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GAMMA-RAY EXPOSURE HAZARD DUE TO STOWAGE OF M-774 APFSDS ROUNDS IN A LEOPARD C-1 MAIN BATTLE TANK

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H.A. Robitaille

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ABSTRACT

The M-774 APFSDS anti-tank round contains a depleted-uranium penetrator of 3.4 kgram mass. Since depleted uranium is naturally radioactive, the storage of a substantial number of these rounds inside a Leopard C-1 main battle tank creates a gamma radiation field within the vehicle.

Gamma-ray exposure rates have been measured using a sodium-iodide spectrometer at each of the four crew-member locations and for two turret orientations, with 59 rounds stowed in the vehicle. In all cases the measured gamma-ray dose rates were less than a maximum of 0.17 millirad per hour observed at the loader's position. Assuming the loader spent an entire week (168 hours) at his station, his integrated dose would amount to 29 mRad - approximately a factor of 4 lower than the maximum currently allowed by Canadian Forces regulations. It is therefore concluded that the M774 round does not represent a significant gamma radiation hazard to Leopard C1 crewmembers.

RÉSUMÉ

L'obus antichar stabilisé par empennage et à sabot détachable M-774 contient un pénétrateur en uranium appauvri de 3,4 kg. Comme l'uranium appauvri est radioactif, la présence d'une certaine quantité de ces obus à l'intérieur d'un char de combat principal Léopard C1 crée un rayonnement gamma dans le char.

Les débits d'exposition aux rayons gamma ont été mesurés à l'aide d'un spectromètre à iodure de sodium, et ce aux quatre postes de l'équipage et en orientant la tourelle à deux positions. Au cours de cette expérience, 59 obus de ce type se trouvaient dans le char. Dans tous les cas, les débits d'exposition mesurés ont été inférieurs à 0,17 millirad par heure au poste du chargeur. En supposant que le chargeur passe toute une semaine à son poste, soit 168 heures, le débit total d'exposition serait de 29 millirads, c'est-à-dire environ 4 fois moins que l'exposition minimale tolérée en vertu des réglements des Forces canadiennes. Il est donc établi que les obus M-774 présents dans le char Léopard C1 ne sont pas la source d'un rayonnement susceptible de présenter un danger pour l'équipage.

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INTRODUCTION

The M774 APFSDS (Armour-Piercing Fin-Stabilized Discarding-Sabot) is an anti-armour round employing a long-rod penetrator composed of 3.4 kgram of depleted uranium (uranium in which the content of the 235-isotope has been reduced to approximately 0.2 weight-percent). The bulk of uranium in the round is therefore of the 238-isotope and decays radioactively through the emission of an energetic alpha particle, leading to the daughter product 234-Thorium. The thorium so formed decays in turn to 234-Palladium (in an excited state), which then decays either directly to 234-Uranium or to the same isotope through the intermediate ground state of 234-Palladium. All of these transitions from 234-Thorium involve the release of both gamma-rays and beta particles of various energies. The 234-Uranium so formed in this decay chain is alpha-radioactive but with a sufficiently long half-life that its activity and those of its daughters are inconsequential to the present considerations. Figure 1 (adapted from ref. 1) shows the relationship of these isotopes to the originating ^{238}U nucleus:

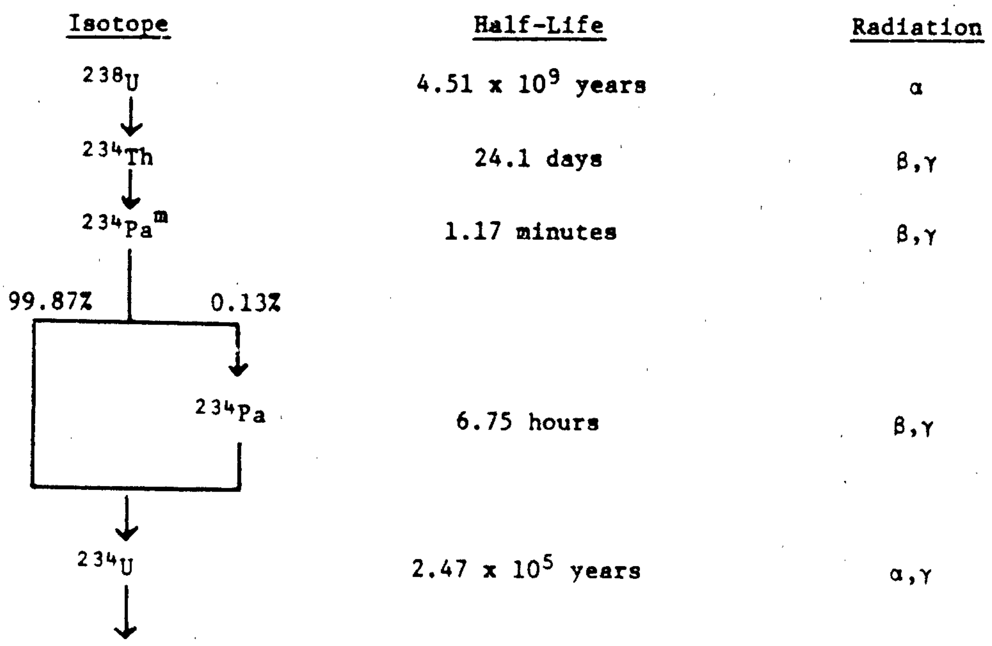

Figure 1: Decay chain of 238-Uranium

The daughter products ^{234}Th, ^{234}Pa^{m} and ^{234}Pa all have sufficiently short half-lives that within a ninety-day period after the initial separation of the depleted uranium their concentrations reach 98% of the maximum values and enter secular equilibirum with the parent ^{238}U. After this period of initial buildup the concentrations of these isotopes will then diminish in constant ratios according to the decay of ^{238}U, with its characteristic half-life of 4.51×10^{9} years. Conversely, due to the much longer half-life of ^{234}U its concentration will continue to increase for about 10^{6} years, however due to this same long half-life its instantaneous decay rate is very low, and consequently the specific contribution of its decay radiation insignificant.

Particles released during these transitions include alpha, beta and gamma-rays of various energies. Alpha and beta particles, being massive and carrying electric charge, have much shorter ranges than the gamma-rays released and very few will escape the encapsulation of the penetrator rod. A previous study[2] established that the radiological hazard associated with the release of alpha and beta particles by the M774 round was insignificant compared to the gamma-ray hazard.

Due to the long range of gamma-rays, the magnitude of the gamma hazard depends to a large extent on the number and unique disposition of the DU rounds, consequently the direction of this study was to establish the specific dose-rates to which crewmembers of the Leopard C-1 main battle tank could be exposed.

EXPERIMENT

As part of another experimental program at the US Army Pulse Radiation Facility (Aberdeen Proving Ground) in 1981, fifty-nine M774 rounds were installed in a Leopard C-1. This number represents the full ammunition stowage capability of the vehicle and consequently a "worst-case" situation establishing the maximum dose-rates to which crewmembers could be exposed. (In military operations a typical vehicle would carry a mix of rounds not all of which would contain uranium, consequently the actual radiological hazard would be reduced).

A 2" x 2" sodium-iodide gamma-ray spectrometer was used to determine particle spectra from which radiation dose-rates would be calculated by folding the data with the appropriate fluence-to-tissue dose conversion factors[3]. Measurements were made at positions corresponding to the mid-chest location of each of the four crew-members, and for two turret orientations: attack (gun forward) and transport (gun rearward). The driver's, loader's and commander's seats were all positioned at their lowest travel and the detector located 47 cm above the seats. The gunner's seat was positioned such that an individual of 180cm height would look comfortably through the gunsight. Data were obtained at each location for twenty minutes, and during this time all hatches remained closed.

RESULTS

The dose-rates measured inside the Leopard are tabulated below, in units of mRad per hour:

Turret	Location	Dose Rate (mR/hr)	Statistical Error
Attack	Commander	0.0388	0.4%
	Loader	0.1561	0.2%
	Gunner	0.0433	0.4%
	Driver	0.1232	0.2%
Transport	Commander	0.0508	0.3%
	Loader	0.1700	0.2%
	Gunner	0.0361	0.4%
	Driver	0.1517	0.2%
Mean	(Average of all measurements)	0.096	

Table 1: Dose-rates measured in the Leopard C1

These data are also shown diagrammatically in Figures 2a and 2b. It is apparent that when in either configuration, the dose-rates to the driver and to the loader are significantly higher than to the other crewmembers. This is a result of the disposition of the rounds; some (42) are stored in the hull just to the driver's left side, the remainder (17) being stored in the turret and in close proximity to the loader, again primarily to his left. As the turret is traversed from 0^o to 180^o, some crew members receive a higher dose-rate as they come into closer proximity to the stored rounds, others receive a lower dose-rate as they move farther away. A mean dose-rate of 0.096 mRad/hour is thus calculated for all orientations and positions. Note that the errors listed are due only to statistical uncertainties - to these must be added a possible 5% calibration error reflecting the overall uncertainty in the absolute detector efficiency.

Raw data recorded during the eight measurements were also combined with equal weight and the resulting pulse-height spectrum shown in Figure 3. Thus, these data represent the mean spectrum recorded over a 160-minute period within the vehicle. After unfolding (correction for detector response and efficiency), a mean gamma-ray flux spectrum is also shown in Figure 4. The observed peaks near energies of 0.75, 1.0, 1.45 and 1.8 MeV correspond very well with the expected intensities due to the major transitions of $^{234}Pa^m$ (ref 4), thus identifying this isotope as dominant in the production of gamma radiation from the M774 round.

Numerical data corresponding to the spectrum of Figure 4 are to be found in the Appendix.

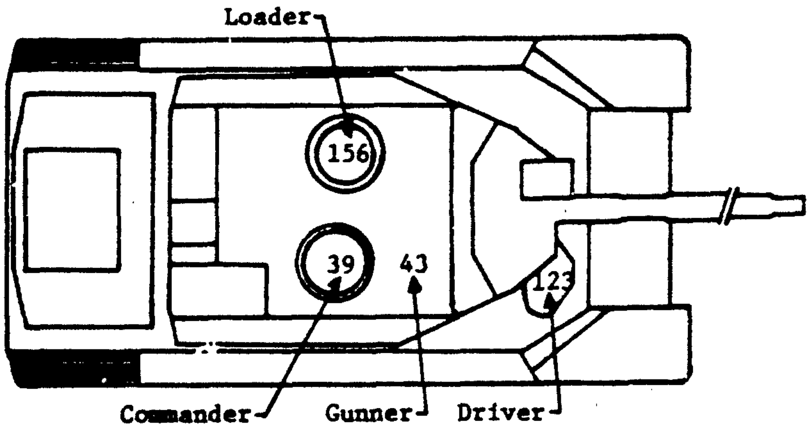

Figure 2a: Doserates measured in the attack configuration (μR/hr)

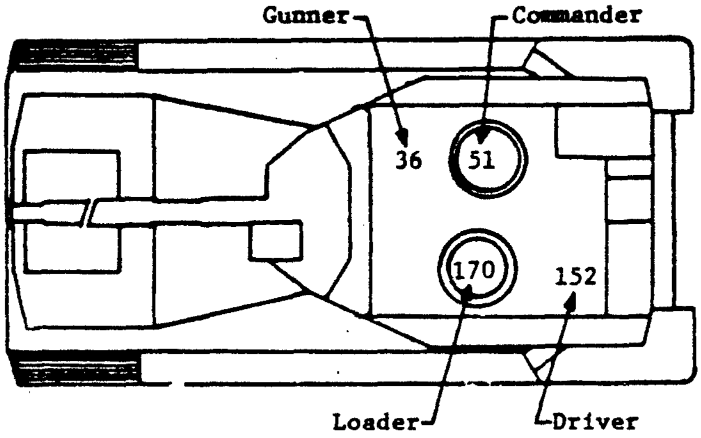

Figure 2b: Doserates measured in the transport configuration (μR/hr).

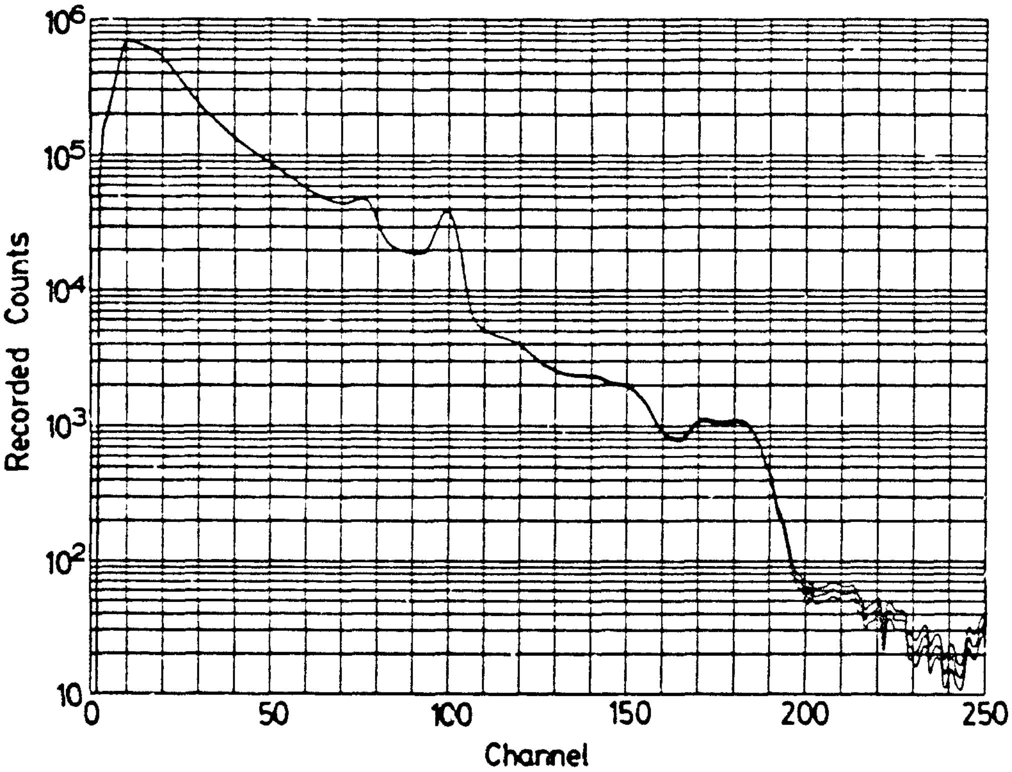

Figure 3: Sum of recorded gamma-ray spectra.

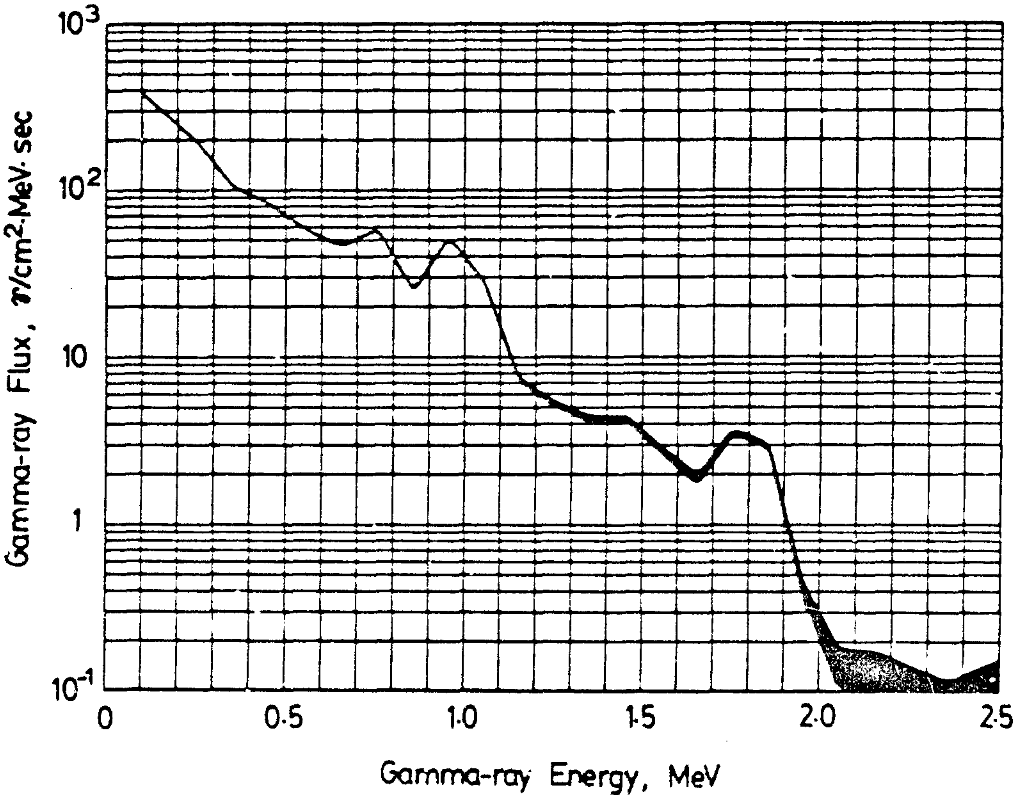

Figure 4: Unfolded mean gamma-ray flux spectrum.

CONCLUSIONS

The mean gamma radiation dose-rate resulting from the storage of fifty-nine depleted-uranium M774 anti-armour rounds in a Leopard C-1 main battle tank has been determined experimentally as 0.096 mRad per hour. The maximum dose-rate measured was found at the loader's station when the turret was in its transport configuration (i.e. gun rearward) and equalled 0.17 mRad per hour. At such a dose-rate if the loader spent an entire week (168 hours) in this location his accumulated gamma-ray dose would amount to 29 mRads, or approximately one-fourth of that currently permitted atomic energy workers in Canada [5] and members of the Canadian Forces. [6]

Under actual circumstances the weekly dose received by Leopard C-1 crewmembers would be much less than this for three reasons: firstly not all rounds in a typical tank would be of the M774 type, secondly the average complement of all rounds would naturally be less than the maximum stowage capability of the vehicle, and finally a crewmember would not be confined for an entire week without respite inside the vehicle.

For these reasons it must be concluded that the storage of the M774 APFSDS round in Leopard C-1 main battle tanks would not result in a significant exposure of the vehicle crew to gamma radiation.

ACKNOWLEDGEMENT

The author is grateful for the assistance of the staff of the US Army Pulse Radiation Division at the Aberdeen Proving Ground in co-ordinating the loan of the M774 rounds and providing the necessary resources to enable these measurements.

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2. "Radiation Characterization and Exposure Rate Measurements from Cartridge 105-mm APFSDS-T, XM774"; W.T. Bartlett, R.L. Gilchrist, G.W.R. Enders, Battelle Pacific Northwest Laboratories; PNL-2947, Richland, WA; Nov, 1979.

3. "Dose Rates in a Slab Phantom from Monoenergetic Gamma-rays"; H.C. Claiborne and D.K. Trubey; Nuclear Applications and Technology, 8, 450 (1970).

4. "Atomic Data and Nuclear Data Tables", 13, No 2-3 (1974), page 279.

5. "Atomic Energy Control Act", Canada Gazette Part II, Vol 108, No 12, 26 June 1974.

6. "General Ionizing Radiation Safety"; Canadian Forces Technical Order C-02-040-004/TP-000, 5 June 78.

APPENDIX: LISTED DATA

The data listed below comprise the mean gamma-ray flux spectrum recorded within the Leopard C-1, corresponding to Figure 4 in the main text.

GROUP	UPPER ENERGY (MEV)	PARTICLE FLUX (PARTICLES/ CM2-MEV-SEC)	ERROR (STD. DEV.)	ERROR (%)	RUNNING INTEGRAL (/CM2-SEC)
2	0.2	2.987E+02	4.95E-01	0.17	2.987E+01
3	0.3	1.925E+02	4.24E-01	0.22	4.912E+01
4	0.4	1.036E+02	4.01E-01	0.39	5.947E+01
5	0.5	8.292E+01	4.09E-01	0.49	6.776E+01
6	0.6	5.739E+01	3.91E-01	0.68	7.350E+01
7	0.7	4.558E+01	4.22E-01	0.93	7.806E+01
8	0.8	5.878E+01	4.07E-01	0.69	8.394E+01
9	0.9	2.472E+01	3.95E-01	1.60	8.641E+01
10	1.0	5.210E+01	4.10E-01	0.79	9.162E+01
11	1.1	2.787E+01	2.98E-01	1.07	9.441E+01
12	1.2	7.203E+00	2.08E-01	2.89	9.513E+01
13	1.3	5.173E+00	1.91E-01	3.69	9.565E+01
14	1.4	4.202E+00	1.86E-01	4.42	9.607E+01
15	1.5	4.308E+00	1.76E-01	4.09	9.650E+01
16	1.6	2.763E+00	1.50E-01	5.41	9.677E+01
17	1.7	1.862E+00	1.45E-01	7.78	9.696E+01
18	1.8	3.591E+00	1.47E-01	4.08	9.732E+01
19	1.9	2.930E+00	1.06E-01	3.62	9.761E+01
20	2.0	4.076E-01	4.95E-02	12.14	9.765E+01
21	2.1	1.432E-01	3.91E-02	27.27	9.767E+01
22	2.2	1.408E-01	3.57E-02	25.32	9.768E+01
23	2.3	1.113E-01	3.08E-02	27.65	9.769E+01
24	2.4	8.754E-02	2.95E-02	33.74	9.770E+01
25	2.5	1.213E-01	2.21E-02	18.18	9.771E+01

TOTAL FLUENCE = 9.771E+01 /CM2-SEC

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