Radiological Assessment of Cartridge 120-mm, APFSDS-T, XM829 Ammunition

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December 1983

Prepared for
Tank Ammunition Section
Munitions System Division
Large Caliber Weapons System Laboratory
Armament Research and Development Center

Pacific Northwest Laboratory
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Pacific Northwest Laboratory
Richland, Washington 99352

SUMMARY

The Department of the Army contracted with Pacific Northwest Laboratory (PNL) to investigate the health physics problems associated with the handling, shipping and storage of 120-mm, APFSDS-T, XM829 ammunition. Each round of this ammunition contains a penetrator of depleted uranium, which is classified as a radioactive source material.

The study carried out by PNL included laboratory and simulated storage analyses and an assessment of potential health physics problems. The data sought included: the characteristics of radiation emitted from a projectile; and the radiation levels emitted from a bare penetrator, projectiles, cartridges (both packaged and unpackaged), and a 16-round pallet of XM829 ammunition.

The results of the study showed the following:

- The components of the XM829 round effectively shield out nonpenetrating beta radiation emitted by the depleted uranium; however, photons can penetrate the components of the round and are therefore the predominant emission.
- The radiation levels associated with the XM829 ammunition are low. The maximum emissions measured from a cartridge are not likely to result in exposure to military personnel above the maximum permissible nonoccupational dose limits listed in Army Regulation (AR) 40-14, Control and Recording Procedures for Exposure to Ionizing Radiation and Radioactive Materials.
- Based upon the specifications contained in 49 CFR 173.424 and the radiation measurement data obtained from this study, the XM829 shipping package may be excepted from the specification packaging, marking and labeling requirements of subpart 49 CFR 173 as long as the outer surface of the uranium is enclosed in an inactive sheath and the conditions specified in 49 CFR 421 (b), (c), and (d) are met.

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1.0 INTRODUCTION

The Department of the Army (DA) handles, stores and ships 120-mm APFSDS-T, XM829 ammunition. This ammunition has a projectile made up of a windshield, sabot, fin and penetrator. The penetrator is made up of depleted uranium (DU). A shell casing and ignition-propulsion unit are assembled to the projectile to complete the XM829 cartridge or round. Because DU is classified as a radioactive source material, the DA, through the Tank Ammunition Section, Munitions System Division, Large Caliber Weapons System Laboratory, Armament Research and Development Center (ARDC), contracted with the Pacific Northwest Laboratory (PNL)^(a) to study and evaluate the radiological hazard associated with the ammunition.

The purpose of this study was to determine the types and levels of radiation emitted from the XM829 ammunition. The U.S. Code of Federal Regulations, Title 10, Part 20, "Standards for Protection Against Radiation" (10 CFR 20) and Army Regulation 40-14, "Control and Recording Procedures for Exposure to Ionizing Radiation and Radioactive Materials" (AR 40-14) both list limits for radiation exposures. Title 49, Parts 171 through 179, of the Code of Federal Regulations (especially Parts 173.401-173.478) regulate the transportation of radioactive materials. Therefore, this study also evaluated the measured exposure rates in light of 1) the exposure limits for personnel given in 10 CFR 20 and AR 40-14 and 2) the shipping requirements in 49 CFR 171-179. Sections 2.0 through 5.0 of this report cover these topics as follows:

- Section 2.0--the types of radiation emitted by the XM829 ammunition
- Section 3.0--the radiation detection devices and calibration techniques used in the study
- Section 4.0--the radiation measurements made on the XM829 ammunition
- Section 5.0--evaluation of the radiological hazard from the measured emissions.

(a) Operated for the Department of Energy by Battelle Memorial Institute.

The conclusions drawn from the study are presented in Section 6.0. Figures and diagrams showing measurement positions and results are listed in Section 8.0.

2.0 TYPES OF RADIATION EMITTED BY THE XM829 AMMUNITION

Spectral measurements to determine the types of radiation emitted from ammunition with a DU penetrator were made at PNL in earlier unpublished studies of M-735E1 ammunition and in published studies of XM774 ammunition (Bartlett et. al., 1979). Some of the results of these studies are as follows:

- Beta particles constitute the predominant type of radiation emitted from bare DU penetrators.
- Gamma rays are the predominant type of radiation emitted from the assembled ammunition (projectiles and cartridges), because beta particles are largely attenuated by the windshield, sabot and fin assembly materials.
- Gamma spectrometry results do not indicate a significant photon buildup from beta interactions (Bremstrahlung) in the windshield, sabot or fin materials.
- The gamma spectra indicate no significant difference between the energy range of the gamma rays emitted from a bare penetrator and the energy range of those emitted from a projectile. The measurements were taken with germanium-lithium [Ge(Li)] detectors, which are presently state-of-the-art instrumentation for gamma spectrometry.

Figure 1 shows a typical gamma spectrum from an assembled XM829 projectile.

FIGURE 1. Typical Gamma Spectrum from an Assembled XM829 Projectile

3.0 RADIATION DETECTION DEVICES AND CALIBRATION TECHNIQUES

Radiation levels produced by the XM829 ammunition were measured with the ammunition in various stages of assembly and packaging, and in storage configurations. The measurements were made using the following types of radiation detection devices:

1. thermoluminescent dosimeters (TLDs)
2. portable exposure rate meters
3. a semiportable monitoring system, known as the TASC-4.

The TLDs were the primary measurement device for the bare penetrator, the unpackaged single cartridge, and the multipackage pallet array. Exposure rate meters were used to substantiate these photon radiation levels and also as the primary measurement device for the packaged single cartridge. The TASC-4 system provided on-the-spot information on photon levels at points of interest being measured by the TLDs. Measurement methods and data are discussed in detail in Section 4.0 of this document.

3.1 THERMOLUMINESCENT DOSIMETERS

The TLDs used in this study were constructed of lithium fluoride phosphor enriched in Li_7 (TLD 700s), which is sensitive to both beta and gamma (photon) radiation. This material is able to trap deposited energy from ionizing radiation and store the energy in an electron lattice. When heated, the material releases a portion of the trapped energy in the form of light emissions, which can be accurately measured. The quantity of radiation absorbed in the material can be determined by comparing the amount of light emitted to the amount given off by similar phosphors that have been exposed to a known quantity and quality of radiation.

Six thermoluminescent (TL) chips were incorporated into the dosimeter used for XM829 measurements. The chips were screened by a special process to ensure their response to within $\pm 5\%$ of each other when exposed to the same amount of radiation under like conditions. Documented sensitivity levels for the chips were also specified in the purchase agreement with the manufacturer.

The Dosimetry Technology Section of PNL designed a special holder which allowed three of the TL chips to be under a 0.25 mils (6.4×10^{-4} cm) mylar covered window and the other three under a 32 mils (0.1 cm) thick aluminum covered window. Beta (nonpenetrating) radiation with energies greater than or equal to that of krypton-85 ($E_{\max} = 0.67$ Mev) were capable of penetrating the mylar window but were effectively attenuated in passing through the aluminum covered window. Most photon radiation produced by the DU was capable of penetrating both the mylar and aluminum covered windows. The difference between the responses for the two windows gave an indication of the nonpenetrating component of the delivered radiation.

The overall size of the TLD holder is approximately 1/2 in. by 3/4 in. (1.3 cm by 1.9 cm). This small size allows the dosimeter to be placed on or close to the surfaces being measured and eliminates the need for geometry corrections. Studies have shown that TLDs have only a slight angular dependence (Kathren, Kocher, and Endres 1971).

3.2 PORTABLE EXPOSURE RATE METERS

Portable radiation detection instruments are commonly used to determine radiation levels emanating from radioactive shipment packages. For this reason, three types of portable instruments were used to measure the single XM829 shipping container. These were 1) a cylindrical shaped ionization chamber, 2) a rectangular shaped ionization chamber, and 3) an instrument which uses a 1 in. by 1 in. (2.5 cm by 2.5 cm) thallium-activated sodium iodide detector, [NaI(Tl)] known as the micro-R meter.

Of these, ionization chambers are more frequently used to provide "field" measurements (i.e., away from the laboratory) of radioactive devices because they are 1) portable and can be easily hand carried to the measurement location, 2) they detect both gamma and beta radiations and offer capabilities for differentiating between the two radiations, and 3) they provide instantaneous readouts over an intensity range of from zero to several thousand millirem per hour.

In the micro-R meter, the detector is enclosed within the instrument case; therefore, many beta particles are attenuated by the case and do not reach the

detector. The micro-R meter, however, is better suited for measuring very low levels of photon radiation than are the ionization chamber instruments. The intensity range of the instrument is limited to 0 - 3 mR/hr. Radiation measured at the surfaces of the XM829 shipping package were anticipated to be predominantly low-intensity photons, approaching natural background levels at some points. Therefore, the micro-R meter was used in conjunction with the ionization chambers to obtain measurements of the shipping package.

3.3 TASC-4 ENVIRONMENTAL MONITORING SYSTEM

Thalium-activated sodium iodine detectors are commonly used for photon spectrometry. The variable response of the NaI (Tl) detector system, modified for energy response, is appropriate for measurements of low photon exposure rates. Such a system is the TASC-4 environmental radiation monitoring system.

This system consists of a 2 in. by 2 in. (5.1 cm by 5.1 cm) NaI (Tl) detector coupled to a photomultiplier tube and a substantial electronics package. It is not normally used as a portable survey instrument. It offers greater sensitivity to photon radiation than does the micro-R meter, but like the micro-R meter, it does not detect low-energy beta radiations. The TASC-4 performs continuous, real-time monitoring of both natural and man-made gamma-ray (photon) emissions. Precise reliable readings of exposure rate are displayed on panel meters calibrated directly in $\mu\text{R/hr}$. A TASC-4 system was used in the study to provide backup information to the portable exposure rate meters and TLDs, where photon levels were expected to be low.

3.4 CALIBRATION

3.4.1 Thermoluminescent Dosimeters

The TLDs were calibrated by exposing a group of five dosimeters to selected radioactive sources that produced known exposure rates at specific distances. A natural uranium slab and a strontium-90 source were used as beta-emitting sources, and a cesium-137 source was used to produce a photon, or gamma, spectrum. These sources were calibrated in the following ways:

- natural uranium slab - An extrapolation chamber was placed close to the slab to measure the surface exposure rate.
- strontium-90 - This source was calibrated at the National Bureau of Standards (NBS) and carries a certified calibration at a source-to-detector distance of 13.8 in. (35 cm).
- cesium-137 - This source was calibrated at PNL's Dosimetry Technology Laboratory using an intercomparison standard ionization chamber that carries a certified ^{137}Cs calibration from NBS. The source-to-detector distance was 39.4 in. (100 cm).

The selection of the three sources used to calibrate the TLDs was based upon several parameters. Natural uranium was used because it produces an energy spectrum much like that of depleted uranium. Strontium-90 was used to provide another data point on the beta spectrum, which can be used to assess whether a detector's response varies with a change in the beta energy. Cesium-137 is frequently used as a source to calibrate devices that detect photon radiation; the average photon energy of ^{137}Cs (662 keV) is in the range over which many detectors generally do not underrespond or overrespond. Spectral measurements show that the average photon energy from depleted uranium is approximately 1.0 MeV (Bartlett et. al. 1979), which is also within the true response region for many detectors.

The known exposure rates produced by the sources at specified distances were used to calibrate the TLDs as follows. A group of five dosimeters, each containing three TL chips behind the beta window and three behind the gamma window, was exposed to each radioactive source. The duration of the exposure was calculated so that a known amount of radiation would be delivered to the dosimeters. The TL chips from the dosimeters were then read out, and the readings were averaged for all 15 chips from each dosimeter position. This value was then compared to the delivered exposure value, and the ratio became the calibration factor for that radiation energy.

3.4.2 Micro-R Meter

The portable micro-R meter was calibrated to NBS traceable ^{137}Cs and 830 keV ^{226}Ra (ATTIX, Roesch, Tochilin 1969) sources at the PNL Instrument

Calibrations Laboratory. Cesium-137 was used as the field check source. With the ^{137}Cs check source at contact with the detector housing, the instrument gave a reading of 160 $\mu\text{R/hr}$. Source activity was 0.940 μCi .

3.4.3 Ionization Chambers

Both the cylindrical and rectangular shaped ionization chambers were calibrated to NBS traceable ^{137}Cs sources at the PNL Instrument Calibrations Laboratory.

3.4.4 TASC-4

The TASC-4 system was calibrated to both a 356 keV ^{133}Ba source and a 662 keV ^{137}Cs source for photon energy response. A ^{137}Cs source of known activity was used as a field check source.

4.0 RADIATION MEASUREMENTS MADE ON THE XM829 AMMUNITION

Radiation levels produced by the XM829 ammunition were measured with the ammunition in various stages of assembly and packaging, and in a simulated storage array. The measurements were made at two locations: 1) emissions from the bare penetrator and from two unpackaged projectiles were measured at PNL's Dosimetry Technology Laboratory in Richland, Washington; and 2) emissions from an unpackaged cartridge, a packaged cartridge in a shipping box, and a pallet load of 16 cartridges (each individually packaged and boxed) were made in Building 1089 at the Aberdeen Proving Ground (APG) in Aberdeen, Maryland. At both locations, background measurements were taken to document the response of the detectors to ambient radiation levels.

All of the radiation detection devices discussed in Section 3.0, TLDs, portable exposure rate meters, and the TASC-4 environmental monitoring system, were used to measure the radiation emitted from the XM829 ammunition. Exposure rates that were based on TLD measurements were calculated from the total measured exposure by dividing by the exposure time. All of the other instruments had direct exposure rate-per-time readout capabilities. The TLD data were used to report direct surface measurements of the unpackaged, assembled and unassembled XM829, as well as for the 16 round pallet for the following reasons:

- These dosimeters were able to measure all aspects of the radiation emitted from the ammunition. They are sensitive to both photon and beta radiation, and because of their small size, they could be placed at all measurement locations.
- Because the TLDs could be placed directly on the surfaces of the ammunition and packages, the TLD readings did not have to be corrected for angular dependence, measurements could be taken in a consistent manner at all locations, and the resulting data provided reliable exposure information.
- The calibration of the TLDs was directly traceable to the NBS. Portable instruments were used to measure the shipping package because they are more commonly used for that purpose than are TLDs.

Measurement data were also used to calculate the maximum allowable exposure times for personnel handling the ammunition. A factor that affects the determination of maximum allowable exposure times is the dose limit below which exposures must be maintained. A comparison of the occupational dose limits set by the U.S. Code of Federal Regulations (in 10 CFR 20) and the U.S. Army (in AR 40-14) is given in Table 1. The nonoccupational dose limits set by the Army are one-tenth of the occupational dose limits given in AR 40-14.

TABLE 1. Dose Limits From Federal and Army Regulations

Part of the Body	Quarterly and Annual Occupational Dose Limits	
	AR 40-14	10 CFR 20
Whole Body	(a) 1.25 rems/cal qtr	1.25 rems/cal qtr
	(b) 5 rems/cal yr	5(N-18) rems/cal yr ^(a)
Hands	(a) 18.75 rems/cal qtr	18.75 rems/cal qtr
	(b) 75.0 rems/cal yr	75.0 rems/cal yr
Forearms	(a) 10 rems/cal qtr	18.75 rems/cal qtr
	(b) 30 rems/cal yr	75 rems/cal yr
Skin (other than hands and forearms)	(a) 7.5 rems/cal qtr	7.5 rems/cal qtr
	(b) 30 rems/cal yr	30 rems/cal yr

(a) Where "N" equals the individual's age in years at his last birthday.

Because the dose limits in Ar 40-14 are more restrictive than those in 10 CFR 20, allowable exposure times were calculated based on the dose limits in AR 40-14. Exposure times were calculated for hand, forearm, and whole-body exposures assuming contact with the surface of each configuration of the ammunition. Some exposure times were also calculated for personnel at a distance from the ammunition.

The exposure rates measured and the maximum allowable exposure times determined from the measured rates are discussed in the following sections for a bare DU penetrator and for unpackaged and packaged ammunition.

4.1 BARE PENETRATOR

The locations and results of TLD measurements of a bare DU penetrator are shown in Exhibit 1. Measurements were taken both at the surface of the penetrator and at a distance of 3.3 ft (1 m) parallel to it.

The surface of the penetrator was found to produce exposure rates averaging 243 ± 21.4 mrem/hr. Of this amount, the beta (nonpenetrating) component measured 217 ± 20.4 mrem/hr, and the gamma (penetrating) component measured 26.0 ± 2.7 mR/hr. The open literature shows that natural uranium slabs typically produce beta surface dose rates of approximately 233 mrem/hr through 7 mg/cm^2 of mylar (Radiological Health Handbook 1970). These data indicate that the bare DU penetrator produces dose rates much like those of natural uranium and that the nonpenetrating component is predominant.

The maximum exposure rate reading from eight dosimeters placed 3.3 ft (1 m) from the penetrator was 0.660 mR/hr. At this rate, 757 hours of exposure would be required for an individual to receive the annual nonoccupational whole-body dose limit of 0.5 rem as set by AR 40-14.

4.2 UNPACKAGED AMMUNITION

The unpackaged ammunition, two single projectiles and a single cartridge, yielded measured surface exposure rates that were considerably lower than those of the bare penetrator. A reduction in the exposure rate was to be expected based upon the attenuation of the radiation emitted from the penetrator by components such as the fins, windshield and sabot. TLD surface measurements resulted in exposure rate patterns that were similar for the two projectiles, although the maximum exposure rates were different (18.6 mR/hr and 22.9 mR/hr, respectively; see Exhibit 2). In both cases, the windshield area yielded the highest exposure rates.

The maximum exposure rate determined by a TLD at the surface of the single cartridge (6.3 mR/hr, see Exhibit 3) was also from the windshield area, although the reading was much lower than the projectile readings (see Exhibit 3 for TLD data, Exhibit 4 for Micro-R data, and Exhibit 5 for TASC-4 data). These data indicate that the addition of the ignition-propulsion unit to a projectile results in a significant reduction in the exposure rate at the

windshield area. A review of the measurements taken of the XM774 ammunition indicates a similar difference between the windshield area readings for the projectile and the cartridge (See Section 4.4).

Table 2 shows the maximum surface exposure rates to the hands measured from the unpackaged XM829 ammunition, and the calculated allowable nonoccupational exposure times. These times are based on the limits in AR 40-14 and the maximum exposure rate for each configuration. The annual limits established in AR 40-14 are: 7.5 rem to the hands, 3.0 rem to the forearms and 0.5 rem to the whole body.

TABLE 2. Maximum Surface TLD Results for Exposure to the Hands from Unpackaged XM829 Ammunition

<u>Source</u>	<u>Location</u>	<u>Maximum Exposure Rate, mR/hr</u>	<u>Maximum Allowable Exposure Time, hr</u>
Projectile	Windshield	22.9	327.5
Single Cartridge	Windshield	6.3	1,190.5

The forearm and whole body exposure limits may also be used with the measured maximum surface exposure rates to calculate an allowable exposure time. This calculation is only valid if the rounds are either in contact with the forearms or an area of the whole body such as the chest. One possibility for this configuration would be the cradling of a round when moved by personnel.

Exposure measurements were taken at 3.3 ft (1 m) from the projectiles; 10 TLDs were positioned parallel to each of the two rounds (see Exhibit 2). The maximum 1-m measurement for the two projectiles was 0.095 mR/hr, and the average measurements were 0.080 mR/hr and 0.074 mR/hr, respectively. Based on the maximum value at 1 m, it would require 5263 hours of exposure to reach the AR 40-14 limit for nonoccupational dose to the whole body.

4.3 PACKAGED AMMUNITION

The locations at which radiation measurements were taken on the surfaces of a 16-round pallet are shown in Exhibits 6, 7, and 8 respectively. The

results of these measurements in mR/hr are also shown. Measurements of the single boxed cartridge were made with three portable exposure rate instruments (2 ionization chambers and 1 micro-R meter). Survey points are shown in Exhibit 9 and mR/hr values are shown in Table 3. An analysis of the data indicates that exposure rates at all surfaces of the packaged ammunition do not constitute a significant radiological hazard. The maximum surface exposure rates measured for each configuration are:

- 16-round pallet 0.867 mR/hr
- single boxed cartridge 0.400 mR/hr.

TABLE 3. Portable Instrument Measurements of anXM829 Shipping Container^(a)

Position	SIDES								
	Top			Front			Back		
	A	B	C	A	B	C	A	B	C
1	0.02	0.1	0.1	0.02	0.1	0.1	0.02	0.1	0.1
2	0.03	0.1	0.1	0.03	0.1	0.1	0.02	0.1	0.1
3	0.07	0.1	0.1	0.07	0.1	0.1	0.08	0.1	0.1
4	0.15	0.1	0.1	0.17	0.1	0.1	0.19	0.2	0.2
5	0.22	0.1	0.1	0.26	0.1	0.2	0.30	0.2	0.3
6	0.24	0.1	0.2	0.27	0.2	0.3	0.40	0.3	0.3
7	0.21	0.1	0.2	0.24	0.2	0.2	0.30	0.3	0.3
8	0.13	0.1	0.1	0.14	0.1	0.2	0.18	0.2	0.2
9	0.06	0.1	0.1	0.07	0.1	0.1	0.07	0.1	0.1
10	0.01	0.1	0.1	0.02	0.1	0.1	0.03	0.1	0.1
11	0.03	0.1	0.1	0.03	0.1	0.1	0.04	0.1	0.1
12	0.07	0.1	0.1	0.07	0.1	0.1	0.08	0.1	0.1
13	0.16	0.1	0.1	0.19	0.1	0.2	0.18	0.1	0.2
14	0.29	0.2	0.2	0.30	0.2	0.3	0.40	0.2	0.3
15	0.35	0.2	0.2	0.35	0.2	0.4	0.40	0.2	0.4
16	0.30	0.2	0.2	0.30	0.2	0.3	0.40	0.3	0.3
17	0.13	0.1	0.1	0.15	0.1	0.2	0.20	0.2	0.2
18	0.06	0.1	0.1	0.07	0.1	0.2	0.07	0.1	0.1
19	0.02	0.1	0.1	0.02	0.1	0.1	0.03	0.1	0.1
20	0.03	0.1	0.1	0.04	0.1	0.1	0.04	0.1	0.1
21	0.07	0.1	0.1	0.08	0.1	0.1	0.08	0.2	0.1
22	0.15	0.1	0.1	0.17	0.1	0.1	0.17	0.2	0.2
23	0.23	0.2	0.2	0.26	0.1	0.2	0.29	0.2	0.3

Distance Measurements (maximum)
 1 foot 3 feet
 0.09 0.03

A. Micro-R
 B. Cylindrical Ion Chamber
 C. Rectangular Ion Chamber

(a) All values in mR/hr.

TABLE 3. (contd)

SIDES (contd)									
Position	Top			Front			Back		
	A	B	C	A	B	C	A	B	C
24	0.25	0.2	0.2	0.28	0.1	0.2	0.29	0.2	0.3
25	0.22	0.1	0.1	0.24	0.1	0.2	0.30	0.2	0.3
26	0.14	0.1	0.1	0.14	0.1	0.2	0.15	0.1	0.2
27	0.06	0.1	0.1	0.07	0.1	0.1	0.07	0.1	0.1

ENDS						
	Front			Back		
	A	B	C	A	B	C
28	0.04	0.1	0.1	0.01	0.1	0.1
29	0.05	0.1	0.1	0.01	0.1	0.1
30	0.04	0.1	0.1	0.01	0.1	0.1
31	0.04	0.1	0.1	0.01	0.1	0.1
32	0.05	0.1	0.1	0.01	0.1	0.1
33	0.04	0.1	0.1	0.02	0.1	0.1
34	0.04	0.1	0.1	0.02	0.1	0.1
35	0.04	0.1	0.1	0.02	0.1	0.1
36	0.04	0.1	0.1	0.02	0.1	0.1

Distance Measurements (maximum)

1 foot	3 feet
0.09	0.03

- A. Micro-R
 B. Cylindrical Ion Chamber
 C. Rectangular Ion Chamber

(a) All values in mR/hr.

Table 4 lists, for each package configuration, the amount of accrued exposure time that would result in the annual nonoccupational dose limit listed in AR 40-14 for the hands using the maximum measured exposure rates for the packaged XM829 ammunition.

In addition to the determination of surface exposure rates, distance exposure measurements were taken by placing TLDs at 18 in. (45.7 cm), 36 in. (91.4 cm), and 72 in. (182.9 cm) from one side and one end of the 16-round pallet. Table 5 is a listing of the maximum exposure rates determined and the allowable nonoccupational time limits at these distances for whole body exposure.

TABLE 4. Maximum Surface Exposure Rates and Allowable Exposure Times to the Hands from Packaged XM829 Ammunition

<u>Source</u>	<u>Maximum Exposure Rate, mR/hr</u>	<u>Maximum Allowable Exposure Time, hr</u>
Single Boxed Cartridge	0.400	18,750
16-Round Pallet	0.867	8,651

TABLE 5. Maximum TLD Results at Distances From Pallet

<u>Source</u>	<u>Distance, in.</u>	<u>Maximum Exposure Rate, mR/hr</u>	<u>Annual Nonoccupational Whole Body Limit, rem^(a)</u>	<u>Maximum Allowable Exposure Time, hr</u>
16-Round Pallet (Side)	18	0.267	0.5	1,872
	36	0.089	0.5	5,618
	72	0.022	0.5	22,727
16-Round Pallet (End)	18	0.200	0.5	2,500
	36	0.044	0.5	11,363
	72	0.044	0.5	11,363

(a) From Ar 40-14.

4.4 COMPARATIVE MEASUREMENTS OF XM829 AND XM774 AMMUNITIONS

The radiation measurement data taken from the XM829 and the XM774 (Bartlett et. al., 1979) ammunitions were compared. Many more data points were available from the packaged (boxed) portion of the XM829 study than from the XM774 study, both for single boxed cartridges and for multi-round pallet configurations. The numbers of measurement points for unpackaged ammunition were more closely equated. A comparison of the data for the two types of ammunition is shown in Table 6.

The maximum exposure rates measured in the windshield area of the unpackaged cartridges and the single packaged cartridges are similar. In contrast, there is a large difference in the windshield area measurements of the

TABLE 6. Comparison of Radiation Measurements of XM829 and XM774 Ammunition

Source	Position	Maximum Exposure Rate, mR/hr ^(a)	
		XM829	XM774 ^(b)
Bare Penetrator	(Maximum)	272 mrem/hr	247 mrem/hr
	(Average)	243 ± 21.4 mrem/hr (includes 26 mR/hr)	214 ± 17.0 mrem/hr (gamma component not available)
Single Projectile (Unpackaged)	Windshield	22.9	59.5
Single Cartridge (Unpackaged)	Windshield	6.3	5.358
Single Cartridge (Packaged)	Top	0.350	0.29
	Side	0.400	0.4
	End	0.045	0.02
Pallet (Packaged)	Top	0.867	0.229
	Side	0.800	0.583
	End	0.378	0.145

(a) Units in mR/hr except where noted.

(b) Data source: Bartlett et. al. 1979.

unpackaged single projectiles, without the ignition-propulsion system attached. The exposure rates from the XM829 ammunition are considerably lower than those from the XM774 ammunition for the unpackaged projectiles. This is the result of the full encasement of the DU penetrator on the XM829; the XM774 did not have a fully encased penetrator. The increased exposure rates from the XM829 pallet reflect the increased amount of DU material in that round as compared to the XM774.

5.0 EVALUATION OF RADIOLOGICAL HAZARD FROM MEASURED EMISSIONS

The PNL study provided information that can be used to evaluate the radiological hazard to personnel handling the XM829 ammunition and to determine whether federal and Army regulations are complied with in the handling and shipping of the ammunition. Both 10 CFR 20 and AR 40-14 (which is also designated regulation DLAR 1000.28 of the Defense Logistics Agency) prescribe permissible dose levels and concentration standards. The standards in 10 CFR 20 apply to Nuclear Regulatory Commission licensees. The standards in AR 40-14 implement the guidelines in 10 CFR 20 and regulate the exposure of personnel (military and civilian, federal and nonfederal) to ionizing radiation at installations of the Department of the Army or the Defense Logistics Agency. As previously discussed, the occupational and nonoccupational dose limits set in AR 40-14 are more restrictive than those in 10 CFR 20. The shipping of radioactive materials is regulated by 49 CFR 171-179 (especially Parts 173.401-173.478).

5.1 EXPOSURE OF PERSONNEL TO RADIATION FROM XM829 AMMUNITION

The maximum exposure rates shown in Section 4.0 were based on actual measurements, and were calculated from total measured dose per unit time. Several factors affect how these exposure rates relate to personnel working with the ammunition:

- the low probability of personnel being exposed to the DU material in each measurement array
- the low probability of personnel remaining for a significant time near the localized areas at which the maximum exposure rates were measured
- the low probability of personnel receiving whole-body exposures, for which dose limits are the most restrictive.

Considering these factors, and considering that the dose limits used to determine maximum allowable exposure times were the most restrictive (the guidelines in AR 40-14 for nonoccupational exposures allow only one-tenth of the permissible occupational exposures), the assumptions used in this study to assess the radiation hazard to personnel handling the XM829 ammunition could be said to represent worst-case situations. Therefore, no significant problem

is anticipated in maintaining exposure to personnel at levels below those spelled out in AR 40-14, and in complying with the philosophy of reducing and maintaining exposures to as low as reasonably achievable.

5.2 REMOVABLE CONTAMINATION

During the study of the XM829 ammunition, a bare DU penetrator was handled in the laboratory. Cotton gloves were worn and were surveyed for possible loose contamination from the penetrator. (Cotton gloves used in handling potentially contaminated material can be very effective as a "smear" or "swipe" medium.) No contamination was detected. Further, personnel working with the XM829 ammunition in all phases of this study were monitored for possible contamination. No contamination was detected throughout the project. Nevertheless, personnel handling bare DU penetrators should wear cotton or leather gloves and perform periodic personal surveys as a precautionary measure.

5.3 SHIPPING XM829 AMMUNITION

Army regulation AR 40-14 refers to 49 CFR 171-179 (Department of Transportation (DOT), "Hazardous Materials Regulations") as the criteria for shipping radioactive materials. Requirements for the packaging and transport of such materials are given in 49 CFR 171-179 (DOT requirements).

Revisions to requirements of Hazardous Materials Regulations concerning radioactive materials became effective July 1, 1983. A review of the data collected from this study, in light of these revisions, indicates that the XM829 shipping package should be transported under the specifications listed in 49 CFR 173.424, "Excepted Articles Containing Natural Uranium or Thorium." These specifications are:

"Manufactured articles in which the sole radioactive material content is natural or depleted uranium or natural thorium are excepted from the specification packaging, marking and labeling requirements of this subchapter and requirements of this subpart if --

- (a) The outer surface of the uranium or thorium is enclosed in an inactive sheath made of metal or other protective material; and

(b) The conditions specified in 173.421 (b), (c), and (d) are met."

The conditions specified in 49 CFR 173.421 are as follows:

"(b) The radiation level at any point on an external surface of the package does not exceed 0.5 millirem per hour.

(c) The nonfixed (removable) radioactive surface contamination on the external surface of the package does not exceed the limits specified in 173.443(a)." Which are:

- (1) for beta-gamma emitting radionuclides; all radionuclides with half-lives less than 10 days; natural uranium; natural thorium; uranium-235; uranium-238; thorium-232; thorium-228; and thorium-230 when contained in ores or physical concentrates; the maximum permissible limits are 10^{-5} $\mu\text{Ci}/\text{cm}^2$ or 22 dpm/cm², and
- (2) for all other alpha emitting radionuclides the maximum permissible limits are 10^{-6} $\mu\text{Ci}/\text{cm}^2$ or 2.2 dpm/cm² when averaged over a surface area of 300 square centimeters.

"(d) The outside of the inner packaging or if there is no inner packaging, the outside of the packaging itself bears the marking "Radioactive."

The depleted uranium penetrator employed in the XM829 cartridge is fully enclosed within an inactive metal sheath. The maximum radiation level obtained at any point on the external surface of the shipping package from the study was 0.4 millirem per hour. No removable contamination was detected from "swipes" taken of the penetrator and component parts throughout the study. Based upon these factors, all criteria listed in 49 CFR 173.424 and 49 CFR 173.421 (b), (c), and (d) are satisfied by the XM829 shipping package, providing that the word "Radioactive" is stenciled on the inner or outer container.

5.4 STORAGE OF XM829 AMMUNITION

Radiation measurements were taken of a 16-round XM829 pallet array simulating a storage configuration. A typical storage array may consist of several pallets; however, reasonable conclusions may be drawn, concerning exposure rates at other points of interest, by using the single pallet measurement data.

Due to the physical dimensions of the pallet array, only a limited number of additional pallets may be positioned closely enough to contribute significantly to the exposure rate at any one position. For example, if pallets were divided along each perimeter by a 3-ft wide aisle, the radiation measurement at the center point in the aisle would largely reflect the contribution from only two pallets. If pallets along each side of the aisle were stored end to end, thus forming a solid wall along each side, it is conceivable that four pallets may contribute equally to the exposure rate at some central point among them.

Based upon this study, the maximum radiation measurement at 18 inches from the pallet was 0.340 mR/hr. From this information it can be assumed that a person standing 18 inches equidistant from 4 pallets would be exposed to approximately 1.4 mR/hr. At this rate, it would require 357 hours of exposure to receive the maximum allowable nonoccupational whole-body dose of 500 mrem, as specified in AR 40-14.

6.0 CONCLUSIONS

The predominant radiations emitted from the assembled XM829 cartridge were shown to be photons with a family of energies. The most prominent energy peaks were noted in the 100 keV to 200 keV range; however, these photon energies are largely attenuated by the shipping/storage package materials. Therefore, energy peaks at approximately 775 keV and 1000 keV, respectively, remain as the most prominent photons reaching the exterior surfaces of the shipping/storage container.

The PNL studies indicate that the radiation levels associated with the assembled XM829 ammunition, both packaged and unpackaged, are very low. A worker would have to be exposed to packaged ammunition for at least 577 hr in order to receive the most restrictive annual, nonoccupational dose permitted by AR 40-14. This exposure time is for the top of a 16-round pallet and assumes direct whole-body contact with the surface of the pallet at the point where the maximum exposure rate was measured. The minimum time for receiving the annual allowable doses to the forearm and hand would be 3460 hr and 8651 hr, respectively. Therefore, it may be concluded that under normal conditions, handling of the XM829 ammunition does not present a significant radiological hazard.

Use of the basic dose reduction techniques of time, distance, and shielding, could further reduce the potential for personnel exposures to radiation from the XM829 ammunition.

The XM829 shipping package studies satisfied all of the criteria specified in 49 CFR 173.421 and 173.424. Therefore, the package should be excepted from the specification packaging, marking, and labeling requirements of 49 CFR 173, provided that the inner or outer shipping package contains the marking "Radioactive."

Measured exposure rates from a 16-round pallet never exceeded 1.0 mR/hr at any surface point and all measurements were less than 0.2 mR/hr at a distance of 3 feet from the pallet. These values show that the storage of XM829 ammunition, even in a several pallet array, does not present a significant exposure hazard to personnel working in the storage area.

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8.0 EXHIBITS 1 THROUGH 9

EX.1

EXHIBIT 1. TLD Measurements (mrem/hr) of Bare Penetrator

EX.2

EXHIBIT 2. TLD Measurements (mR/hr) of Two individual Projectiles

EX.3

EXHIBIT 3. TLD Measurements (mR/hr) of Unpackaged Cartridge

EX.4

EXHIBIT 4. Micro-R Measurements (mR/hr) of Unpackaged Cartridge

EX.5

EXHIBIT 5. TASC-4 Measurements (mR/hr) of Unpackaged Cartridge

EX.6

EXHIBIT 6. TLD Measurements (mR/hr) of 16-Round Pallet

EX. 7

EXHIBIT 7. Micro-R Measurements (mR/hr) of 16-Round Pallet

EX. 8

EXHIBIT 8. TASC-4 Measurements (mR/hr) of 16-Round Pallet

EXHIBIT 9. Portable Instrument Measurement Points on Shipping Container

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