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Radiation to Personnel from Activities Induced in Tank Armor for Enhanced-Radiation and Fission Nuclear Weapons

H. A. Sandmeier
M. E. Battat*

*Consultant at Los Alamos. 1817 Chelwood Park Boulevard NE, Albuquerque, NM 87112.

Los Alamos
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RADIATION TO PERSONNEL FROM ACTIVITIES INDUCED IN TANK ARMOR FOR ENHANCED-RADIATION AND FISSION NUCLEAR WEAPONS

by

H. A. Sandmeier and M. E. Battat

ABSTRACT

On the nuclear battlefield, the armored-force commander must know the possible hazard to personnel who replace original crews that have been incapacitated by the very short initial prompt dose from neutrons and neutron induced gamma rays. After the initial prompt dose, the initial prompt neutrons will activate the chrome-nickel steel armor of the tank at $t = 0^+$, and the neutron-activated steel will have a time-dependent emission rate of gamma rays that will impinge on the tank crew. We evaluate this time-dependent dose on the replacement crew from induced activity for both a pure 1-kt fusion and a 1-kt fission nuclear weapon.

I. INTRODUCTION

Assuming a height of burst (HOB) of 200 m, we calculate the time-dependent activation dose rate and integral dose for a person inside a tank for the time $t = 0^+$ to 1000 h and time t = 1 to 1000 h. At time $t = 0^+$, the very short initial prompt neutron burst will impinge on the tank with an assumed chrome-nickel (Cr-Ni) steel thickness of 15 cm (6 in.). The crew will receive the prompt initial dose from neutrons and neutron induced gamma rays. In a previous report,[1] we showed that for a 1-kt burst at a 200-m HOB, a 16 000-rad free-field radiation dose to man occurs at 810-, 710-, and 440-m ground range for pure fusion, 50/50, and pure fission weapons. A free-field radiation dose of 16 000 rads produces about 8000 rads inside the tank, which means immediate incapacitation of the crew. The prompt initial neutrons will activate the steel armor of the tank at $t = 0^+$ and the neutron-activated steel will have a time-dependent emission rate of gamma rays with varying energy that will impinge on the tank crew.

This report, more detailed than previous accounts of all radioactive isotopes in the tank armor, was made possible because additional and more detailed gamma production data are now available at Los Alamos.

To obtain the dose rates and quantities described here, several steps (II through V) in our calculations are required.

The prompt initial gamma source from the weapon is negligible and is not considered here; that is, we consider only neutron induced gamma rays in the tank armor, which are subsequently transported to the tank crew, and the dose to the crew is evaluated. The prompt neutron dose inside and outside the armor is also obtained.

II. PROMPT NEUTRON FLUX IN TANK ARMOR FROM A 1-kt FUSION AND FISSION SOURCE

The neutron transport calculations were done assuming spherical geometry. The use of two- and three-dimensional discrete-ordinates and/or Monte Carlo calculations cannot be justified at this stage of the investigation.

The spherical geometry specifications were

0-1.50 m Air

1.50-1.65 m Cr-Ni steel

1.65-200 m Air.

The source, either 1-kt, 14-MeV, D-T fusion, or fission,[1] was contained in a thin shell at a 200-m radius. The neutron source from these devices was

1.48×10^{24} neutrons (D-T fusion)

or

0.25×10^{24} neutrons (fission spectrum),

corresponding to 1-kt nuclear devices. As mentioned before, the prompt gamma source can be neglected.

The armor used was a typical Cr-Ni steel with a density of 7.87 g/cm^3.

The neutron and subsequent gamma transport calculations were performed using the discrete-ordinates finite-element ONETRAN code.[2] A coupled set of multigroup cross sections, 30 neutrons and 12 gamma-ray groups,[3] generated at Los Alamos, was used in the calculations. From the results of the ONETRAN problems (fusion and fission source), we obtained the spatial and energy distribution of the neutron flux in the steel shell.

In Table I, we list the prompt neutron and neutron induced gamma dose at the *outside* of the steel armor shell from a 1-kt fusion source.

Prompt neutron dose at outside of armor	1.36×10^6 rad
Neutron induced gamma dose at outside of armor	0.18×10^6 rad
Total dose at *outside* of armor from 1-kt fusion source	1.54×10^6 rad

As a comparison, we obtain from Ref. 4 the same quantity. Here, an air/ground two-dimensional geometry was assumed.

Total air-over-ground dose	2.10×10^6 rad

In Table II, we list the prompt neutron and neutron induced gamma dose at the *center* of the steel armor shell from a 1-kt fusion source.

Prompt neutron dose at center of armor	6.78×10^5 rad
Neutron induced gamma dose at center of armor	0.52×10^5 rad
Total dose at *center* of armor from 1-kt fusion source	7.30×10^5 rad

The ratio $(1.54 \times 10^6)/(7.30 \times 10^5) = 2.054$ is the effectiveness of 15-cm (6-in.) tank armor to reduce the prompt fusion dose inside the tank; that is, the prompt outside dose has to be multiplied by $1/2.054 = 0.487$ to obtain the dose *inside* the armor.

In Table III, we list the prompt neutron and neutron induced gamma dose at the *outside* of the steel armor shell from a 1-kt fission source.

Prompt neutron dose at outside of armor	1.40×10^5 rad
Neutron induced gamma dose at outside of armor	0.01×10^5 rad
Total dose at *outside* of armor from 1-kt fission source	1.41×10^5 rad

As a comparison, we obtain from Ref. 4 the same quantity. Here an air/ground two-dimensional geometry was assumed.

Total air-over-ground dose	1.90×10^5 rad

In Table IV, we list the prompt neutron and neutron induced gamma dose at the *center* of the steel armor shell from a 1-kt fission source.

Prompt neutron dose at center of armor	8.20×10^4 rad
Neutron induced gamma dose at center of armor	0.26×10^4 rad
Total dose at *center* of armor from 1-kt fission source	8.46×10^4 rad

The ratio $(1.41 \times 10^5)/(8.46 \times 10^4) = 1.67$ is the effectiveness of 15-cm (6-in.) tank armor to reduce the prompt fission dose *inside* the tank; that is, the *outside* dose has to be multiplied by $1/1.67 = 0.60$ to obtain the dose *inside* the armor.

III. NEUTRON ACTIVATION OF TANK ARMOR FROM PROMPT NEUTRONS

The neutron flux in the armor itself in different armor shell regions is multiplied by the relevant neutron gamma-activation cross section, which produces gamma

TABLE I. Prompt Neutron and Neutron Induced Gamma Dose at Outside of Armor from 1-kt D-T Fusion (ONETRAN Calculation)

Group	Flux ONETRAN Outside Armor (1-kt Fusion)	Dose Conv. Factor Neutron and Gamma NWEF 1102 (Ref. 3)	Rad Tissue Flux x Dose Factor (rad)
1	0	5.8(−9)	0
2	1.1(14)	5.7(−9)	6.1(5)
3	3.0(13)	5.6(−9)	1.7(5)
4	1.4(13)	5.4(−9)	7.6(4)
5	8.4(12)	5.1(−9)	4.3(4)
6	1.5(13)	4.8(−9)	7.2(4)
7	2.8(13)	4.3(−9)	1.2(5)
8	1.7(13)	3.6(−9)	6.1(4)
9	1.7(13)	3.2(−9)	5.4(4)
10	1.3(13)	3.0(−9)	3.9(4)
11	1.1(13)	2.9(−9)	3.2(4)
12	1.7(13)	2.6(−9)	4.4(4)
13	1.3(13)	1.8(−9)	2.3(4)
14	8.1(12)	1.4(−9)	1.1(4)
15	4.9(12)	1.1(−9)	5.4(3)
16	6.4(12)	7.3(−10)	4.7(3)
17	3.3(12)	3.6(−10)	1.2(3)
18	2.0(12)	1.5(−10)	3.0(2)
19	1.4(12)	0.9(−10)	1.3(2)
20	9.8(11)	0	0
21	7.0(11)	0	0
22	5.2(11)	0	0
23	4.0(11)	0	0
24	3.1(11)	0	0
25	2.3(11)	0	0
26	1.7(11)	0	0
27	1.2(11)	0	0
28	7.8(10)	0	0
29	4.7(10)	0	0
30	3.3(10)	0	0
			1.36(6) neutron dose
31	3.8(10)	2.3(−9)	8.7(1)
32	1.2(12)	2.1(−9)	2.5(3)
33	9.2(12)	2.0(−9)	1.8(4)
34	1.3(13)	1.7(−9)	2.2(4)
35	8.9(12)	1.6(−9)	1.4(4)
36	1.1(13)	1.4(−9)	1.5(4)
37	1.2(13)	1.2(−9)	1.4(4)
38	1.7(13)	9.2(−10)	1.6(4)
39	1.2(13)	6.7(−10)	8.0(3)
40	1.9(13)	3.8(−10)	7.2(3)
41	4.2(13)	1.5(−10)	6.3(3)
42	1.2(13)	0.7(−10)	8.4(2)
			0.18(6) gamma dose

Total neutron + gamma dose = 1.54(6) rad prompt dose outside armor

TABLE II. Prompt Neutron and Neutron Induced Gamma Dose at Center of Armor from 1-kt D-T Fusion (ONETRAN Calculation)

Group	Flux ONETRAN Center Armor (1-kt Fusion)	Dose Conv. Factor Neutron and Gamma NWEF 1102 (Ref. 3)	Rad Tissue Flux x Dose Factor (rad)
1	0	5.8(−9)	0
2	1.4(13)	5.7(−9)	8.04(4)
3	5.0(12)	5.6(−9)	2.8(4)
4	2.2(12)	5.4(−9)	1.2(4)
5	1.6(12)	5.1(−9)	8.2(3)
6	2.1(12)	4.8(−9)	1.0(4)
7	4.5(12)	4.3(−9)	1.9(4)
8	3.9(12)	3.6(−9)	1.4(4)
9	6.0(12)	3.2(−9)	1.9(4)
10	7.7(12)	3.0(−9)	2.3(4)
11	9.6(12)	2.9(−9)	2.8(4)
12	3.3(13)	2.6(−9)	8.6(4)
13	5.8(13)	1.8(−9)	1.0(5)
14	8.7(13)	1.4(−9)	1.2(5)
15	2.5(13)	1.1(−9)	2.8(4)
16	9.8(13)	7.3(−10)	7.2(4)
17	7.6(13)	3.6(−10)	2.7(4)
18	1.4(13)	1.5(−10)	2.1(3)
19	1.3(13)	0.9(−10)	1.2(3)
20	8.7(12)	0	0
21	4.8(12)	0	0
22	3.6(12)	0	0
23	2.9(12)	0	0
24	2.3(12)	0	0
25	1.7(12)	0	0
26	1.1(12)	0	0
27	5.9(11)	0	0
28	2.5(11)	0	0
29	7.9(10)	0	0
30	1.4(10)	0	0
			6.78(5) neutron dose
31	2.8(11)	2.3(−9)	6.4(2)
32	4.9(11)	2.1(−9)	1.0(3)
33	1.7(12)	2.0(−9)	3.4(3)
34	1.6(12)	1.7(−9)	2.7(3)
35	1.8(12)	1.6(−9)	2.9(3)
36	2.4(12)	1.4(−9)	3.4(3)
37	4.2(12)	1.2(−9)	5.0(3)
38	6.3(12)	9.2(−10)	5.8(3)
39	1.3(13)	6.7(−10)	8.7(3)
40	3.0(13)	3.8(−10)	1.1(4)
41	5.1(13)	1.5(−10)	7.7(3)
42	5.2(11)	0.7(−10)	3.6(1)
			0.52(5) gamma dose

Total neutron + gamma dose = 7.30(5) rad prompt dose center of armor

TABLE III. Prompt Neutron and Neutron Induced Gamma Dose at Outside of Armor from 1-kt Fission (ONETRAN Calculation)

Group	Flux ONETRAN Outside Armor (1-kt Fission)	Dose Conv. Factor Neutron and Gamma NWEF 1102 (Ref. 3)	Rad Tissue Flux x Dose Factor (rad)
1	5.6(8)	5.8(−9)	3.2(0)
2	1.6(9)	5.7(−9)	9.1(0)
3	5.0(9)	5.6(−9)	2.8(1)
4	2.6(10)	5.4(−9)	1.4(2)
5	1.5(11)	5.1(−9)	7.7(2)
6	5.0(11)	4.8(−9)	2.4(3)
7	2.6(12)	4.3(−9)	1.1(4)
8	2.7(12)	3.6(−9)	9.7(3)
9	4.3(12)	3.2(−9)	1.4(4)
10	4.6(12)	3.0(−9)	1.4(4)
11	5.0(12)	2.9(−9)	1.5(4)
12	1.1(13)	2.6(−9)	2.9(4)
13	1.1(13)	1.8(−9)	2.0(4)
14	6.8(12)	1.4(−9)	9.5(3)
15	5.1(12)	1.1(−9)	5.6(3)
16	6.6(12)	7.3(−10)	4.8(3)
17	4.1(12)	3.6(−10)	1.5(3)
18	2.8(12)	1.5(−10)	4.2(2)
19	2.1(12)	0.9(−10)	1.9(2)
20	1.5(12)	0	0
21	1.1(12)	0	0
22	8.7(11)	0	0
23	6.7(11)	0	0
24	5.2(11)	0	0
25	3.9(11)	0	0
26	2.9(11)	0	0
27	2.1(11)	0	0
28	1.4(11)	0	0
29	8.2(10)	0	0
30	5.9(10)	0	0
			1.40(5) neutron dose
31	3.0(9)	2.3(−9)	6.9(0)
32	1.7(9)	2.1(−9)	3.6(0)
33	1.5(10)	2.0(−9)	3.0(1)
34	2.3(10)	1.7(−9)	3.9(1)
35	3.9(12)	1.6(−9)	6.2(1)
36	3.1(10)	1.4(−9)	4.3(1)
37	2.7(10)	1.2(−9)	3.2(1)
38	2.0(11)	9.2(−10)	1.8(2)
39	1.3(11)	6.7(−10)	8.7(1)
40	2.3(11)	3.8(−10)	8.7(1)
41	3.5(11)	1.5(−10)	5.3(1)
42	6.9(10)	0.7(−10)	4.8(0)
			0.01(5) gamma dose

Total neutron + gamma dose = 1.41(5) rad prompt dose outside armor

TABLE IV. Prompt Neutron and Neutron Induced Gamma Dose at Center of Armor from 1-kt Fission (ONETRAN Calculation)

Group	Flux ONETRAN Center Armor (1-kt Fission)	Dose Conv. Factor Neutron and Gamma NWEF 1102 (Ref. 3)	Rad Tissue Flux x Dose Factor (rad)
1	7.5(7)	5.8(−9)	4.4(−1)
2	2.1(8)	5.7(−9)	1.2(0)
3	6.8(8)	5.6(−9)	3.8(0)
4	3.2(9)	5.4(−9)	1.7(1)
5	1.6(10)	5.1(−9)	8.2(1)
6	4.5(10)	4.8(−9)	2.2(2)
7	2.0(11)	4.3(−9)	8.6(2)
8	2.5(11)	3.6(−9)	9.0(2)
9	5.4(11)	3.2(−9)	1.7(3)
10	7.9(11)	3.0(−9)	2.4(3)
11	1.1(12)	2.9(−9)	3.2(3)
12	4.6(12)	2.6(−9)	1.2(4)
13	9.2(12)	1.8(−9)	1.7(4)
14	1.4(13)	1.4(−9)	2.0(4)
15	4.3(12)	1.1(−9)	4.7(3)
16	1.9(13)	7.3(−10)	1.4(4)
17	1.5(13)	3.6(−10)	5.4(3)
18	3.4(12)	1.5(−10)	5.1(2)
19	3.2(12)	0.9(−10)	2.9(2)
20	2.3(12)	0	0
21	1.3(12)	0	0
22	1.0(12)	0	0
23	9.1(11)	0	0
24	7.7(11)	0	0
25	5.8(11)	0	0
26	3.9(11)	0	0
27	2.2(11)	0	0
28	9.5(10)	0	0
29	3.1(10)	0	0
30	5.3(9)	0	0
			8.20(4) neutron dose
31	2.5(10)	2.3(−9)	5.8(1)
32	3.0(10)	2.1(−9)	6.3(1)
33	2.3(11)	2.0(−9)	4.6(2)
34	7.1(10)	1.7(−9)	1.2(2)
35	7.8(10)	1.6(−9)	1.2(2)
36	9.6(10)	1.4(−9)	1.3(2)
37	1.4(11)	1.2(−9)	1.7(2)
38	2.0(11)	9.2(−10)	1.8(2)
39	3.4(11)	6.7(−10)	2.3(2)
40	1.7(12)	3.8(−10)	6.5(2)
41	2.8(11)	1.5(−10)	4.2(2)
42	3.2(10)	0.7(−10)	2.2(0)
			0.26(4) gamma dose

Total neutron + gamma dose = 8.46(4) rad prompt dose center of armor rays. The neutron activation cross sections and gamma-ray data used in this study were extracted from the GAMMON Activation Library.[5] In our calculations, we considered a total of 60 reactions listed in Table V. As an example, the first entry lists cross-section data for the neutron activation reaction

$$^{28}Si_{14}\,(n,p)\,^{28}Al_{13}\ .$$

Aluminum-28 will decay with 1.7788-MeV gamma/disintegration and a half-life $T_{1/2}$ of 2.24 min. The 30 neutron activation cross sections (in barns) are listed first, followed by 12 gamma yields per 100 disintegrations. For the decay of ^{28}Al, we get 100 gamma rays per 100 disintegrations in gamma group 9 (1-2 MeV).

In a previous steel activation analysis,[6] we considered only seven reactions:

$^{56}Fe_{26}\,(n,p)\,^{56}Mn_{25}$
$^{58}Fe_{26}\,(n,\gamma)\,^{59}Fe_{26}$
$^{58}Ni_{28}\,(n,p)\,^{58}Co_{27}$
$^{98}Mo_{42}\,(n,\gamma)\,^{99}Mo_{42}$
$^{63}Cu_{29}\,(n,\gamma)\,^{64}Cu_{29}$
$^{55}Mn_{25}\,(n,\gamma)\,^{56}Mn_{25}$
$^{50}Cr_{24}\,(n,\gamma)\,^{51}Cr_{24}$

More is not necessarily better, but we used the newest additional, more updated, detailed gamma production data in the GAMMON Activation Library.[5] All the activation analyses in Ref. 6 were done by hand computer. Here, we have 60 reactions to consider and the handling of such a large amount of data must be done on a full-scale computer.

The general expression for the activity A_0(dis/cm$^3\cdot$s) induced in a material containing N atoms/cm^3, with activation cross section σ_{act}, and exposed to a flux of ϕ neutrons/cm$^2\cdot$s, is

$$A_o = \lambda n = \sigma_{act}\, N\, \phi\, (1 - e^{-\lambda t})\ , \quad (1)$$

where

λ = decay constant = 0.693 / $T_{1/2}$,
$T_{1/2}$ = half-life of decay product,
n = number of radioactive nuclei at time t, and
t = irradiation time.

If σ_{act} is in barns, N is in units of atoms/barn$\cdot$cm. For a neutron burst, $t \ll T_{1/2}$, and the expression reduces to

$$A_o = \lambda \sigma_{act}\ N(\phi t)\ . \quad (2)$$

In general, at time T after the burst, the activity is

$$A_o = \lambda \sigma_{act}\ N(\phi t)\ e^{-\lambda T}\ , \quad (3)$$

with (ϕt) equal to the neutron fluence. Of course, to obtain the total activity, Eqs. (2) and (3) must be summed over the fluxes in the 30 neutron groups and over the number of reactions specified in the calculations.

To give an indication of the activities induced in the steel armor, we tabulated A_0 in Tables VI (fusion) and VII (fission). The data shown are for the *outermost* mesh point in the armor steel and at a time immediately after the burst ($t = 0^+$ explosion time).

In addition to the neutron activation cross sections supplied, it was also necessary to supply spectral data (photons/dis) in each of the 12 photon groups and for each reaction. These data, together with the calculated activities, provided the source terms for the gamma-ray transport calculations.

In the fusion neutron problem, Table VI, some of the more important reactions leading to decay half-lives ($T_{1/2}$) of a *few minutes* are

$^{28}Si_{14}\,(n,p)\,^{28}Al_{13}$
$^{52}Cr_{24}\,(n,p)\,^{52}V_{23}$
$^{53}Cr_{24}\,(n,p)\,^{53}V_{23}$
$^{63}Cu_{29}\,(n,2n)\,^{62}Cu_{29}$
$^{100}Mo_{42}\,(n,\gamma)\,^{101}Mo_{42}$
$^{51}V_{23}\,(n,\gamma)\,^{52}V_{23}$
$^{51}V_{23}\,(n,p)\,^{51}Ti_{22}$

However, the dominant activity for times *one hour* after the burst was the $^{56}Fe_{26}$ (n,p) $^{56}Mn_{25}$ reaction with a half-life of 2.58 h.

In the case of fission, Table VII, the important *short-lived* products are

$^{28}Si_{14}\,(n,p)\,^{28}Al_{13}$
$^{52}Cr_{24}\,(n,p)\,^{52}V_{23}$
$^{100}Mo_{42}\,(n,\gamma)\,^{101}Mo_{42}$
$^{51}V_{23}\,(n,\gamma)\,^{52}V_{23}$

As in the D-T fusion case, the dominant *long-lived* activity was the 2.58-h $^{56}Mn_{25}$ produced by the $^{55}Mn_{25}$ (n,γ) reaction.

TABLE V. Activation Data: 30 Neutron Groups, 12 Gamma Groups (60 Reactions)

```
 SI   28  (N,P)      AL   28    2.24        M      UKAEA          1.77880               14283  0
                     AL   28     .30E-05              1.24700
    .23577E+00  .33243E+00  .39865E+00  .45941E+00  .43884E+00  .32530E+00
    .23108E-01 O.           O.          O.          O.          O.
  O.           O.           O.          O.          O.          O.
  O.           O.           O.          O.          O.          O.
  O.           O.           O.          O.          O.          O.
    0.00000    0.00000    0.00000    0.00000    0.00000    0.00000    0.00000
    0.00000  100.00000    0.00000    0.00000    0.00000
 P    31  (N,P)      SI   31    2.62        H      UKAEA           .00089               15313  0
                     SI   31     .30E-07               .59000
    .84200E-01  .84200E-01  .99899E-01  .12536E+00  .14464E+00  .14612E+00
    .12769E+00  .92866E-01  .62924E-01  .11882E-01 O.           O.
  O.           O.           O.          O.          O.          O.
  O.           O.           O.          O.          O.          O.
  O.           O.           O.          O.          O.          O.
    0.00000    0.00000    0.00000    0.00000    0.00000    0.00000    0.00000
    0.00000     .07000    0.00000    0.00000    0.00000
 CR   50  (N,2N)     CR   49   42.0         M      BNL-325        1.09205               24501  0
                     CR   49     .30E-05               .58000
    .11516E-01  .11516E-01  .22986E-03 O.           O.          O.
  O.           O.           O.          O.          O.          O.
  O.           O.           O.          O.          O.          O.
  O.           O.           O.          O.          O.          O.
  O.           O.           O.          O.          O.          O.
    0.00000    0.00000    0.00000    0.00000    0.00000    0.00000    0.00000
    0.00000    0.00000  192.00000   29.50000   79.00000
 CR   50  (N,G)      CR   51   27.71        D      BNL-325         .03137               24502  0
                     CR   51     .80E-07               .00500
    .15853E-02  .15853E-02  .17308E-02  .19945E-02  .23653E-02  .27654E-02
    .33741E-02  .40340E-02  .44349E-02  .48650E-02  .52696E-02  .59828E-02
    .81105E-02  .10594E-01  .13084E-01  .16517E-01  .24989E-01  .62318E-01
    .23459E+00  .12149E+00  .12808E+00  .27962E+00  .43928E+00  .62795E+00
    .87181E+00  .36421E+01  .81546E+01  .12541E+02  .48637E+01  .12512E+02
    0.00000    0.00000    0.00000    0.00000    0.00000    0.00000    0.00000
    0.00000    0.00000    0.00000    9.80000    0.00000
 CR   50  (N,P)      V    50    4.    E+16  Y      THRESH         1.32273               24503  0
                     V    50     .10E-09               .12000
    .33320E+00  .34436E+00  .35114E+00  .34937E+00  .32219E+00  .25936E+00
    .14481E+00  .50693E-01  .94877E-02  .14344E-02  .20813E-03  .12151E-04
  O.           O.           O.          O.          O.          O.
  O.           O.           O.          O.          O.          O.
  O.           O.           O.          O.          O.          O.
    0.00000    0.00000    0.00000    0.00000    0.00000    0.00000    0.00000
    0.00000   70.00000   30.00000    0.00000    0.00000
 CR   50  (N,T)      V    48   15.98        D      THRESH         2.91406               24507  0
                     V    48     .20E-08               .14700
    .27300E-06  .27300E-06  .25697E-09 O.           O.          O.
  O.           O.           O.          O.          O.          O.
  O.           O.           O.          O.          O.          O.
  O.           O.           O.          O.          O.          O.
  O.           O.           O.          O.          O.          O.
    0.00000    0.00000    0.00000    0.00000    0.00000    0.00000    0.00000
    2.50000   98.12000  207.20000    0.00000    0.00000
 CR   52  (N,2N)     CR   51   27.71        D      BNL-325         .03137               24521  0
                     CR   51     .80E-07               .00500
    .25776E+00  .25776E+00  .59696E-01 O.           O.          O.
  O.           O.           O.          O.          O.          O.
  O.           O.           O.          O.          O.          O.
  O.           O.           O.          O.          O.          O.
  O.           O.           O.          O.          O.          O.
    0.00000    0.00000    0.00000    0.00000    0.00000    0.00000    0.00000
    0.00000    0.00000    0.00000    9.80000    0.00000
 CR   52  (N,P)      V    52    3.76        M      BNL-325        1.44694               24523  0
```

TABLE V. (cont)

```
65                         V   52     .35E-06 DK        .73300
66    .98305E-01  .11280E+00  .12172E+00  .11857E+00  .99731E-01  .83385E-01
67    .44744E-01  .37594E-02 O.          O.          O.          O.
68  O.          O.          O.          O.          O.          O.
69  O.          O.          O.          O.          O.          O.
70  O.          O.          O.          O.          O.          O.
71     0.00000   0.00000   0.00000   0.00000   0.00000   0.00000   0.00000
72     0.00000 100.92000   0.00000    .04000   0.00000
73 CR  52  (N,T)       V   50     4.    E+16  Y     THRESH      1.32273            24527  0
74                         V   50     .10E-09           .12000
75    .13500E-07  .13500E-07  .12707E-10 O.          O.          O.
76  O.          O.          O.          O.          O.          O.
77  O.          O.          O.          O.          O.          O.
78  O.          O.          O.          O.          O.          O.
79  O.          O.          O.          O.          O.          O.
80     0.00000   0.00000   0.00000   0.00000   0.00000   0.00000   0.00000
81     0.00000  70.00000  30.00000   0.00000   0.00000
82 CR  53  (N,P)       V   53     1.55        M     THRESH      1.03990            24533  0
83                         V   53     .30E-05          1.00000
84    .55300E-01  .55300E-01  .53987E-01  .49291E-01  .35770E-01  .19592E-01
85    .27293E-02  .53247E-06 O.          O.          O.          O.
86  O.          O.          O.          O.          O.          O.
87  O.          O.          O.          O.          O.          O.
88  O.          O.          O.          O.          O.          O.
89     0.00000   0.00000   0.00000   0.00000   0.00000   0.00000   0.00000
90     0.00000 100.00000   0.00000    .76000   0.00000
91 CR  53  (N,NP+D)    V   52     3.76        M     THRESH      1.44694            24535  0
92                         V   52     .35E-06 DK        .73300
93    .23690E-01  .23690E-01  .14300E-01  .13796E-02 O.          O.
94  O.          O.          O.          O.          O.          O.
95  O.          O.          O.          O.          O.          O.
96  O.          O.          O.          O.          O.          O.
97  O.          O.          O.          O.          O.          O.
98     0.00000   0.00000   0.00000   0.00000   0.00000   0.00000   0.00000
99     0.00000 100.92000   0.00000    .04000   0.00000
100 CR 54  (N,P)       V   54     43.         S     THRESH      4.04000            24543  0
101                        V   54     .30E-05           .88000
102   .26400E-01  .26400E-01  .22076E-01  .13060E-01  .28205E-02  .11356E-04
103 O.          O.          O.          O.          O.          O.
104 O.          O.          O.          O.          O.          O.
105 O.          O.          O.          O.          O.          O.
106 O.          O.          O.          O.          O.          O.
107    0.00000   0.00000   0.00000   0.00000   0.00000   0.00000   0.00000
108  100.00000   0.00000 200.00000   0.00000   0.00000
109 CR 54  (N,A)       TI  51     5.75        M     THRESH       .35955            24544  0
110                        TI  51     .30E-05           .62000
111   .13400E-01  .13400E-01  .99420E-02  .46448E-02  .13702E-02  .12119E-03
112   .22318E-07 O.          O.          O.          O.          O.
113 O.          O.          O.          O.          O.          O.
114 O.          O.          O.          O.          O.          O.
115 O.          O.          O.          O.          O.          O.
116    0.00000   0.00000   0.00000   0.00000   0.00000   0.00000   0.00000
117    0.00000   0.00000   6.50000  95.00000   0.00000
118 CR 54  (N,NP+D)    V   53     1.55        M     THRESH      1.03990            24545  0
119                        V   53     .30E-05          1.00000
120   .10700E-01  .10700E-01  .21774E-02  .22380E-05 O.          O.
121 O.          O.          O.          O.          O.          O.
122 O.          O.          O.          O.          O.          O.
123 O.          O.          O.          O.          O.          O.
124 O.          O.          O.          O.          O.          O.
125    0.00000   0.00000   0.00000   0.00000   0.00000   0.00000   0.00000
126    0.00000 100.00000   0.00000    .76000   0.00000
127 CR 54  (N,T)       V   52     3.76        M     THRESH      1.44694            24547  0
128                        V   52     .35E-06 DK        .73300
```

TABLE V. (cont)

```
 .30200E-05  .30200E-05  .28427E-08 0.          0.          0.
0.          0.          0.          0.          0.          0.
0.          0.          0.          0.          0.          0.
0.          0.          0.          0.          0.          0.
0.          0.          0.          0.          0.          0.
  0.00000   0.00000   0.00000   0.00000   0.00000   0.00000   0.00000
  0.00000 100.92000   0.00000    .04000   0.00000
MN  55  (N,2N)    MN  54    312.5     D     ENDF/B-IV     .83463           25551  0
                  MN  54     .10E-08          .00560
 .10119E+01  .78739E+00  .60043E+00  .14427E+00 0.          0.
0.          0.          0.          0.          0.          0.
0.          0.          0.          0.          0.          0.
0.          0.          0.          0.          0.          0.
0.          0.          0.          0.          0.          0.
  0.00000   0.00000   0.00000   0.00000   0.00000   0.00000   0.00000
  0.00000   0.00000  99.97800   0.00000   0.00000
MN  55  (N,G)     MN  56    2.580     H     ENDF/B-IV    1.78233           25552  0
                  MN  56     .20E-07          .80000
 .80849E-03  .80849E-03  .68550E-03  .62693E-03  .63560E-03  .77787E-03
 .10679E-02  .14765E-02  .17219E-02  .19222E-02  .22466E-02  .27200E-02
 .35732E-02  .51129E-02  .85342E-02  .16589E-01  .37149E-01  .77543E-01
 .46565E-01  .23992E+00  .15057E+01  .85957E+01  .41068E+00  .41358E+00
 .59598E+00  .93949E+00  .15235E+01  .24969E+01  .40992E+01  .10546E+02
  0.00000   0.00000   0.00000   0.00000   0.00000   0.00000    .28000
 17.96000  30.00000  99.00000   0.00000   0.00000
MN  55  (N,P)     CR  55    3.55      M     ENDF/B-IV     .00078           25553  0
                  CR  55     .30E-05         1.00000
 .46797E-01  .46797E-01  .43009E-01  .32202E-01  .27197E-01  .23476E-01
 .70980E-02  .42308E-04  .35006E-05  .73924E-06 0.          0.
0.          0.          0.          0.          0.          0.
0.          0.          0.          0.          0.          0.
0.          0.          0.          0.          0.          0.
  0.00000   0.00000   0.00000   0.00000   0.00000   0.00000   0.00000
   .00430    .04450   0.00000    .00200   0.00000
MN  55  (N,A)     V   52    3.76      M     ENDF/B-IV    1.44694           25554  0
                  V   52     .35E-06 DK       .73300
 .33129E-01  .33129E-01  .30695E-01  .18710E-01  .93591E-02  .24745E-02
 .92593E-04  .11692E-05  .85956E-06  .59824E-06  .41028E-06  .20224E-06
 .24857E-07 0.          0.          0.          0.          0.
0.          0.          0.          0.          0.          0.
0.          0.          0.          0.          0.          0.
  0.00000   0.00000   0.00000   0.00000   0.00000   0.00000   0.00000
  0.00000 100.92000   0.00000    .04000   0.00000
FE  54  (N,P)     MN  54    312.5     D     ENDF/B-IV     .83463           26543  0
                  MN  54     .10E-08          .00560
 .22218E+00  .35093E+00  .43889E+00  .52870E+00  .58200E+00  .56664E+00
 .38437E+00  .17781E+00  .75476E-01  .14297E-01  .12518E-02  .64341E-05
0.          0.          0.          0.          0.          0.
0.          0.          0.          0.          0.          0.
0.          0.          0.          0.          0.          0.
  0.00000   0.00000   0.00000   0.00000   0.00000   0.00000   0.00000
  0.00000   0.00000  99.97800   0.00000   0.00000
FE  54  (N,A)     CR  51    27.71     D     BNL-325       .03137           26544  0
                  CR  51     .80E-07          .00500
 .92043E-01  .92043E-01  .80317E-01  .61857E-01  .39932E-01  .21235E-01
 .85474E-02  .38863E-02  .28434E-02  .19256E-02  .11125E-02  .24236E-03
 .43314E-07 0.          0.          0.          0.          0.
0.          0.          0.          0.          0.          0.
0.          0.          0.          0.          0.          0.
  0.00000   0.00000   0.00000   0.00000   0.00000   0.00000   0.00000
  0.00000   0.00000   0.00000   9.80000   0.00000
FE  56  (N,P)     MN  56    2.580     H     ENDF/B-IV    1.78233           26563  0
                  MN  56     .20E-07          .80000
 .10560E+00  .11010E+00  .11056E+00  .87670E-01  .54966E-01  .28679E-01
```

TABLE V. (cont)

.31097E-02	.40043E-06	.13280E-07	0.	0.	0.		
0.	0.	0.	0.	0.	0.		
0.	0.	0.	0.	0.	0.		
0.	0.	0.	0.	0.	0.		
0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	.28000	
17.96000	30.00000	99.00000	0.00000	0.00000			
FE 56 (N,T)	MN 54	312.5	D	THRESH	.83463	26567	0
	MN 54	.10E-08		.00560			
.11800E-04	.11800E-04	.11107E-07	0.	0.	0.		
0.	0.	0.	0.	0.	0.		
0.	0.	0.	0.	0.	0.		
0.	0.	0.	0.	0.	0.		
0.	0.	0.	0.	0.	0.		
0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	
0.00000	0.00000	99.97800	0.00000	0.00000			
FE 57 (N,P)	MN 57	1.59	M	THRESH	.04673	26573	0
	MN 57	.30E-05		.97000			
.72100E-01	.72100E-01	.70759E-01	.65576E-01	.49599E-01	.28644E-01		
.83522E-02	.56432E-04	.50904E-06	0.	0.	0.		
0.	0.	0.	0.	0.	0.		
0.	0.	0.	0.	0.	0.		
0.	0.	0.	0.	0.	0.		
0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	
0.00000	.47000	3.16000	11.96000	0.00000			
FE 57 (N,NP+D)	MN 56	2.580	H	THRESH	1.78233	26575	0
	MN 56	.20E-07		.80000			
.26840E-01	.26840E-01	.16156E-01	.23929E-02	0.	0.		
0.	0.	0.	0.	0.	0.		
0.	0.	0.	0.	0.	0.		
0.	0.	0.	0.	0.	0.		
0.	0.	0.	0.	0.	0.		
0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	.28000	
17.96000	30.00000	99.00000	0.00000	0.00000			
FE 58 (N,G)	FE 59	44.6	D	ENDF/B-IV	1.19234	26582	0
	FE 59	.20E-08		.11800			
.81725E-02	.81725E-02	.48060E-02	.17739E-02	.91071E-03	.98631E-03		
.11929E-02	.12252E-02	.12226E-02	.12245E-02	.12458E-02	.14094E-02		
.26041E-02	.26201E-02	.28725E-02	.39513E-02	.53600E-02	.12901E-01		
.23504E-01	.54620E-03	.89329E-03	.11765E+01	.85971E-02	.21300E-01		
.43061E-01	.77085E-01	.13121E+00	.21869E+00	.35781E+00	.92050E+00		
0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	
0.00000	100.05600	0.00000	3.93200	0.00000			
FE 58 (N,P)	MN 58	65.	S	THRESH	2.53675	26583	0
	MN 58	.30E-05		1.37000			
.37400E-01	.37400E-01	.32448E-01	.20956E-01	.77118E-02	.34714E-03		
.13681E-07	0.	0.	0.	0.	0.		
0.	0.	0.	0.	0.	0.		
0.	0.	0.	0.	0.	0.		
0.	0.	0.	0.	0.	0.		
0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	
6.70000	92.93000	118.00000	22.54000	0.00000			
FE 58 (N,A)	CR 55	3.55	M	THRESH	.00078	26584	0
	CR 55	.30E-05		1.00000			
.15500E-01	.15500E-01	.11403E-01	.50703E-02	.14379E-02	.11710E-03		
.10213E-07	0.	0.	0.	0.	0.		
0.	0.	0.	0.	0.	0.		
0.	0.	0.	0.	0.	0.		
0.	0.	0.	0.	0.	0.		
0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	
.00430	.04450	0.00000	.00200	0.00000			
FE 58 (N,NP+D)	MN 57	1.59	M	THRESH	.04673	26585	0
	MN 57	.30E-05		.97000			
.12910E-01	.12910E-01	.52366E-02	.30349E-04	0.	0.		
0.	0.	0.	0.	0.	0.		

TABLE V. (cont)

```
 O.          O.          O.          O.          O.          O.
 O.          O.          O.          O.          O.          O.
 O.          O.          O.          O.          O.          O.
   0.00000     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
   0.00000      .47000     3.16000    11.96000     0.00000
FE  58  (N,T)      MN  56     2.580      H     THRESH        1.78233              26587  O
                   MN  56      .20E-07              .80000
  .51000E-05  .51000E-05  .48005E-08 O.          O.          O.
 O.          O.          O.          O.          O.          O.
 O.          O.          O.          O.          O.          O.
 O.          O.          O.          O.          O.          O.
 O.          O.          O.          O.          O.          O.
   0.00000     0.00000     0.00000     0.00000     0.00000     0.00000      .28000
  17.96000    30.00000    99.00000     0.00000     0.00000
NI  58  (N,2N)     NI  57    36.1      . H     ENDF/B-IV    2.10649              28581  O
                   NI  57      .10E-09              .13000
  .25102E-01  .25102E-01  .77342E-02 O.          O.          O.
 O.          O.          O.          O.          O.          O.
 O.          O.          O.          O.          O.          O.
 O.          O.          O.          O.          O.          O.
 O.          O.          O.          O.          O.          O.
   0.00000     0.00000     0.00000     0.00000     0.00000     0.00000      .03400
    .24700   106.51000    99.16800    15.15600     0.00000
NI  58  (N,P)      CO  58    70.8        D     ENDF/B-IV     .97420              28583  O
                   CO  58      .20E-08              .03650
  .22359E+00  .36901E+00  .47375E+00  .61176E+00  .65791E+00  .63487E+00
  .45856E+00  .22620E+00  .11649E+00  .38441E-01  .15758E-01  .28038E-02
  .67929E-04  .83337E-06  .16296E-08 O.          O.          O.
 O.          O.          O.          O.          O.          O.
 O.          O.          O.          O.          O.          O.
   0.00000     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
   0.00000      .53000   130.13000     0.00000     0.00000
NI  58  (N,NP+D)   CO  57   271.         D     THRESH         .12148              28585  O
                   CO  57      .60E-08              .02230
  .21394E+00  .15074E+00  .10623E+00  .51096E-01  .73103E-02  .24219E-04
 O.          O.          O.          O.          O.          O.
 O.          O.          O.          O.          O.          O.
 O.          O.          O.          O.          O.          O.
 O.          O.          O.          O.          O.          O.
   0.00000     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
   0.00000     0.00000      .16600    96.20730     9.50000
NI  58  (N,T)      CO  56    78.5        D     THRESH        3.64227              28587  O
                   CO  56      .10E-09              .11000
  .63900E-03  .63900E-03  .64419E-05 O.          O.          O.
 O.          O.          O.          O.          O.          O.
 O.          O.          O.          O.          O.          O.
 O.          O.          O.          O.          O.          O.
 O.          O.          O.          O.          O.          O.
   0.00000     0.00000     0.00000     0.00000     0.00000     0.00000    14.28900
  28.85500   106 11200   150.12200      .10200     0.00000
NI  60  (N,P)      CO  60     5.27       Y     ENDF/B-IV    2.50443              28603  O
                   CO  60      .30E-09              .09670
  .11021E+00  .12692E+00  .13934E+00  .15933E+00  .12692E+00  .61298E-01
  .86282E-02  .41114E-03  .92161E-04  .94012E-08 O.          O.
 O.          O.          O.          O.          O.          O.
 O.          O.          O.          O.          O.          O.
 O.          O.          O.          O.          O.          O.
   0.00000     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
    .00124   199.88000      .00700     0.00000     0.00000
NI  61  (N,P)      CO  61     1.650      H     THRESH         .06066              28613  O
                   CO  61      .30E-05              .46000
  .91300E-01  .91300E-01  .90244E-01  .85944E-01  .70645E-01  .46116E-01
  .19361E-01  .24893E-02  .32881E-03  .23461E-04  .15832E-05 O.
 O.          O.          O.          O.          O.          O.
```

TABLE V. (cont)

```
O.            O.            O.            O.            O.            O.
O.            O.            O.            O.            O.            O.
  0.00000   0.00000   0.00000   0.00000   0.00000   0.00000   0.00000
  0.00000   0.00000   0.00000   0.00000  90.00000
NI  62  (N,A)      FE  59    44.6        D      THRESH       1.19234              28624  O
                   FE  59     .20E-08            .11800
  .19200E-01  .19200E-01  .15960E-01  .80493E-02  .24705E-02  .38833E-03
  .35215E-06 O.           O.            O.            O.            O.
O.            O.            O.            O.            O.            O.
O.            O.            O.            O.            O.            O.
O.            O.            O.            O.            O.            O.
  0.00000   0.00000   0.00000   0.00000   0.00000   0.00000   0.00000
  0.00000 100.05600   0.00000   3.93200   0.00000
NI  62  (N,NP+D)   CO  61    1.650       H      THRESH        .06066              28625  O
                   CO  61     .30E-05            .46000
  .15540E-01  .15540E-01  .80391E-02  .51463E-03 O.            O.
O.            O.            O.            O.            O.            O.
O.            O.            O.            O.            O.            O.
O.            O.            O.            O.            O.            O.
O.            O.            O.            O.            O.            O.
  0.00000   0.00000   0.00000   0.00000   0.00000   0.00000   0.00000
  0.00000   0.00000   0.00000   0.00000  90.00000
NI  64  (N,A)      FE  61    6.0         M      THRESH       1.26947              28644  O
                   FE  61     .30E-05           1.05000
  .50200E-02  .50200E-02  .32275E-02  .11767E-02  .16875E-03  .75698E-07
O.            O.            O.            O.            O.            O.
O.            O.            O.            O.            O.            O.
O.            O.            O.            O.            O.            O.
O.            O.            O.            O.            O.            O.
  0.00000   0.00000   0.00000   0.00000   0.00000   0.00000   0.00000
  1.10000  97.60000   0.00000  29.60000   0.00000
NI  64  (N,NP+D)   CO  63    27.         S      THRESH        .12514              28645  O
                   CO  63     .30E-05           1.37000
  .32290E-02  .32290E-02  .49206E-03  .99096E-07 O.            O.
O.            O.            O.            O.            O.            O.
O.            O.            O.            O.            O.            O.
O.            O.            O.            O.            O.            O.
O.            O.            O.            O.            O.            O.
  0.00000   0.00000   0.00000   0.00000   0.00000   0.00000   0.00000
  0.00000   0.00000   6.00000   4.60000 100.00000
CU  63  (N,2N)     CU  62    9.74        M      ENDF/B-3     1.00912              29631  O
                   CU  62     .30E-05 DK        1.25000
  .80832E+00  .49789E+00  .27633E+00  .27903E-01 O.            O.
O.            O.            O.            O.            O.            O.
O.            O.            O.            O.            O.            O.
O.            O.            O.            O.            O.            O.
O.            O.            O.            O.            O.            O.
  0.00000   0.00000   0.00000   0.00000   0.00000   0.00000    .01280
   .05400    .38967 196.15000   0.00000   0.00000
CU  63  (N,G)      CU  64    12.71       H      ENDF/B-IV     .19659              29632  O
                   CU  64     .40E-07            .13300
  .27252E-02  .27252E-02  .29010E-02  .32700E-02  .38738E-02  .44773E-02
  .50199E-02  .56258E-02  .63041E-02  .70940E-02  .81512E-02  .10285E-01
  .13996E-01  .23644E-01  .25224E-01  .26787E-01  .55617E-01  .11421E+00
  .18453E+00  .40895E+00  .11013E+01  .37314E-01  .41159E-01  .66240E-01
  .12271E+00  .30004E+00  .50338E+00  .83771E+00  .13861E+01  .35658E+01
  0.00000   0.00000   0.00000   0.00000   0.00000   0.00000   0.00000
  0.00000    .48000  37.00000   0.00000   0.00000
CU  63  (N,A)      CO  60    5.27        Y      ENDF/B-IV    2.50443              29634  O
                   CO  60     .30E-09            .09670
  .36813E-01  .36813E-01  .39508E-01  .43506E-01  .27740E-01  .95866E-02
  .27733E-03 O.           O.            O.            O.            O.
O.            O.            O.            O.            O.            O.
O.            O.            O.            O.            O.            O.
```

```
 0.             0.             0.             0.             0.             0.
  0.00000   0.00000   0.00000   0.00000   0.00000   0.00000   0.00000
   .00124 199.88000    .00700   0.00000   0.00000
CU  65  (N,2N)    CU  64    12.71      H      ENDF/B-IV     .19659              29651  0
                  CU  64     .40E-07              .13300
  .12114E+01  .92751E+00  .70070E+00  .19805E+00 0.             0.
 0.             0.             0.             0.             0.             0.
 0.             0.             0.             0.             0.             0.
 0.             0.             0.             0.             0.             0.
 0.             0.             0.             0.             0.             0.
  0.00000   0.00000   0.00000   0.00000   0.00000   0.00000   0.00000
  0.00000    .48000  37.00000   0.00000   0.00000
CU  65  (N,P)     NI  65    2.520      H      ENDF/B-3      .58880              29653  0
                  NI  65     .20E-07              .63100
  .20900E-01  .20900E-01  .20386E-01  .17343E-01  .11420E-01  .73682E-02
  .33887E-02  .65763E-04 0.             0.             0.             0.
 0.             0.             0.             0.             0.             0.
 0.             0.             0.             0.             0.             0.
 0.             0.             0.             0.             0.             0.
  0.00000   0.00000   0.00000   0.00000   0.00000   0.00000   0.00000
  0.00000  41.89000    .64000   4.80000   0.00000
CU  65  (N,A)     CO  62    13.9       M      ENDF/B-3     2.76048              29654  0
                  CO  62     .20E-05             1.13000
  .36100E-01  .36100E-01  .37827E-01  .36401E-01  .25089E-01  .80680E-02
  .27253E-03 0.             0.             0.             0.             0.
 0.             0.             0.             0.             0.             0.
 0.             0.             0.             0.             0.             0.
 0.             0.             0.             0.             0.             0.
  0.00000   0.00000   0.00000   0.00000   0.00000   0.00000   0.00000
 28.80000 179.00000   3.40000   0.00000   0.00000
MO 100  (N,2N)    MO  99    66.02      H      THRESH        .15380              42001  0
                  MO  99     .70E-08              .38600
  .16893E+01  .16521E+01  .16143E+01  .13885E+01  .32546E+00  .24863E-03
 0.             0.             0.             0.             0.             0.
 0.             0.             0.             0.             0.             0.
 0.             0.             0.             0.             0.             0.
 0.             0.             0.             0.             0.             0.
  0.00000   0.00000   0.00000   0.00000   0.00000   0.00000   0.00000
  0.00000   0.00000  18.02800   7.32400  12.89000
MO 100  (N,G)     MO 101    14.6       M      COOK          .86161              42002  0
                  MO 101     .30E-05              .59500
 0.             0.             0.             0.             .14823E-03  .49895E-03
  .19676E-02  .56313E-02  .93580E-02  .13753E-01  .12932E-01  .11544E-01
  .21210E-01  .32605E-01  .34144E-01  .37227E-01  .69509E-01  .17251E+00
  .37628E+00  .78964E+00  .29032E+00  .61933E+01  .16827E+00  .88684E-02
  .12954E-01  .20569E-01  .33511E-01  .54941E-01  .61489E-01  .15818E+00
  0.00000   0.00000   0.00000   0.00000   0.00000   0.00000   0.00000
  0.00000  39.00000  49.00000  40.00000   9.00000
MO 100  (N,A)     ZR  97    16.8       H      THRESH        .88769              42004  0
                  ZR  97     .30E-08              .69900
  .38000E-02  .38000E-02  .27268E-02  .12003E-02  .34811E-03  .97357E-04
  .54047E-06 0.             0.             0.             0.             0.
 0.             0.             0.             0.             0.             0.
 0.             0.             0.             0.             0.             0.
 0.             0.             0.             0.             0.             0.
  0.00000   0.00000   0.00000   0.00000   0.00000   0.00000   0.00000
   .03000   8.27000 104.63000   5.02000    .95000
MO  92  (N,NA)    ZR  88    83.4       D      THRESH        .38996              42926  0
                  ZR  88     .10E-09             0.00000
  .81300E-03  .81300E-03  .41553E-03  .12662E-03  .46813E-04  .34715E-04
  .25990E-05 0.             0.             0.             0.             0.
 0.             0.             0.             0.             0.             0.
 0.             0.             0.             0.             0.             0.
 0.             0.             0.             0.             0.             0.
```

TABLE V. (cont)

```
   0.00000   0.00000   0.00000   0.00000   0.00000   0.00000   0.00000
   0.00000   0.00000   0.00000  97.00000  59.00000
MO  96  (N,P)     NB  96    23.4      H     THRESH       2.58183            42963  0
                  NB  96     .10E-09          .24900
  .18300E-01  .18300E-01  .13830E-01  .66922E-02  .20371E-02  .62290E-03
  .25786E-04 0.           0.          0.          0.          0.
 0.          0.           0.          0.          0.          0.
 0.          0.           0.          0.          0.          0.
 0.          0.           0.          0.          0.          0.
   0.00000   0.00000   0.00000   0.00000   0.00000   0.00000   0.00000
   0.00000  76.44500 205.13000  57.36800   0.00000
MO  97  (N,NP+D)  NB  96    23.4      H     THRESH       2.58183            42975  0
                  NB  96     .10E-09          .24900
  .44140E-02  .44140E-02  .23163E-02  .47067E-03  .47223E-04 0.
 0.          0.           0.          0.          0.          0.
 0.          0.           0.          0.          0.          0.
 0.          0.           0.          0.          0.          0.
 0.          0.           0.          0.          0.          0.
   0.00000   0.00000   0.00000   0.00000   0.00000   0.00000   0.00000
   0.00000  76.44500 205.13000  57.36800   0.00000
MO  98  (N,G)     MO  99    66.02     H     COOK          .15380            42982  0
                  MO  99     .70E-08          .38600
 0.          0.           0.          0.          .53139E-03  .17823E-02
  .63211E-02  .16740E-01  .26743E-01  .38584E-01  .38012E-01  .35831E-01
  .52903E-01  .70677E-01  .73942E-01  .78958E-01  .12691E+00  .21016E+00
  .39630E+00  .99227E-01  .27370E+01  .14399E+01  .36915E-02  .43251E-02
  .79352E-02  .10217E-01  .16569E-01  .27194E-01  .43077E-01  .11082E+00
   0.00000   0.00000   0.00000   0.00000   0.00000   0.00000   0.00000
   0.00000   0.00000  18.02800   7.32400  12.89000
MO  98  (N,A)     ZR  95    64.0      D     THRESH        .72460            42984  0
                  ZR  95     .10E-08          .11500
  .74600E-02  .74600E-02  .57974E-02  .29465E-02  .93787E-03  .28578E-03
  .20464E-04 0.           0.          0.          0.          0.
 0.          0.           0.          0.          0.          0.
 0.          0.           0.          0.          0.          0.
 0.          0.           0.          0.          0.          0.
   0.00000   0.00000   0.00000   0.00000   0.00000   0.00000   0.00000
   0.00000   0.00000  97.60000   0.00000    .12000
MO  98  (N,T)     NB  96    23.4      H     THRESH       2.58183            42987  0
                  NB  96     .10E-09          .24900
  .42200E-03  .42200E-03  .13157E-04 0.          0.          0.
 0.          0.           0.          0.          0.          0.
 0.          0.           0.          0.          0.          0.
 0.          0.           0.          0.          0.          0.
 0.          0.           0.          0.          0.          0.
   0.00000   0.00000   0.00000   0.00000   0.00000   0.00000   0.00000
   0.00000  76.44500 205.13000  57.36800   0.00000
V   50  (N,A)     SC  47     3.41     D     THRESH        .11158            23504  0
                  SC  47     .20E-07          .16100
  .43600E-01  .43600E-01  .39932E-01  .29346E-01  .13845E-01  .51676E-02
  .86236E-03  .11977E-05  .14763E-08 0.          0.          0.
 0.          0.           0.          0.          0.          0.
 0.          0.           0.          0.          0.          0.
 0.          0.           0.          0.          0.          0.
   0.00000   0.00000   0.00000   0.00000   0.00000   0.00000   0.00000
   0.00000   0.00000   0.00000  70.00000   0.00000
V   51  (N,G)     V   52     3.76     M     ENDF/B-IV    1.44694            23512  0
                  V   52     .35E-06 DK       .73300
  .17030E-03  .17030E-03  .18463E-03  .21816E-03  .27299E-03  .34718E-03
  .50312E-03  .74154E-03  .94284E-03  .11948E-02  .13568E-02  .15350E-02
  .17124E-02  .29543E-02  .45959E-02  .60093E-02  .95640E-02  .28296E-01
  .10284E+00  .35681E-01  .32487E-01  .76787E-01  .14287E+00  .12976E+00
  .21209E+00  .34889E+00  .57487E+00  .94686E+00  .15563E+01  .40037E+01
   0.00000   0.00000   0.00000   0.00000   0.00000   0.00000   0.00000
```

TABLE V. (cont)

```
   0.00000 100.92000   0.00000    .04000   0.00000
V   51  (N,P)      TI  51    5.75       M     ENDF/B-IV     .35955              23513  0
                   TI  51     .30E-05          .62000
  .36091E-01  .36091E-01  .35728E-01  .33855E-01  .27544E-01  .17733E-01
  .56297E-02  .27014E-04  .31555E-08 0.          0.          0.
 0.          0.          0.          0.          0.          0.
 0.          0.          0.          0.          0.          0.
 0.          0.          0.          0.          0.          0.
   0.00000   0.00000   0.00000   0.00000   0.00000   0.00000   0.00000
   0.00000   0.00000   6.50000  95.00000   0.00000
V   51  (N,A)      SC  48   43.7        H     ENDF/B-IV    3.35248              23514  0
                   SC  48     .50E-08          .21800
  .19797E-01  .19797E-01  .14948E-01  .65951E-02  .19129E-02  .15587E-03
 0.          0.          0.          0.          0.          0.
 0.          0.          0.          0.          0.          0.
 0.          0.          0.          0.          0.          0.
 0.          0.          0.          0.          0.          0.
   0.00000   0.00000   0.00000   0.00000   0.00000   0.00000   0.00000
   0.00000 200.50000 100.00000   6.00000   0.00000
V   51  (N,NA)     SC  47    3.41       D     ENDF/B-IV     .11158              23516  0
                   SC  47     .20E-07          .16100
  .20291E-03  .20291E-03  .12187E-03  .29061E-04 0.          0.
 0.          0.          0.          0.          0.          0.
 0.          0.          0.          0.          0.          0.
 0.          0.          0.          0.          0.          0.
 0.          0.          0.          0.          0.          0.
   0.00000   0.00000   0.00000   0.00000   0.00000   0.00000   0.00000
   0.00000   0.00000   0.00000  70.00000   0.00000
```

IV. GAMMA-RAY TRANSPORT OUT OF THE ARMOR SOURCE REGIONS AT DIFFERENT GAMMA DECAY TIMES T AFTER THE INITIAL BURST AT $t = 0^+$

From Eq. (3) we obtain the induced gamma activity rate for discrete values, T = 0, 1, 10...1000 h. These gamma-ray sources then become the ONETRAN source input to solve the transport of gamma rays and the gamma-ray fluxes at time T(h) after the initial prompt burst at $t = 0^+$ at the center of the armor.

V. INDUCED GAMMA DOSE RATE AT CENTER OF ARMOR

Finally, the gamma fluxes were converted to dose rates[4] using the appropriate gamma-to-dose-rate conversion factors. A plot of the dose rate versus time after the prompt burst in the time domain of 1 to 1000 h is shown in Fig. 1 for both the 1-kt fission and 1-kt fusion sources. In Table VIII, the same data are listed for 0 to 10 000 h, and in Table IX, the dose rate is integrated to obtain the dose from 0 to 1000 h and 1 to 1000 h, respectively.

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2. T. R. Hill, "ONETRAN: A Discrete Ordinates Finite Element Code for the Solution of the One-Dimensional Multigroup Transport Equation," Los Alamos Scientific Laboratory report LA-5990-MS (June 1975).

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6. H. A. Sandmeier and G. E. Hansen, "Activation Produced in an Iron Containment Shell by Fusion and Fission Sources," Los Alamos Scientific Laboratory Group TD-6 memorandum, July 1972.

TABLE VI. Chrome-Nickel Armor Steel Activation D-T Fusion Neutrons

($t = 0^+$ explosion time)

						Half-Life ($T_{1/2}$)	Gamma MeV per Disintegration	Activity A_o (Disintegration/ $cm^3 \cdot s$)
1.	Si	28	(N,P)	Al	28	2.240E+00 m*	1.779E+00	9.152E+07
2.	P	31	(N,P)	Si	31	2.620E+00 h	8.900E-04	2.776E+04
3.	Cr	50	(N,2N)	Cr	49	4.200E+01 m	1.092E+00	8.375E+03
4.	Cr	50	(N,G)	Cr	51	2.771E+01 d	3.137E-02	1.548E+02
5.	Cr	50	(N,P)	V	50	4.000E+16 y	1.323E+00	9.495E-16
6.	Cr	50	(N,T)	V	48	1.598E+01 d	2.914E+00	3.602E-04
7.	Cr	52	(N,2N)	Cr	51	2.771E+01 d	3.137E-02	4.057E+03
8.	Cr	52	(N,P)	V	52	3.760E+00 m	1.447E+00	3.294E+07
9.	Cr	52	(N,T)	V	50	4.000E+16 y	1.323E+00	3.754E-22
10.	Cr	53	(N,P)	V	53	1.550E+00 m	1.040E+00	3.769E+06
11.	Cr	53	(N,NP+D)	V	52	3.760E+00 m	1.447E+00	5.022E+05
12.	Cr	54	(N,P)	V	54	4.300E+01 s	4.040E+00	8.209E+05
13.	Cr	54	(N,A)	Ti	51	5.750E+00 m	3.596E-01	4.997E+04
14.	Cr	54	(N,NP+D)	V	53	1.550E+00 m	1.040E+00	1.211E+05
15.	Cr	54	(N,T)	V	52	3.760E+00 m	1.447E+00	1.323E+01
16.	Mn	55	(N,2N)	Mn	54	3.125E+02 d	8.346E-01	7.908E+02
17.	Mn	55	(N,G)	Mn	56	2.580E+00 h	1.782E+00	7.374E+05
18.	Mn	55	(N,P)	Cr	55	3.550E+00 m	7.800E-04	7.499E+06
19.	Mn	55	(N,A)	V	52	3.760E+00 m	1.447E+00	4.462E+06
20.	Fe	54	(N,P)	Mn	54	3.125E+02 d	8.346E-01	5.193E+03
21.	Fe	54	(N,A)	Cr	51	2.771E+01 d	3.137E-02	8.737E+03
22.	Fe	56	(N,P)	Mn	56	2.580E+00 h	1.782E+00	4.308E+07
23.	Fe	56	(N,T)	Mn	54	3.125E+02 d	8.346E-01	1.026E+00
24.	Fe	57	(N,P)	Mn	57	1.590E+00 m	4.673E-02	6.628E+07
25.	Fe	57	(N,NP+D)	Mn	56	2.580E+00 h	1.782E+00	1.871E+05
26.	Fe	58	(N,G)	Fe	59	4.460E+01 d	1.192E+00	1.049E+02
27.	Fe	58	(N,P)	Mn	58	6.500E+01 s	2.537E+00	6.110E+06
28.	Fe	58	(N,A)	Cr	55	3.550E+00 m	7.800E-04	7.229E+05
29.	Fe	58	(N,NP+D)	Mn	57	1.590E+00 m	4.673E-02	1.173E+06
30.	Fe	58	(N,T)	Mn	56	2.580E+00 h	1.782E+00	4.210E+00
31.	Ni	58	(N,2N)	Ni	57	3.610E+01 h	2.106E+00	6.893E+03
32.	Ni	58	(N,P)	Co	58	7.080E+01 d	9.742E-01	5.701E+03
33.	Ni	58	(N,NP+D)	Co	57	2.710E+02 d	1.215E-01	2.680E+02
34.	Ni	58	(N,T)	Co	56	7.850E+01 d	3.642E+00	3.069E+00
35.	Ni	60	(N,P)	Co	60	5.270E+00 y	2.504E+00	1.663E+01
36.	Ni	61	(N,P)	Co	61	1.650E+00 h	6.066E-02	1.377E+04
37.	Ni	62	(N,A)	Fe	59	4.460E+01 d	1.192E+00	1.149E+01
38.	Ni	62	(N,NP+D)	Co	61	1.650E+00 h	6.066E-02	5.247E+03
39.	Ni	64	(N,A)	Fe	61	6.000E+00 m	1.269E+00	7.432E+03
40.	Ni	64	(N,NP+D)	Co	63	2.700E+01 s	1.251E-01	5.371E+04

*s = seconds, m = minutes, h = hours, d = days, y = years.

TABLE VI. (cont)

(t = 0^+ explosion time)

						Half-Life ($T_{1/2}$)	Gamma MeV per Disintegration	Activity A_o (Disintegration/ $cm^3 \cdot s$)
41.	Cu	63	(N,2N)	Cu	62	9.740E+00 m	1.009E+00	1.653E+06
42.	Cu	63	(N,G)	Cu	64	1.271E+01 h	1.966E–01	6.646E+03
43.	Cu	63	(N,A)	Co	60	5.270E+00 y	2.504E+00	5.966E–01
44.	Cu	65	(N,2N)	Cu	64	1.271E+01 h	1.966E–01	1.879E+04
45.	Cu	65	(N,P)	Ni	65	2.520E+00 h	5.888E–01	2.708E+03
46.	Cu	65	(N,A)	Co	62	1.390E+01 m	2.760E+00	5.043E+04
47.	Mo	100	(N,2N)	Mo	99	6.602E+01 h	1.538E–01	3.048E+03
48.	Mo	100	(N,G)	Mo	101	1.460E+01 m	8.616E–01	1.191E+05
49.	Mo	100	(N,A)	Zr	97	1.680E+01 h	8.877E–01	2.438E+01
50.	Mo	92	(N,NA)	Zr	88	8.340E+01 d	3.900E–01	6.279E–02
51.	Mo	96	(N,P)	Nb	96	2.340E+01 h	2.582E+00	1.493E+02
52.	Mo	97	(N,NP+D)	Nb	96	2.340E+01 h	2.582E+00	1.866E+01
53.	Mo	98	(N,G)	Mo	99	6.602E+01 h	1.538E–01	1.420E+03
54.	Mo	98	(N,A)	Zr	95	6.400E+01 d	7.246E–01	1.352E+00
55.	Mo	98	(N,T)	Nb	96	2.340E+01 h	2.582E+00	3.816E+00
56.	V	50	(N,A)	Sc	47	3.410E+00 d	1.116E–01	2.063E+00
57.	V	51	(N,G)	V	52	3.760E+00 m	1.447E+00	7.705E+05
58.	V	51	(N,P)	Ti	51	5.750E+00 m	3.596E–01	6.717E+05
59.	V	51	(N,A)	Sc	48	4.370E+01 h	3.352E+00	6.269E+02
60.	V	51	(N,NA)	Sc	47	3.410E+00 d	1.116E–01	3.196E+00

TABLE VII. Chrome-Nickel Armor Steel Activation Fission Neutrons

($t = 0^+$ explosion time)

						Half-Life ($T_{1/2}$)	Gamma MeV per Disintegration	Activity A_o (Disintegration/ $cm^3 \cdot s$)
1.	Si	28	(N,P)	Al	28	2.240E+00 m*	1.779E+00	4.076E+05
2.	P	31	(N,P)	Si	31	2.620E+00 h	8.900E–04	1.103E+03
3.	Cr	50	(N,2N)	Cr	49	4.200E+01 m	1.092E+00	1.747E–01
4.	Cr	50	(N,G)	Cr	51	2.771E+01 d	3.137E–02	1.293E+02
5.	Cr	50	(N,P)	V	50	4.000E+16 y	1.323E+00	1.078E–17
6.	Cr	52	(N,T)	V	48	1.598E+01 d	2.914E+00	7.227E–09
7.	Cr	52	(N,2N)	Cr	51	2.771E+01 d	3.137E–02	1.178E–01
8.	Cr	52	(N,P)	V	52	3.760E+00 m	1.447E+00	2.806E+05
9.	Cr	52	(N,T)	V	50	4.000E+16 y	1.323E+00	7.534E–27
10.	Cr	53	(N,P)	V	53	1.550E+00 m	1.040E+00	9.655E+03
11.	Cr	53	(N,NP+D)	V	52	3.760E+00 m	1.447E+00	2.648E+01
12.	Cr	54	(N,P)	V	54	4.300E+01 s	4.040E+00	2.002E+02
13.	Cr	54	(N,A)	Ti	51	5.750E+00 m	3.596E–01	1.241E+01
14.	Cr	54	(N,NP+D)	V	53	1.550E+00 m	1.040E+00	3.398E+00
15.	Cr	54	(N,T)	V	52	3.760E+00 m	1.447E+00	2.654E–04
16.	Mn	55	(N,2N)	Mn	54	3.125E+02 d	8.346E–01	6.414E–02
17.	Mn	55	(N,G)	Mn	56	2.580E+00 h	1.782E+00	6.402E+05
18.	Mn	55	(N,P)	Cr	55	3.550E+00 m	7.800E–04	3.396E+04
19.	Mn	55	(N,A)	V	52	3.760E+00 m	1.447E+00	3.183E+03
20.	Fe	54	(N,P)	Mn	54	3.125E+02 d	8.346E–01	1.275E+02
21.	Fe	54	(N,A)	Cr	51	2.771E+01 d	3.137E–02	5.525E+01
22.	Fe	56	(N,P)	Mn	56	2.580E+00 h	1.782E+00	8.021E+04
23.	Fe	56	(N,T)	Mn	54	3.125E+02 d	8.346E–01	2.058E–05
24.	Fe	57	(N,P)	Mn	57	1.590E+00 m	4.673E–02	2.454E+05
25.	Fe	57	(N,NP+D)	Mn	56	2.580E+00 h	1.782E+00	1.100E+01
26.	Fe	58	(N,G)	Fe	59	4.460E+01 d	1.192E+00	6.341E+01
27.	Fe	58	(N,P)	Mn	58	6.500E+01 s	2.537E+00	2.318E+03
28.	Fe	58	(N,A)	Cr	55	3.550E+00 m	7.800E–04	1.664E+02
29.	Fe	58	(N,NP+D)	Mn	57	1.590E+00 m	4.673E–02	4.167E+01
30.	Fe	58	(N,T)	Mn	56	2.580E+00 h	1.782E+00	8.448E–05
31.	Ni	58	(N,2N)	Ni	57	3.610E+01 h	2.106E+00	2.189E–01
32.	Ni	58	(N,P)	Co	58	7.080E+01 d	9.742E–01	1.702E+02
33.	Ni	58	(N,NP+D)	Co	57	2.710E+02 d	1.215E–01	4.317E–02
34.	Ni	58	(N,T)	Co	56	7.850E+01 d	3.642E+00	6.276E–05
35.	Ni	60	(N,P)	Co	60	5.270E+00 y	2.504E+00	5.561E–02
36.	Ni	61	(N,P)	Co	61	1.650E+00 h	6.066E–02	8.104E+01
37.	Ni	62	(N,A)	Fe	59	4.460E+01 d	1.192E+00	3.708E–03
38.	Ni	62	(N,NP+D)	Co	61	1.650E+00 h	6.066E–02	2.379E–01
39.	Ni	64	(N,A)	Fe	61	6.000E+00 m	1.269E+00	9.232E–01
40.	Ni	64	(N,NP+D)	Co	63	2.700E+01 s	1.251E–01	1.402E+00

*s = seconds, m = minutes, h = hours, d = days, y = years.

TABLE VII. (cont)

						(t = 0⁺ explosion time)		
						Half-Life ($T_{1/2}$)	Gamma MeV per Disintegration	Activity A_o (Disintegration/ $cm^3 \cdot s$)
41.	Cu	63	(N,2N)	Cu	62	9.740E+00 m	1.009E+00	8.881E+01
42.	Cu	63	(N,G)	Cu	64	1.271E+01 h	1.966E–01	3.577E+03
43.	Cu	63	(N,A)	Co	60	5.270E+00 y	2.504E+00	1.016E–03
44.	Cu	65	(N,2N)	Cu	64	1.271E+01 h	1.966E–01	1.628E+00
45.	Cu	65	(N,P)	Ni	65	2.520E+00 h	5.888E–01	1.151E+01
46.	Cu	64	(N,A)	Co	62	1.390E+01 m	2.760E+00	7.901E+01
47.	Mo	100	(N,2N)	Mo	99	6.602E+01 h	1.538E–01	1.136E+00
48.	Mo	100	(N,G)	Mo	101	1.460E+01 m	8.616E–01	7.794E+04
49.	Mo	100	(N,A)	Zr	97	1.680E+01 h	8.877E–01	7.198E–03
50.	Mo	92	(N,NA)	Zr	88	8.340E+01 d	3.900E–01	2.313E–05
51.	Mo	96	(N,P)	Nb	96	2.340E+01 h	2.582E+00	5.608E–02
52.	Mo	97	(N,NP+D)	Nb	96	2.340E+01 h	2.582E+00	1.356E–03
53.	Mo	98	(N,G)	Mo	99	6.602E+01 h	1.538E–01	6.885E+02
54.	Mo	98	(N,A)	Zr	95	6.400E+01 d	7.246E–01	5.857E–04
55.	Mo	98	(N,T)	Nb	96	2.340E+01 h	2.582E+00	8.134E–05
56.	V	50	(N,A)	Sc	47	3.410E+00 d	1.116E–01	2.440E–03
57.	V	51	(N,G)	V	52	3.760E+00 m	1.447E+00	5.528E+05
58.	V	51	(N,P)	Ti	51	5.750E+00 m	3.596E–01	3.046E+03
59.	V	51	(N,A)	Sc	48	4.370E+01 h	3.352E+00	1.479E–01
60.	V	51	(N,NA)	Sc	47	3.410E+00 d	1.116E–01	2.213E–04

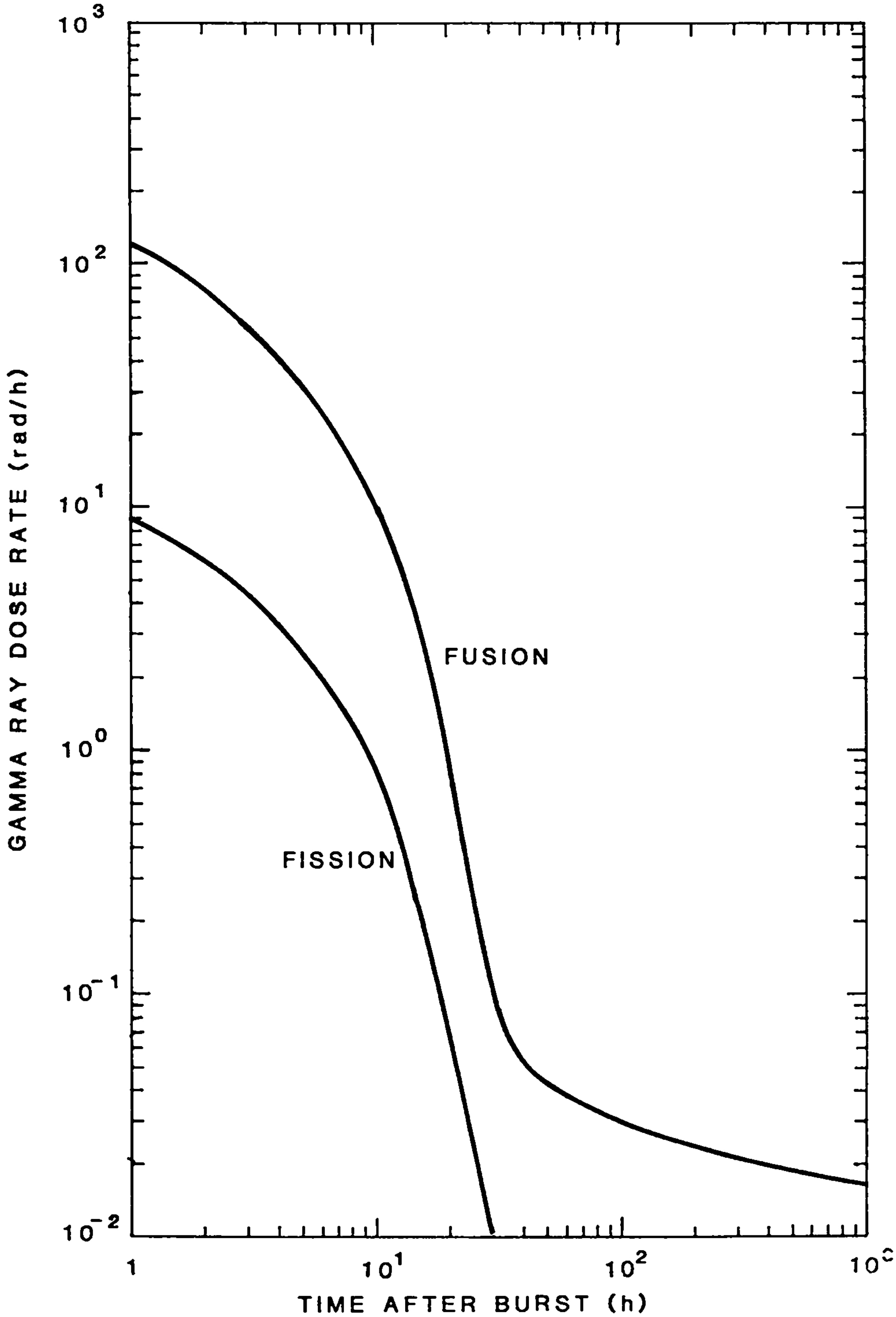

Fig. 1. Prompt neutron induced gamma-ray dose rate/kt at center of armor (D-T fusion and fission).

TABLE VIII. Chrome-Nickel Armor Steel Activation Gamma Dose Rate at Center of Armor: ONETRAN Calculation (1-kt D-T Fusion and 1-kt Fission)

Time after Burst (h)	Rad/h 1-kt D-T Fusion	Rad/h 1-kt Fission
0	587.00	24.00
1	121.00	9.41
10	10.80	0.842
20	0.80	0.064
25	0.300	0.0207
30	0.106	0.00889
40	0.0514	0
50	0.042	0
100	0.0294	0
1000	0.0166	0
10 000	0.00339	0

TABLE IX. Chrome-Nickel Armor Steel Time-Integrated Dose Rate at Center of Armor: ONETRAN Calculation (1-kt D-T Fusion and 1-kt Fission)

Time-Integrated Dose	Rad 1-kt D-T Fusion	Rad 1-kt Fission
0 → 1 h	296	16
1 → 30 h	450	35
30 → 1000 h	49	---
0 → 1000 h	795	51
1 → 1000 h	499	35

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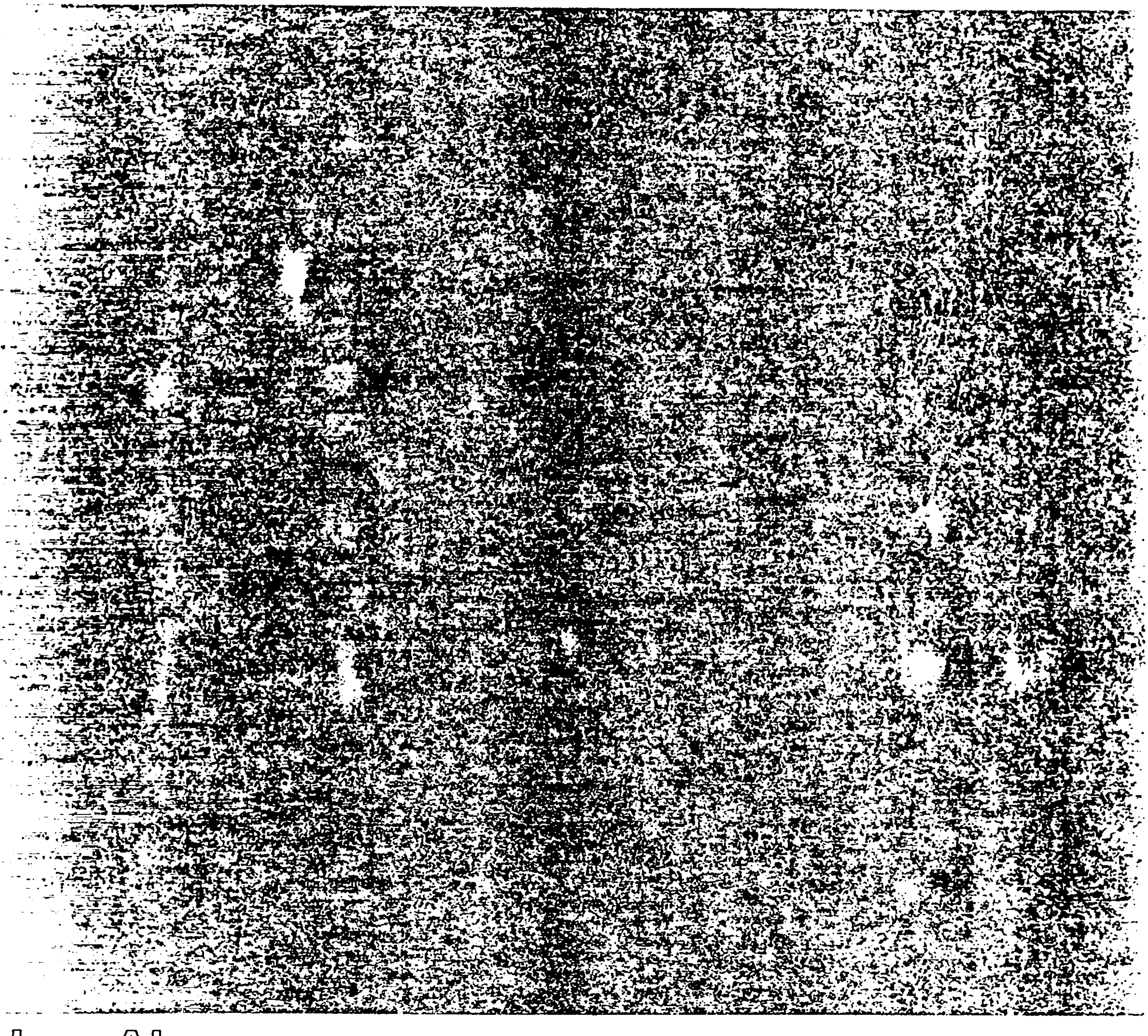

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