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RADIATION ASSOCIATED WITH AN INERTIAL CONFINEMENT FUSION LASER SYSTEM

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ABSTRACT

The primary objective of the LLNL Laser Fusion Program is to understand and develop the science and technology of inertial confinement fusion. Nova, a 100-TW/100-kJ laser system, has demonstrated efficient compression, ignition, and burn of D-T fusion fuel. The LLNL fusion computer program (LASNEX) and experiments strongly support achieving high gain with the proposed multi-MJ laser system. In this paper, I examine the prompt and residual radiations associated with these laser systems.

INTRODUCTION

In inertial confinement fusion (ICF), such as with the Nova laser system, which has achieved the world's highest laser performance (in excess of 100 kJ) and neutron yield (in excess of 1.5×10^{13} neutrons), prompt neutrons are generated during the D-T burn cycle. Interaction of these neutrons with the materials in the Nova target room results in the production of secondary gammas and residual radiation. The Nova target vessel is constructed of aluminum alloy to accommodate maximum credible yields of 2×10^{17} neutrons per shot. The vessel has a designed-in upgrade capability to accommodate yields that are two orders of magnitude higher. In the Nova configuration, we have also examined the radiation levels associated with conducting shots with yields of 10^{20} neutrons. Shots of this magnitude yield probably will be conducted in the proposed High Gain Test Facility (HGTF) at Livermore. The HGTF components, however, will consist of materials that result in significantly lower activation. The calculated results presented in this paper are for nominal yields of 2×10^{17} and 10^{20} neutrons per shot.

PROMPT RADIATION

The physical layout of the Nova target and switchyard sections is illustrated in Fig. 1. The target room is roughly 15x30x26 meters. The outer concrete wall is 1.8 meters thick, and the concrete roof is 1.4 meters thick. There are a number of 1-meter-diameter beam transport openings in the north and east walls of the switchyard room. The openings that result in maximum radiation leakage are those coplanar and in approximate line-of-sight with the target. The radiation levels calculated at various locations inside and near these openings for a 2×10^{17} neutron shot are given in Table 1.

Table 1. Neutron radiation doses inside the Nova facility from leakage through 1-meter-diameter penetrations that are coplanar and in approximate line-of-sight with the target normalized to 2×10^{17} neutron shot. Locations of estimated doses are shown in Fig. 1

Location	Coordinates (cm) x	y	z	Dose (rem)
1	762	0	823	560
2	823	0	823	220
3	884	0	823	34
4	1590	0	823	0.18
5	1590	0	1128	0.17
6	1590	0	1524	4.6
7	1590	0	1555	5.0
8	1590	0	1585	2.2
9	1643	0	1585	1.3

The locations given in Table 1 correspond to those shown in Fig. 1 (The coordinates origin is at the center of the target vessel.)

For a 2×10^{17} neutron shot, the calculated maximum dose outside the 1.8-meter shield wall is 1.5 mrem (1 mrem from neutrons and 0.5 mrem from secondary gammas.) The calculated neutron component appears to be roughly twice that scaled from the measurements made at the Livermore rotating target neutron source (RTNS-II) facility using the de Pangher "precision long counter" (PLC). The calculated gamma component appears to be reasonably close to the level scaled from measurements made at RTNS-II using an ionization chamber and 7.6-cm x 7.6-cm NaI detector. We are planning to extend our work to resolve the difference in the neutron component. The calculations were made with the codes TART (Ref. 1) and Morse (Ref. 2).

RESIDUAL RADIATION

Various materials in the Nova target room exposed to the fusion neutrons are subject to activation. The amounts and types of neutron-induced products generated depend on the neutron energy flux densities and the chemical composition of the exposed materials. The major Nova components subject to activation include the target vessel (aluminum alloy: 218 cm inner radius, 12.7 cm thick); the space frame (mild steel weighing approximately 10^5 kg); and the concrete floor, roof, and walls. The model shown in the lower part of Fig. 2 was used for calculating the neutron activation in these components. The chemical composition of the components is given in Table 2.

Table 2. Chemical composition of major components in the Nova target room

Vacuum Vessel		Space frame		Concrete Shield	
Element	Atomic Fraction	Element	Atomic Fraction	Element	Atomic Fraction
Si	3.86E-3	C	0.0685	H	0.1093
Fe	2.42E-3	K	0.0025	O	0.606
Cu	4.26E-4	S	0.00312	Na	0.0236
Mn	2.22E-3	Mn	0.0364	Mg	0.0123
Mg	4.46E-2	Fe	0.8895	Al	0.0318
Cr	1.30E-3	--	------	Si	0.1752
Zn	1.04E-3	--	------	Ca	0.02998
Al	9.44E-1	--	------	Fe	0.01223

The calculations were made with the codes TART (Ref. 1) and ACTIVE (Ref. 3). In this case, the TART was used for calculating the path lengths in appropriate zones as a function of neutron energy. This information was used in the ACTIVE code to calculate the residual radioactivity. The radiation decay equations were modified as needed for the multiple shots over various intervals. Reactions considered were (n,3n), (n,2n), (n,γ), (n,p), (n,d), (n,t), (n,α) and corresponding isomeric products. The specific activity generated in various components is shown in Table 3 after a one-year's operation at 10^{20} neutrons per shot, assuming one shot every two weeks.

Table 3. Specific activity in materials in the target room following 26 biweekly 10^{20} neutron shots

Material	Specific Activity, Ci/g				
	0	1 Yr.	5 Yrs.	10 Yrs.	50 Yrs.
Target Chamber	1.04E-2	3.57E-8	3.65E-9	7.70E-10	1.22E-11
Space Frame	1.26E-4	1.78E-7	4.96E-8	1.34E-8	7.96E-12
Concrete (inner 40 cm)	2.05E-4	1.31E-9	3.83E-10	1.06E-10	2.39E-13

Dry air was assumed between the vacuum vessel and mild steel space frame and between the space frame and the concrete shield. The important products and amounts generated in the air are listed in Table 4.

Table 4. Neutron-induced activity in the Nova target room air by a 10^{20} neutron shot

Isotope	Half-life	Time Zero Amount in Curies
N-16	7.13 sec.	6.31E4
C-14	5730 yrs.	5.59E-4
N-13	9.99 min.	4.22E2
Ar-39	269 yrs.	1.33E-5
Ar-41	1.83 hrs.	3.24E1
H-3	12.26 yrs.	3.65E-3

The gamma dose rates from the activation for a maximum credible shot of $2x10^{17}$ neutron are shown in Fig. 2. The levels for high gain shots are shown in Figs. 3-6 for various operations and cool-down times. The gamma dose rate measurements made on the Nova laser system following 10^{13} neutron shots confirm the calculations made for the Al target vessel, at least for the short-lived products such as Mg-27 and Na-24. Residual radiation from the longer-lived products can be validated as we get higher neutron yields.

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REFERENCES

1. E.F. Plechety and J.R. Kimlinger, "TARTNP: A Coupled Neutron-Photon Monte Carlo Transport Code," UCRL-50400, Vol. 14, Lawrence Livermore National Laboratory, 1976.

2. T. Wilcox, "Morse-L, A Special Version of the Morse Program Designed to Solve Neutron, Gamma, and Coupled Neutron-Gamma Penetration Problems," UCID-16680, Lawrence Livermore National Laboratory, 1972.

3. R.M. Lesseler, W.E. Alley, and J.B. Green, "The ACT and ACTIVE Codes for Calculating Neutron-Induced Activation," UCRL-51292, Lawrence Livermore National Laboratory, 1972.

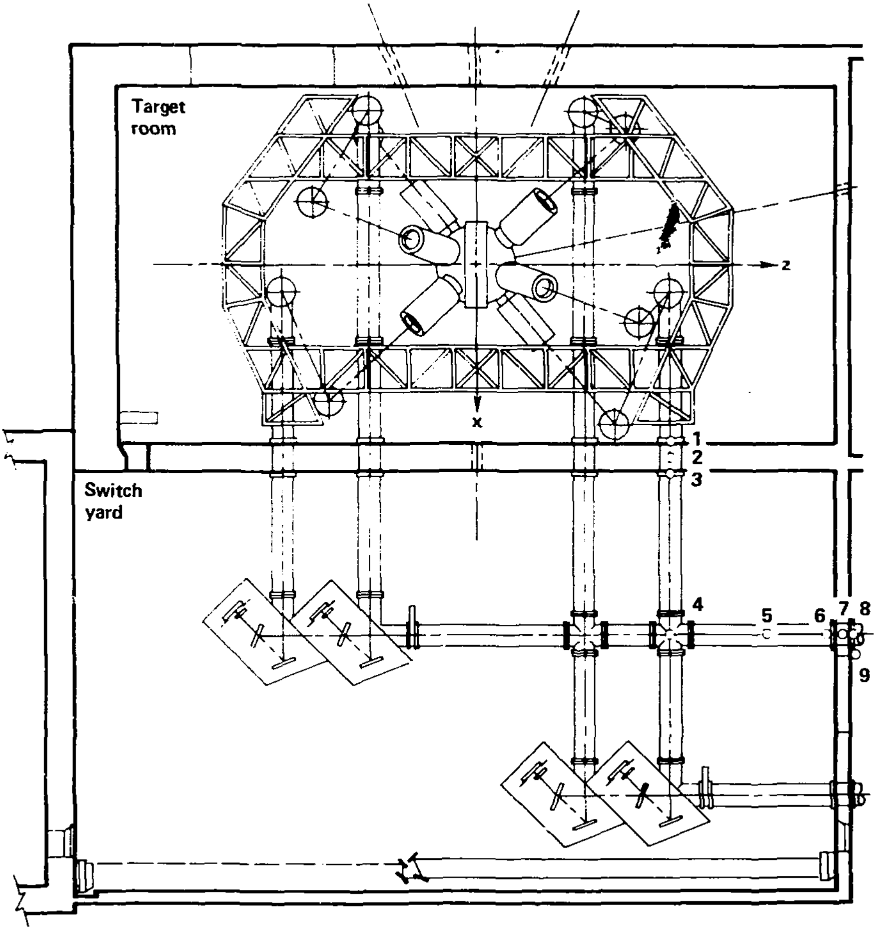

Fig. 1. Plan view of the Nova switchyard and target room. Locations (numbered) are of estimated neutron doses (see Table 1).

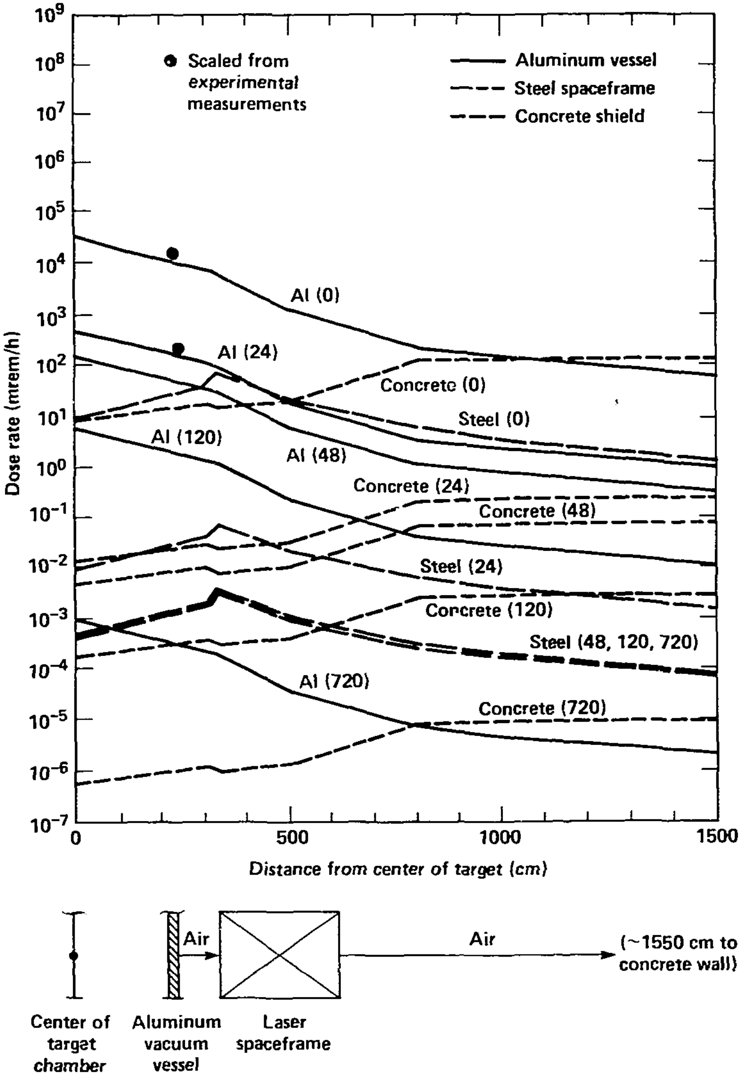

Fig. 2. Residual radiation dose levels in the Nova target room following a single 2×10^{17} neutron shot. The post shot time in hours is indicated in the parentheses () that follow the listed material.

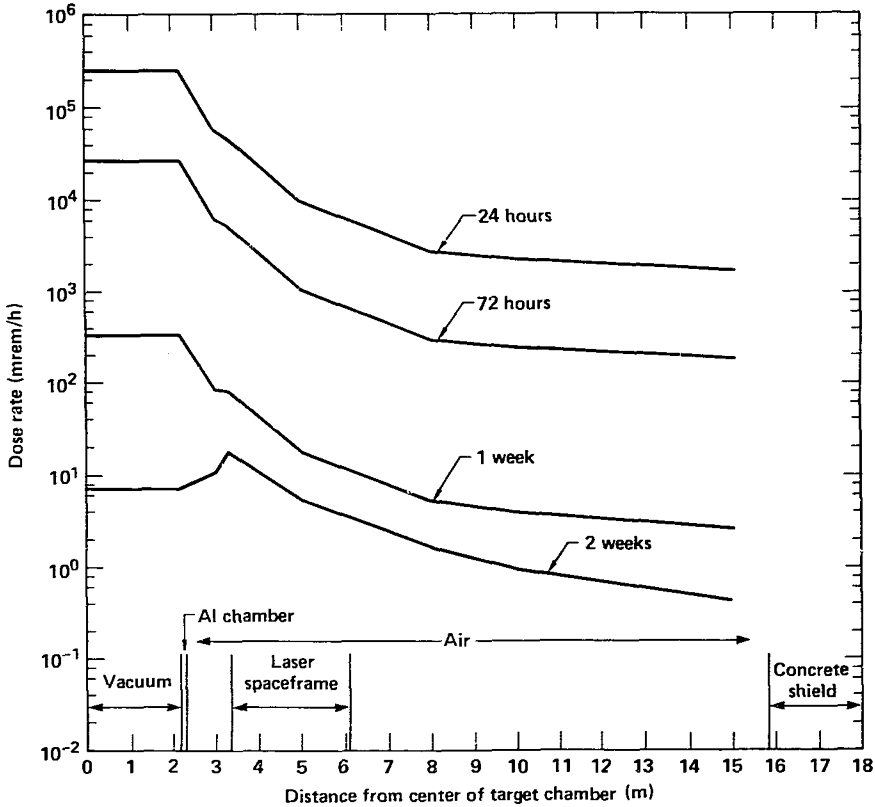

Fig. 3. Residual radiation levels in the Nova target room at various cool-down times following a 10^{20} neutron shot. Activity is from the activation of the Al vessel, steel space frame, and concrete shield.

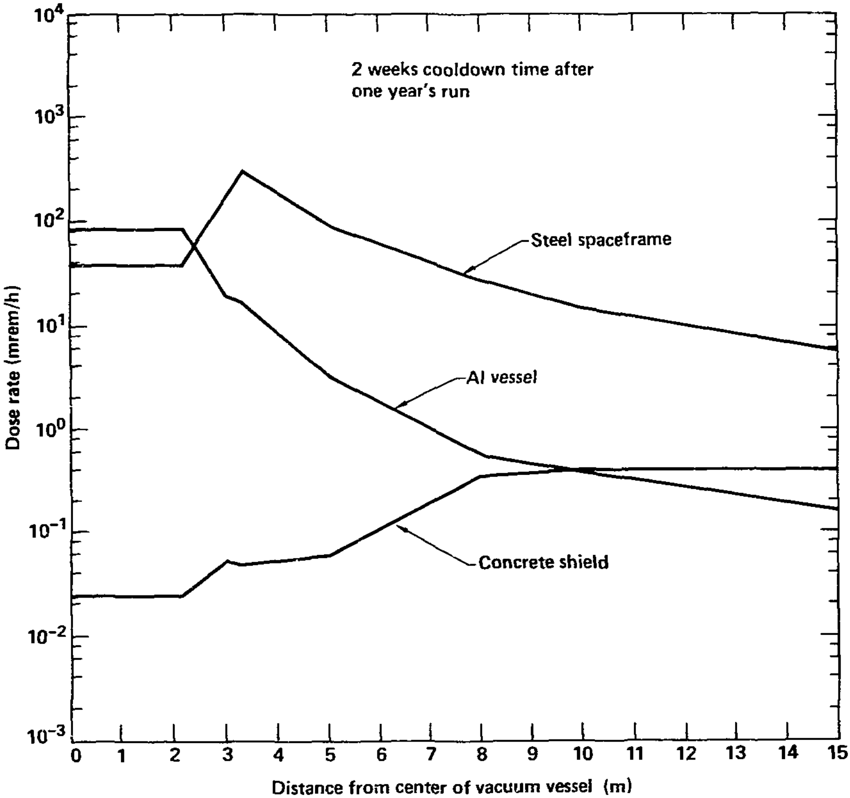

Fig. 4. Residual radiation levels in the Nova target room after one year's operation at 10^{20} neutrons per shot, one shot every two weeks, and two weeks of cool-down time after the last shot. Contribution from each of the components is indicated in the figure.

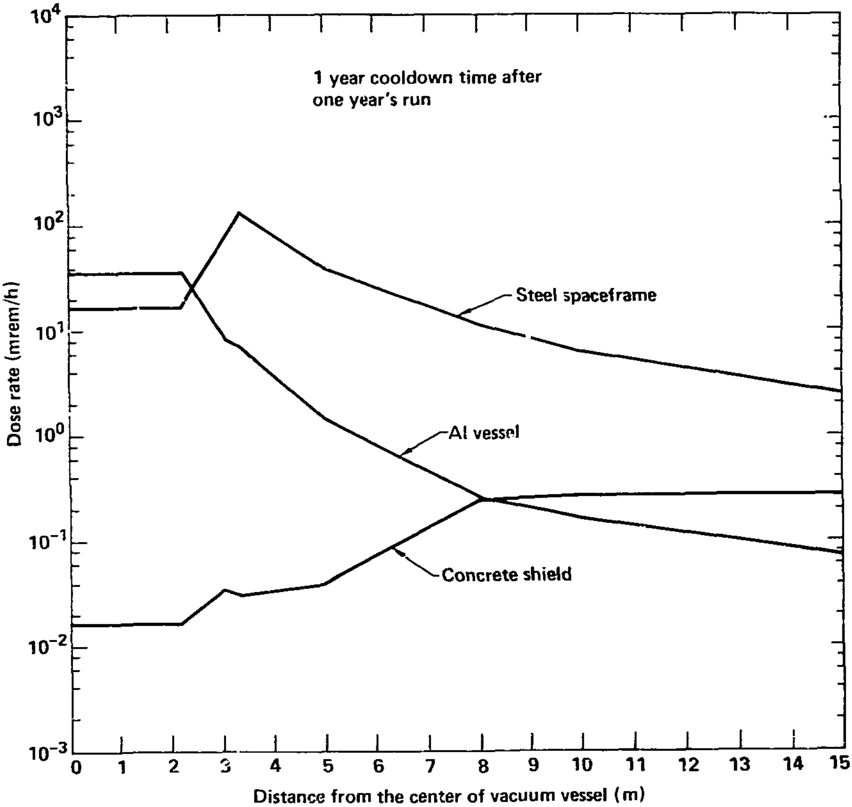

Fig. 5. Residual radiation levels in the Nova target room after one year's operation at 10^{20} neutrons per shot, one shot every two weeks, and one year's cool-down time after the last shot. Contribution from each of the components is indicated in the figure.

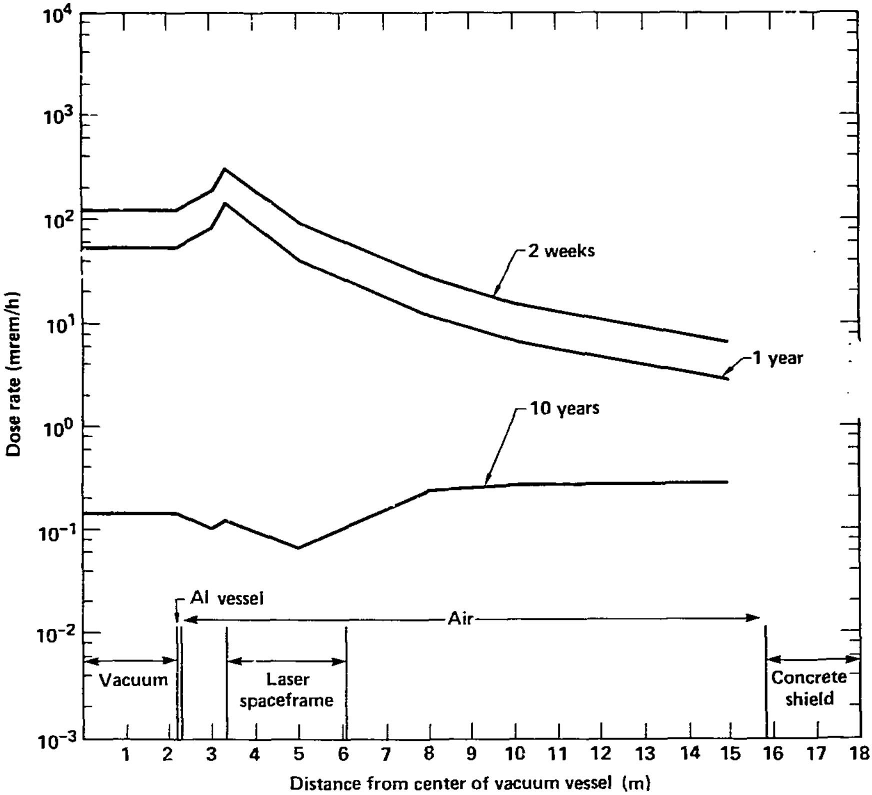

Fig. 6. Residual radiation levels in the Nova target room at various cool-down times after one year's operation at 10^{20} neutrons per shot, one shot every two weeks. Radiation is from the neutron-induced activity in the concrete, Al vessel, and steel space frame.