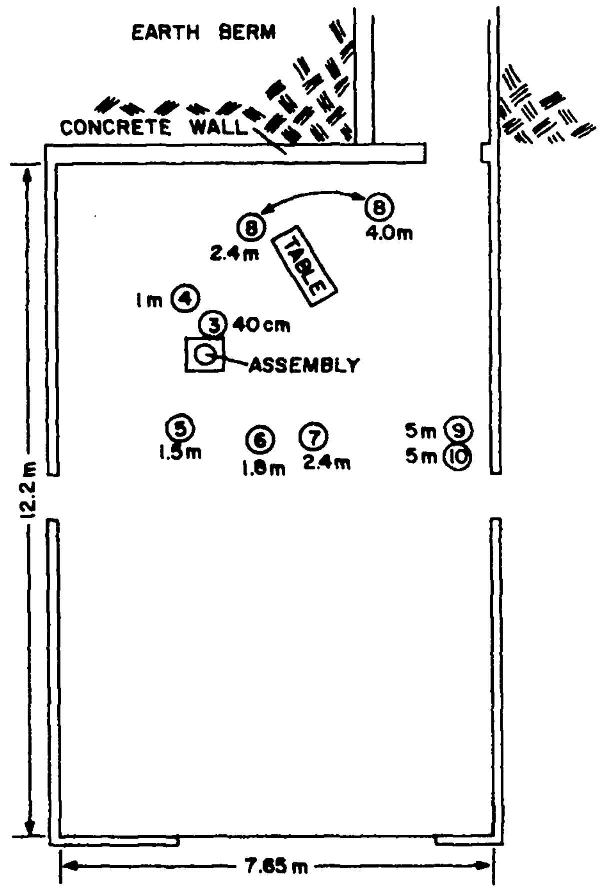


Fig. 7. Location of personnel in LA Accident No. 2.

of his urine sodium and phosphorus and the activation produced in his security badge and in the coins in his pocket indicate that he was either shielded by Case 3 or was farther than 2.4 m from the assembly. However, we can not definitely rule out that he may have been turned sideways at 2.4 m.

Calculated Dose to Personnel

The first collision neutron doses received by those involved in LA Accident No. 2 are given in Table II. The pCi $^{24}$Na/mg $^{23}$Na from 1 rad of fast neutrons was taken from Fig. 4. A correction was made for Case 4 who is known to have been turned sideways at the time of the excursion, and three doses were calculated for Case 8 because his location can not be definitely established. The neutron dose estimates for Case 8 vary from 7.9 to 20 rad and probably represent the extreme limits of his possible dose. The dose for Case 3 has been calculated for the abdominal region. Since he was touching the assembly with one hand and his other hand was close to it, the dose to his hands and lower arms would be significantly higher. However, since the 40 cm is measured from the center of the assembly to the center of the abdominal region, his head and feet would be farther from the assembly and, consequently, receive less dose.

The revised dose estimates given in Table II are based on the blood-sodium activations determined after the excursion. These determinations contain some counting error, and there is an estimated additional error of 15 to 20% in the dose because of the following uncertainities. The location of personnel at the time of the excursion cannot be exactly established. To draw the curve in Fig. 4, we assumed that the Jezebel, Flattop, and Y-12 mockup assemblies would have the same relative dose as a function of distance when moved close to a wall. Also, we assumed that the Y-12 mockup and LA Accident No. 2 leakage spectra, although not indentical, were sufficiently similar to cause identical blood-sodium activations.

In the earlier reports of this excursion, a neutron-to-gamma ratio of 10 to 1 was assumed to exist. We have no information to justify changing this ratio, and we consequently used it in calculating the gamma dose given in Table III. The total first collision dose received in LA Accident No. 2 is given in the fourth column of Table III.

TABLE III

NEUTRON AND GAMMA-RAY DOSE RECEIVED BY PERSONNEL IN LA ACCIDENT No. 2 (Revised January 1968)

| Case No. | First Collision Neutron Dose (rads) | Gamma-ray Exposure[a] (rads) | Total First Collision Dose (rads) |
|---|---|---|---|
| 3 | 1000 | 100 | 1100[b] |
| 4 | 166 | 17 | 183 |
| 5 | 77 | 7.7 | 85 |
| 6 | 51 | 5.1 | 56 |
| 7 | 20 | 2.0 | 22 |
| 8[c] | 7.9 | 0.8 | 8.7 |
| | 12 | 1.2 | 13 |
| | 20 | 2.0 | 22 |
| 9 | 8.8 | 0.9 | 9.7 |
| 10 | 6.9 | 0.7 | 7.6 |

a. A neutron-to-gamma ratio of 10 to 1 is assumed.

b. Dose at the abdominal region (see text).

c. Because of the uncertainity in this man's location at the time of the excursion, three doses were calculated (see text).

APPENDIX

Calculated Neutron Leakage

The assembly involved in LA Accident No. 2 was a 6.9-kg sphere of δ-phase plutonium alloy reflected by an upper 9-in.-o.d. hemisphere and a lower 13-in.-o.d. hemisphere of beryllium. The upper hemisphere was suspended by a screwdriver in a subcritical configuration above the plutonium core. The excursion resulted when an unexpected movement of the screwdriver allowed the upper beryllium shell to fall into place.

For N fission neutrons born in the plutonium core, the number of neutrons per unit area which pass a distant field point, $\underline{R} = R\underline{\Omega}$, is

$$\phi(\underline{R}) = \frac{N}{4\pi R^2} L(\underline{\Omega}) \qquad (1)$$

$L(\underline{\Omega})$ is the number of neutrons per $4\pi$ steradians that leak from the assembly in the direction $\vec{\Omega}$ as the result of one fission neutron born in the core. It is related to the assembly boundary value flux, $\phi(\underline{r_s},\underline{\Omega})$, produced by one fission neutron born per second, as

$$L(\underline{\Omega}) = \int \phi(\underline{r_s},\underline{\Omega})\underline{\Omega}\cdot \underline{dA} \qquad (2)$$

where dA is an outward-directed area element of the assembly boundary surface.

Because the assembly is axially symmetric, the flux, $\phi(\underline{r_s},\underline{\Omega})$, is obtainable from a two-dimensional $(\rho,z)$ neutron transport computation.

A two-dimensional $(\rho,z)$ transport computation by the LASL DDK code in the $S_4$ approximation yields values of $\phi(\underline{r_s},\underline{\Omega})$ for each surface mesh point, i, and for 12 equal-weight $\underline{\Omega}$ directions. If a direction $\underline{\Omega}$ is characterized by the polar and azimuthal angles, $\theta$ and $\varphi$, or, better, by their cosines, $\mu = \cos\theta$, $\nu = \cos\varphi$, the numerical evaluation of $L(\underline{\Omega})$ is accomplished by the following representation of Eq. 2.

$$L(\mu_\alpha > o) = \mu_\alpha \sum_i T_i \sum_{j=1}^{M} \frac{1}{M} \phi_i(\mu_\alpha,\nu_j) + \sqrt{1-\mu_\alpha^2} \sum_i S_i \sum_{j=1}^{M} \frac{1}{M} \nu_j \phi_i(\mu_\alpha,\nu_j) \qquad (3)$$

$$L(\mu_\alpha < o) = |\mu_\alpha| \sum_i B_i \sum_{j=1}^{M} \frac{1}{M} \phi_i(\mu_\alpha,\nu_j) + \sqrt{1-\mu_\alpha^2} \sum_i S_i \sum_{j=1}^{M} \frac{1}{M} \nu_j \phi_i(\mu_\alpha,\nu_j)$$

where $T_i$, $S_i$, and $B_i$ are top, side, and bottom surface areas associated with the mesh point i.

The DDK $S_4$ computation of the No. 2 assembly employed the Hansen-Roach 16-group cross sections described in Los Alamos Scientific Laboratory Report LAMS-2543, a 14 x 25 $\rho$,z space grid, and a delta criticality search on the $\rho$ dimension.

The input dimensions corresponded to those of the No. 2 assembly, and the final critical $\rho$ dimension was 8% less. To permit comparison with simpler beryllium-reflected plutonium critical assemblies, one-dimensional LASL DTK $S_8$ computations were

TABLE A-I

COMPUTED NEUTRON LEAKAGE PER FISSION NEUTRON

| Hansen-Roach Group | Lower Energy Bound | Total Leakage, Lo. Bare Pu | 9-in.-o.d. Be | 13-in.-o.d. Be | No. 2 Assembly |
|---|---|---|---|---|---|
| 1 | 3 MeV-∞ | 0.1251 | 0.0523 | 0.0276 | 0.0404 |
| 2 | 1.4-3 MeV | 0.1980 | 0.1454 | 0.0946 | 0.1259 |
| 3 | 0.9-1.4 MeV | 0.1118 | 0.0709 | 0.0426 | 0.0606 |
| 4 | 0.4-0.9 MeV | 0.1378 | 0.1016 | 0.0622 | 0.0884 |
| 5 | 0.1-4 MeV | 0.0759 | 0.1192 | 0.0876 | 0.1109 |
| 6 | 17-100 keV | 0.0108 | 0.0748 | 0.0691 | 0.0763 |
| 7 | 3-17 keV | | 0.0493 | 0.0602 | 0.0561 |
| 8 | 0.55-3 keV | | 0.0309 | 0.0503 | 0.0398 |
| 9 | 100-550 eV | | 0.0194 | 0.0425 | 0.0288 |
| 10 | 30-100 eV | | 0.0094 | 0.0261 | 0.0158 |
| 11 | 10-30 eV | | 0.0061 | 0.0208 | 0.0115 |
| 12 | 3-10 eV | | 0.0045 | 0.0195 | 0.0098 |
| 13 | 1-3 eV | | 0.0029 | 0.0153 | 0.0071 |
| 14 | 0.4-1.0 eV | | 0.0018 | 0.0112 | 0.0048 |
| 15 | 0.1-0.4 eV | | 0.0017 | 0.0139 | 0.0055 |
| 16 | Thermal | | 0.0030 | 0.0582 | 0.0176 |
| Sum | | 0.6594 | 0.6931 | 0.7015 | 0.6993 |

made on a bare plutonium sphere, a plutonium sphere with a 9-in.-o.d. beryllium reflector, and a plutonium sphere with a 13-in.-o.d. beryllium reflector.

Table A-1 gives the computed neutron leakage, $L_o = \int L(\underline{\Omega})d\Omega/4\pi$, for each of these four critical assemblies. Several simple features are evident in Table A-I. First, the total neutron leakage per fission neutron is essentially independent of beryllium reflector thickness. (The slight increase with thickness is due to n-2n reactions in the beryllium.) Second, the number of leakage neutrons of greater than 100-keV energy, the major contributor to dose, decreases with increasing beryllium reflector thickness. Third, leakage from the No. 2 assembly is, for each energy group, intermediate between the corresponding leakages from the plutonium spheres reflected by 9- and 13-in.-o.d. beryllium shells.

Table A-II gives the directional neutron leakage, $L(\mu)$, for the No. 2 assembly together with total neutron leakage, $L_o$, for the 9- and 13-in.o.d. spherical assemblies There are two physical inequalities: $L(\mu=1$, No. 2 assembly) $>L_o$(9-in.-o.d.) because the greater amount of beryllium in the lower reflector of the No. 2 assembly can only increase its upward neutron emission, and $L(\mu=-1$, No. 2 assembly) $<L_o$(13-in.-o.d.) because the greater amount of beryllium in the top half of the 13-in.-o.d. sphere can only increase its downward neutron emission. The Table A-II entries are consistent with these two inequalities except, perhaps, for the Group-1 $\mu_\alpha = 0.882$ value of $L(\mu)$, and we conclude that the DDK code yields reasonable values for $L(\mu)$ relative to the input cross-section data.

There remains an uncertainty in the $L(\mu)$ values of Table A-II due to uncertainties in the 16-group cross sections. For dosimetry, the uncertainty of primary concern is in the transmission of "fast neu trons" through beryllium. Comparison of observed and computed critical masses of enriched uranium spheres reflected by 1-,

TABLE A-II

COMPUTED DIRECTIONAL DEPENDENCE OF NEUTRON EMISSION FROM THE No. 2 ASSEMBLY

| Hansen-Roach Group | Lower Energy Bound | 9-in.-o.d. Neutron Leakage, Lo. | No. 2 Assembly Neutron Emission, $L(\mu)$ (Neutron 4π steradian per fission neutron) | | | | 13-in.-o.d. Neutron Leakage, Lo. |
|---|---|---|---|---|---|---|---|
| | | | $\mu=0.882$ | $\mu=0.333$ | $\mu=0.333$ | $\mu=0.882$ | |
| 1 | 3.0 MeV | 0.0523 | 0.0509 | 0.0547 | 0.0280 | 0.0241 | 0.0276 |
| 2 | 1.4 MeV | 0.1454 | 0.1608 | 0.1611 | 0.0967 | 0.0841 | 0.0946 |
| 3 | 0.9 MeV | 0.0709 | 0.0803 | 0.0767 | 0.0451 | 0.0367 | 0.0426 |
| 4 | 0.4 MeV | 0.1016 | 0.1262 | 0.1117 | 0.0649 | 0.0510 | 0.0622 |
| 5 | 0.1 MeV | 0.1192 | 0.1564 | 0.1374 | 0.0830 | 0.0682 | 0.0876 |
| 6 | 0.017 MeV | 0.0748 | 0.1051 | 0.0910 | 0.0591 | 0.0526 | 0.0691 |
| 7 | 0.003 MeV | 0.0493 | 0.0745 | 0.0629 | 0.0457 | 0.0449 | 0.0602 |
| 8 | 550 eV | 0.0309 | 0.0490 | 0.0430 | 0.0338 | 0.0362 | 0.0503 |
| 9 | 100 eV | 0.0194 | 0.0334 | 0.0297 | 0.0256 | 0.0288 | 0.0425 |
| 10 | 30 eV | 0.0094 | 0.0174 | 0.0158 | 0.0144 | 0.0171 | 0.0261 |
| 11 | 10 eV | 0.0061 | 0.0121 | 0.0112 | 0.0108 | 0.0131 | 0.0208 |
| 12 | 3 eV | 0.0045 | 0.0098 | 0.0092 | 0.0094 | 0.0118 | 0.0195 |
| 13 | 1 eV | 0.0029 | 0.0068 | 0.0065 | 0.0069 | 0.0089 | 0.0153 |
| 14 | 0.4 eV | 0.0018 | 0.0045 | 0.0043 | 0.0047 | 0.0062 | 0.0112 |
| 15 | 0.1 eV | 0.0017 | 0.0050 | 0.0049 | 0.0055 | 0.0072 | 0.0139 |
| 16 | 0 | 0.0030 | 0.0155 | 0.0154 | 0.0177 | 0.0236 | 0.0582 |

2-, and 4.7-in.-thick shells of beryllium indicates that the 16-group beryllium cross-section set overestimates reflector savings by ~6 to 7%. This bias should produce a comparable underestimate of the fast neutron emmission from the No. 2 assembly. However, the DDK computations apply to an assembly whose ρ dimensions are ~8% smaller than those of the actual No. 2 assembly, and this gives a second error which essentially cancels that from the beryllium cross sections. There is no other evidence of any bias in the Table A-II $L(\mu)$ values nor of any uncertainty greater than 10%.

## References


1. G. S. Hurst et al., Health Physics, <u>5</u>, 179 (1961).
2. G. S. Hurst, R. H. Ritchie, and L. C. Emerson, Health Physics, <u>2</u>, 121 (1959).
3. D. E. Hankins, Los Alamos Scientific Laboratory Report LA-3910 (1968).