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

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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_o(dis/cm^3·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·s, is

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

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·cm. For a neutron burst, $t \ll T_{1/2}$, and the expression reduces to

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

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

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

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_o 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  0
                   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  0
                   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  0
                   CO  58     .20E-08              .03650
 .22359E+00  .36901E+00  .47375E+00  .61176E+00  .65791E+00  .63487E+00
 .45656E+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  0
                   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  0
                   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  0
                   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  0
                   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  0
                   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  0
                   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  0
                   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  0
                   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  0
                   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  0
                   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  0
                   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.
```

TABLE V. (cont)

```
 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
CU  65  (N,2N)      CU  64     12.71      H      ENDF/B-IV     .19659              29651  O
                    CU  64      .40E-07           .13300
  .12114E+01   .92751E+00   .70070E+00   .19805E+00 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     .48000   37.00000    0.00000    0.00000
CU  65  (N,P)       NI  65     2.520      H      ENDF/B-3      .58880              29653  O
                    NI  65      .20E-07           .63100
  .20900E-01   .20900E-01   .20386E-01   .17343E-01   .11420E-01   .73682E-02
  .33887E-02   .65763E-04 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   41.89000     .64000    4.80000    0.00000
CU  65  (N,A)       CO  62     13.9       M      ENDF/B-3     2.76048              29654  O
                    CO  62      .20E-05          1.13000
  .36100E-01   .36100E-01   .37827E-01   .36401E-01   .25089E-01   .80680E-02
  .27253E-03 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
  28.80000  179.00000    3.40000    0.00000    0.00000
MO 100  (N,2N)      MO  99     66.02      H      THRESH        .15380              42001  O
                    MO  99      .70E-08           .38600
  .16893E+01   .16521E+01   .16143E+01   .13885E+01   .32546E+00   .24863E-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.
   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      CDOK          .86161              42002  O
                    MO 101      .30E-05           .59500
 O.           O.           O.           O.           .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  O
                    ZR  97      .30E-08           .69900
  .38000E-02   .38000E-02   .27268E-02   .12003E-02   .34811E-03   .97357E-04
  .54047E-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
     .03000    8.27000  104.63000    5.02000     .95000
MO  92  (N,NA)      ZR  88     83.4       D      THRESH        .38996              42926  O
                    ZR  88      .10E-09          0.00000
  .81300E-03   .81300E-03   .41553E-03   .12662E-03   .46813E-04   .34715E-04
  .25990E-05 O.           O.           O.           O.           O.
 O.           O.           O.           O.           O.           O.
 O.           O.           O.           O.           O.           O.
 O.           O.           O.           O.           O.           O.
```

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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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_0 (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

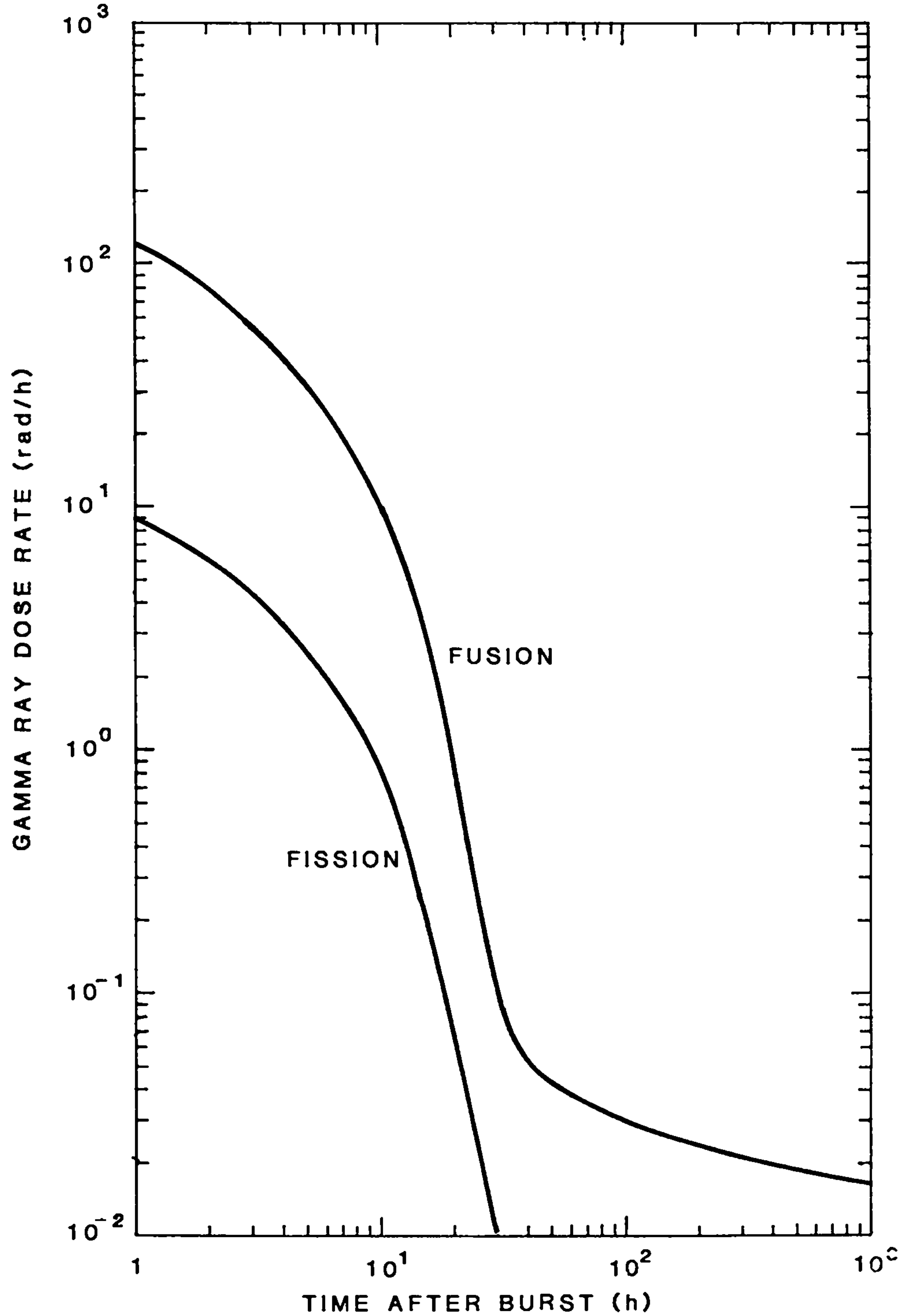

Fig. 1. Prompt neutron induced gamma-ray dose rate/kt at center of armor (D-T fusion and fission).

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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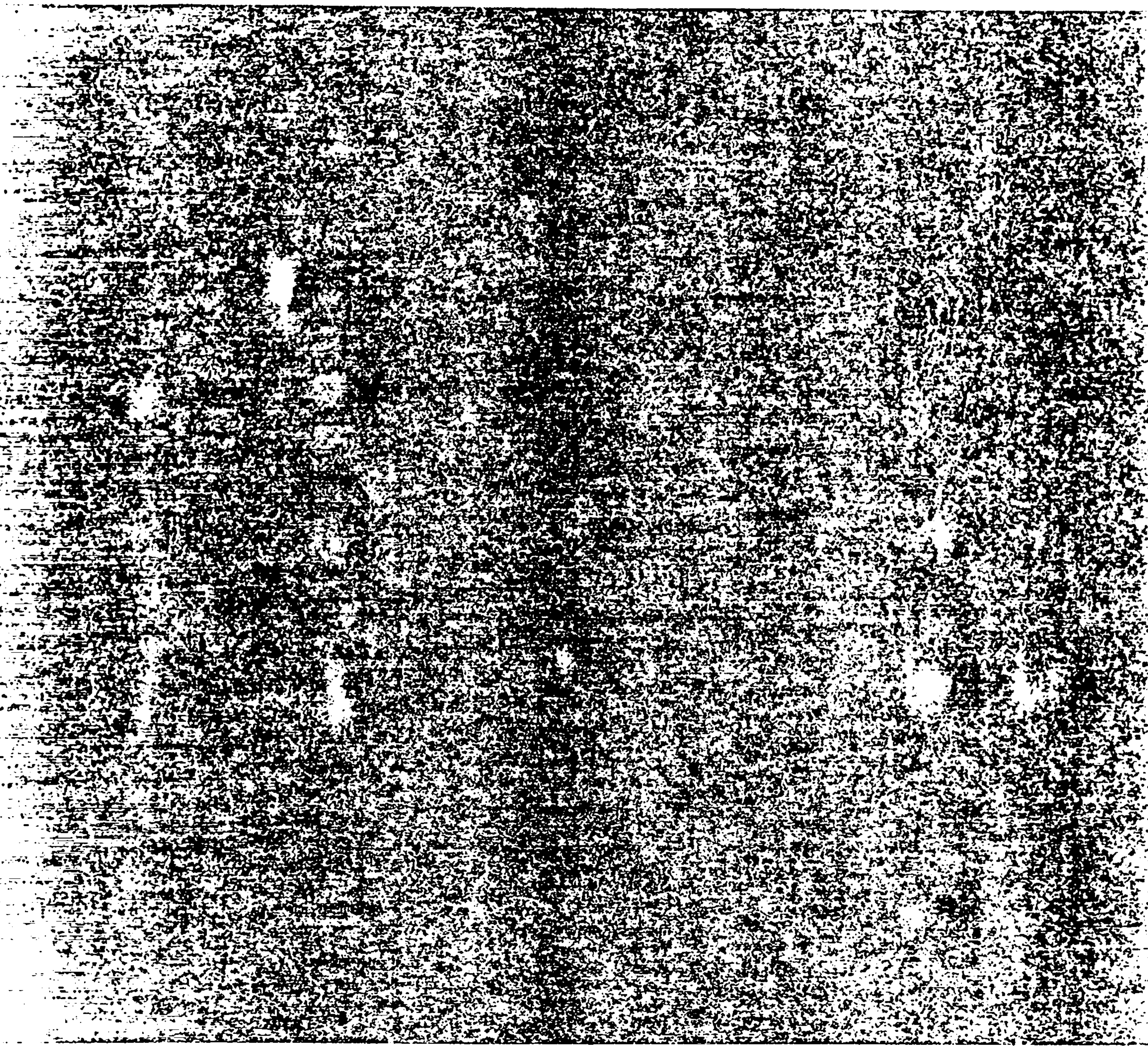

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