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Nondestructive Evaluation of M732 Proximity Fuzes

Ronald G. Johnson and Roald R. Schrack

U.S. DEPARTMENT OF COMMERCE
National Bureau of Standards
Gaithersburg, MD 20899

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Final Report

Prepared for:
Harry Diamond Laboratories
2800 Powder Mill Road
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U.S. DEPARTMENT OF COMMERCE, Malcolm Baldrige, *Secretary*
NATIONAL BUREAU OF STANDARDS, Ernest Ambler, *Director*

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1. Introduction

Under contract with Harry Diamond Laboratories (HDL) the Neutron Measurements and Research Group of the National Bureau of Standards has undertaken a program of nondestructive evaluation (NDE) of M732 proximity fuzes for leaking power supplies. There are three main tasks in this program:

(a) Demonstrate the technical feasibility of using neutron resonance transmission analysis (NRTA) to nondestructively evaluate M732 fuzes for leaking power supplies.

(b) Survey currently available equipment and techniques to determine practical and financial feasibility of sorting the stockpile (of M732 fuzes) using NRTA.

(c) Determine the feasibility of using x-ray fluorescence to nondestructively evaluate M732 fuzes for leaking power supplies.

In this report the results of our studies covering these three tasks are presented. It will be shown that NRTA is a viable method for NDE of M732 fuzes while x-ray fluorescence has some severe limitations. The equipment for NRTA is currently available and could be developed for practical evaluation of the M732 fuze stockpile.

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The M732 power supply is a lead-acid battery with the acid contained in a copper ampule. Upon firing, the copper ampule is punctured releasing the acid to the lead plates thus activating the power supply. A diagram of the power supply, with sufficient detail for this study, is shown in figure 1. In addition to acid the ampule contains methylene bromide as a buffering agent. Failure of these power supplies occurred when holes were etched in the copper ampule releasing the acid prematurely. An evaluation of whether one of these power supplies has failed can be done by detecting the presence of acid or methylene bromide in the volume occupied by the lead plates.

The neutron transmission technique relies on the fact that each element, in fact each isotope, has a unique cross section for neutrons. NRTA has previously been shown to be an effective NDE technique for fresh and spent nuclear fuel,[1] silver brazing,[2] etc. In this application bromine in particular has a favorable resonance structure with a strong resonance at 35.8 eV. A neutron beam passing only through the volume occupied by the lead plates will be preferentially absorbed at 35.8 eV if bromine is present in that volume. The energy of the neutrons is obtained by the neutron time-of-flight technique.

For x-ray fluorescence each element may be identified by its characteristic x rays. Again bromine is favorable because its characteristic K_α line is at 12 keV which is at sufficiently high energy so that a significant fraction can at least penetrate the plastic case.

2. Technical Design for NRTA

The NBS 150-MeV electron linear accelerator (linac) was used as the source of neutrons for this study. Neutrons are produced by the photoneutron reaction in a water-cooled tungsten target where the photons are produced by

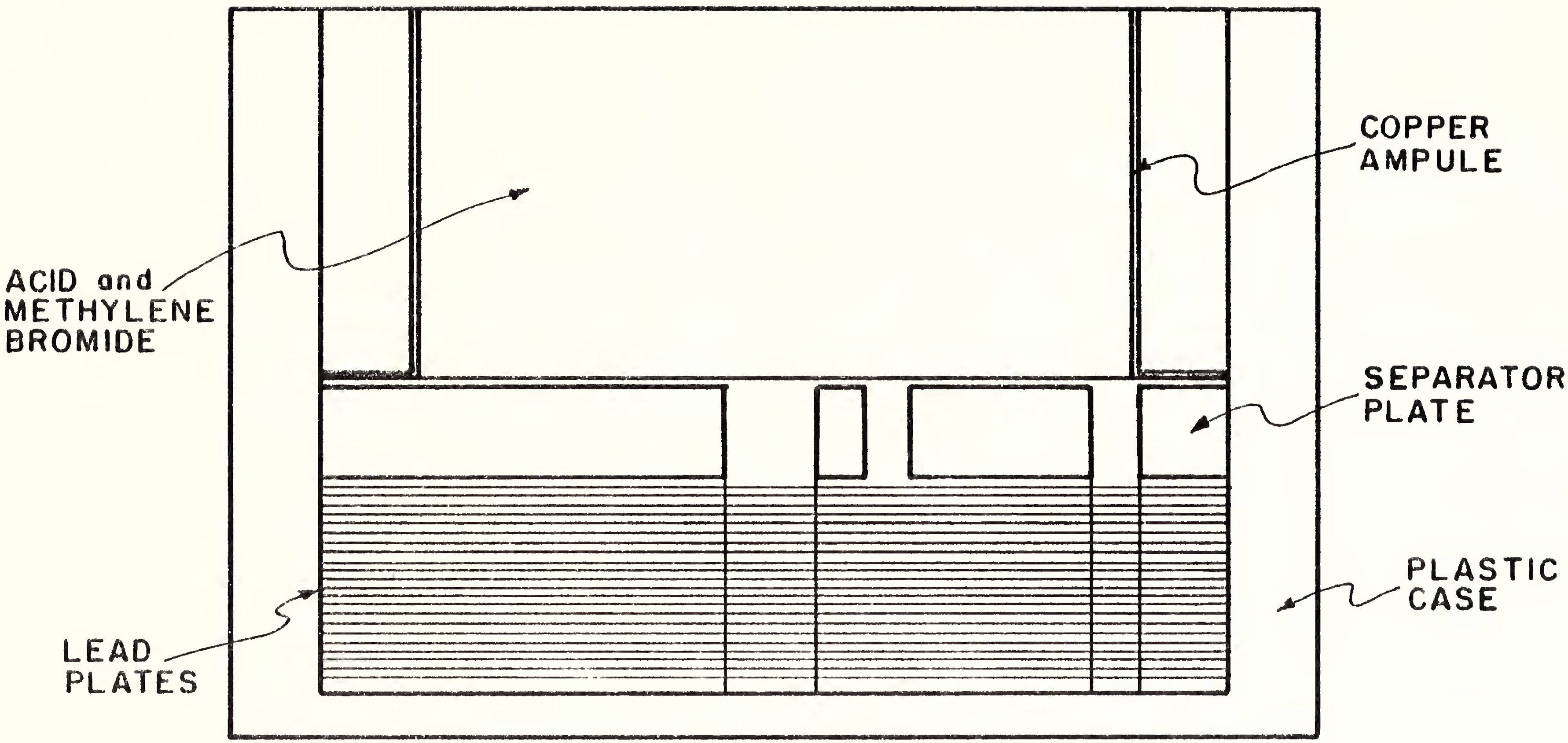

Figure 1. M732 proximity fuze power supply. (Scale ≃ 4:1.)
Full details of the supply are not shown.

bremsstrahlung radiation from electrons incident on the target. The neutrons are moderated by a 2.5-cm thick polyethylene moderator to increase the flux of low-energy neutrons. The electron beam is pulsed at a rate of 720 Hz with a pulse width of ~ 50 ns.

An M732 fuze was placed 5.4 m from the source and the neutron beam was collimated to an area 3.2-cm wide by 0.7-cm high which illuminated only the lead plates of the power supply. Transmitted neutrons were detected at 6.7 m by a ^{6}Li-glass scintillator detector (4.4-cm diameter and 2.5-cm thick). This detector is nearly 100% efficient for neutrons at 35.8 eV. A diagram of the apparatus is shown in figure 2.

It was expected that it would be necessary to determine the presence of methylene bromide vapor. The volume which contains the lead plates is 3.2-cm in diameter and 0.7-cm thick. Assuming a vapor pressure of 34.7 mmHg at 20°C, the areal density (n) of bromine is 6.2×10^{-6} nuclei/b (Note: 1 b(arn) = 10^{-24} cm^2). The peak cross section at 35.8 eV for natural bromine is 2000 b. Consequently, the neutron absorption given by (1-T) would be 1.2%, where $T = e^{-n\sigma}$ is the neutron transmission. To obtain 10% statistical precision for such a transmission dip would require ~ 10^6 counts. The expected flux for a 0.5-eV channel at 35.8 eV for 3.5-kW average power on target is 30 neutrons/s. However, the transmission of the structural materials of the fuze is expected to be only ~ 10%. Consequently, count rates of approximately 3 counts/s are expected. To obtain the estimated statistical precision needed would require runs of about 10 hours.

The data collection system for this measurement is the general purpose system used for time-of-flight measurements at the linac. It is based on standard NIM* modules to process signals from the detector, a time-interval meter to measure the neutron time-of-flight, and a CAMAC**-computer system to record the data. The system was set up to take 1024 time channels of 0.512-μs width.

*NIM (Nuclear Instrument Module)

**CAMAC (Computer Automated Measurement and Control)

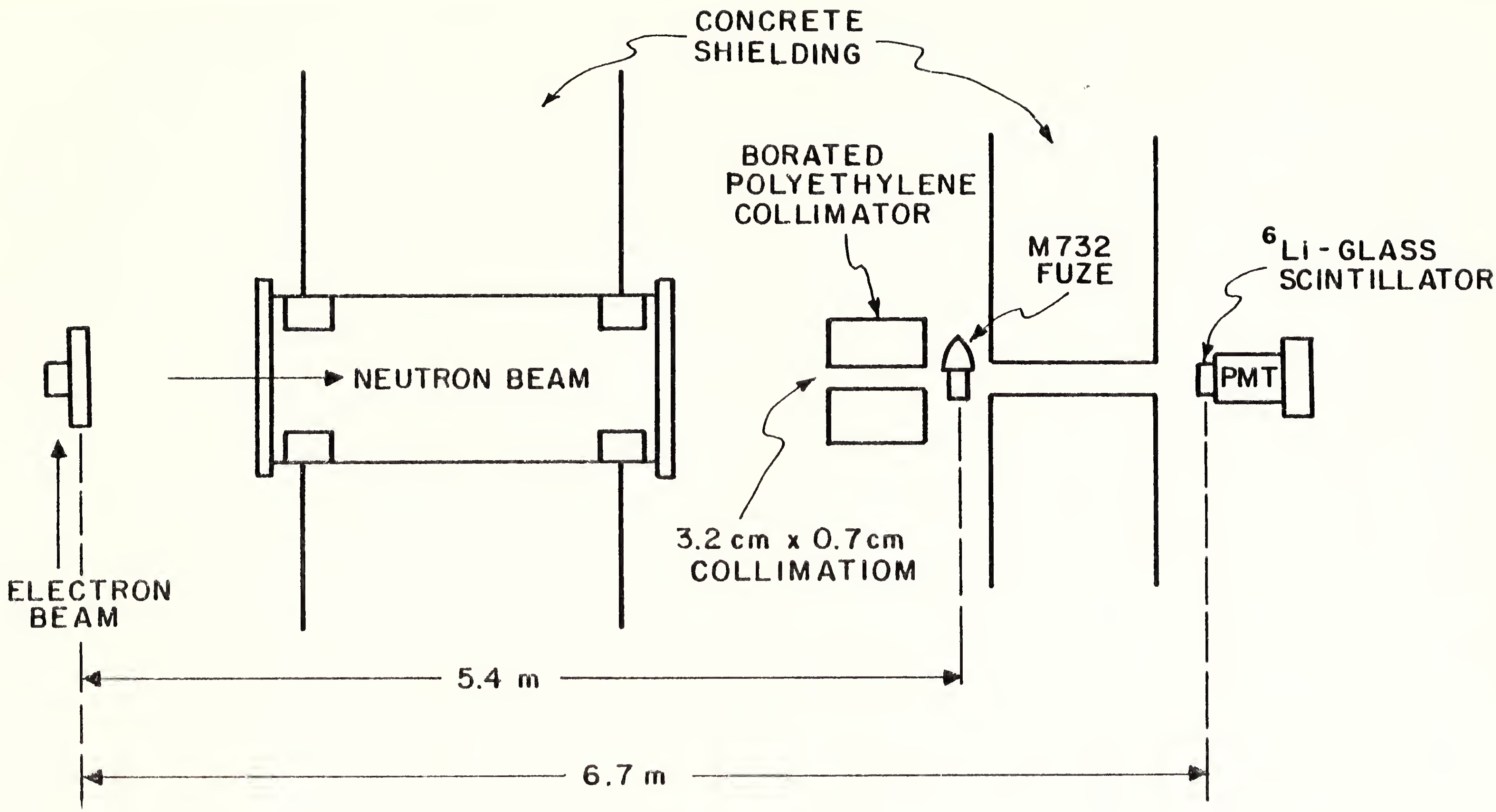

Figure 2. Experimental set up for NRTA on M732 proximity fuzes. (Not to scale.)

3. Results for Power Supplies of Known Status

For the first series of measurements HDL provided power supplies which were known to be good or bad (3 of each) and a M732 fuze body. Each supply was placed in the fuze (upper part only) and positioned in the neutron beam. The mechanical arrangement was slightly different than that shown above. The flight path was 5.5 m.

We started with a known bad supply and it was apparent within minutes that a strong 35.8-eV transmission dip was present. In figure 3 typical results for a good and a bad supply are shown. Because the overall transmission of the fuze is low, the background in these measurements is high, ~ 60%. Subtracting this background the transmission at 35.8 eV is 0.5 which implies a bromine density of 2.7×10^{-4} nuclei/b. This is nearly 50 times the expected amount for methylene bromide vapor. The conclusion is that methylene bromide is being concentrated in the area of the lead plates by some mechanism.

On a suggestion by Dr. J. Nelson of HDL we took apart one of the bad supplies and made separate runs on the plastic case and the lead plates. Nearly all the bromine signal was from the plastic case indicating that the methylene bromide is attacking the plastic and being concentrated there. Further evidence for this effect is the swelling of the plastic case in fuzes with leaking power supplies.

In table 1 the results of this series of runs are summarized. All the known good supplies have transmissions within one or two standard deviations of unity at 35.8 eV while the known bad supplies have transmissions of about 0.5. The measurement times for these runs ranged from 1 to 10 hours but a 5%

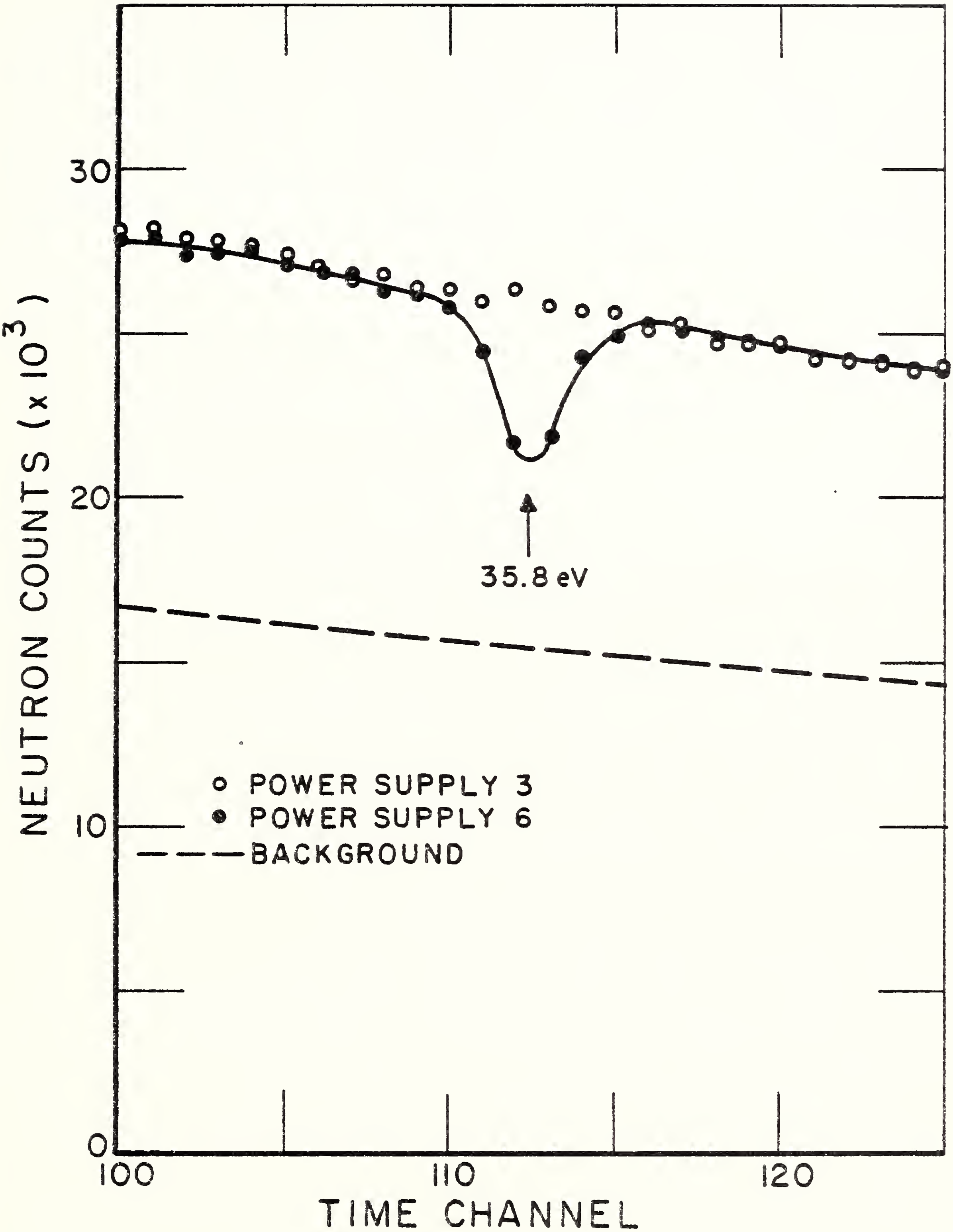

Figure 3. Typical experimental results for NRTA on leaking and non-leaking power supplies. The transmission dip at 35.8 eV is due to bromine.

TABLE 1. Summary of results for power supplies of known status

	Power Supply (Lot number)	Status	Transmission at 35.8 eV	Areal Density of Br (nuclei/b)x10^{-4}
1	(ACC342)	NL[(a)]	0.989±0.007	~ 0
2	(ACC342)	NL	1.008±0.009	~ 0
3	(UCR047)	NL	0.982±0.008	~ 0
4	(ACC002)	L[(b)]	0.584±0.029	2.7
5	(ACC002)	L	0.657±0.013	2.1
6	(ACC019)	L	0.505±0.016	3.4
6a	Plastic case from (6)		0.380±0.005	4.8
6b	Lead plates from (6)		0.953±0.006	0.24

a) NL - non-leaker

b) L - leaker

statistical uncertainty in the transmission can be obtained in about 10 minutes. The experimental results should not be used to predict the absolute amount of methylene bromide, since it is not uniformly distributed over the exposed area. The results of the nonuniformity are clearly seen, since the sum of items (6a) and (6b) are nearly 50% larger than the result for item (6). To accurately determine the absolute density would require a measurement of transmission as a function of position.

4. Results for Power Supplies of Unknown Status

Following the successful experiments using known good and bad power supplies, we received four cases (32 fuzes) of M732 fuzes from HDL for testing. (Detonator explosives had been removed from the fuzes.) The status of the power supplies in these fuzes was unknown.

The experimental equipment was set up as shown in figure 2. This redesign of the experiment with better shielding of the detector reduced the background by more than a factor of two. However, for these runs the fuzes were not disassembled and consequently the neutrons had to penetrate an additional ~1.0 cm of steel. The actual improvement in the background was from 60% to 38%.

Two series of runs were performed on these fuzes separated by 26 days. Between the two series of runs (16 days before the second series) all the fuzes were baked at 65°C for 65.5 hr. In the first series of runs, 21 of the 32 fuzes were tested but in the second series all fuzes were tested. Measurement times per fuze were approximately 1.0 hr in the first series and 2.0 hr in the second series (with a few 8.0-hr overnight runs). Consequently, the statistical precision on the transmission for the two series was 2.6% and 1.8%, respectively. After completion of the measurements at NBS the fuzes were returned to HDL where they were disassembled and tested for leaking power supplies.

The results of these tests are summarized in table 2. In the status columns the experimental results are interpreted in terms of good or bad. However, a detailed examination of the neutron transmission data reveals two classes reported as bad power supplies. In one case large transmission dips are seen (<0.7) and in the other case moderate transmission dips (>0.9) are seen. Typical results for these two cases and for a good power supply are shown in figure 4.

Comparison of the NBS and HDL results reveals several problems. The first problem is that those fuzes with moderate transmission dips (B3, B4, and C1) identified as bad are, in fact, not bad. This misidentification is probably caused by absorption of methylene bromide from the badly leaking power supplies in the same cases (i.e., B1 and C2). Some evidence for this conclusion is the fact that the transmission is nearly the same before and after baking for these misidentified fuzes. One could probably eliminate this misidentification by setting a lower limit on the transmission. However, more experimental measurements would be required to determine exactly where to set this limit. For these runs a transmission limit of 0.85 would eliminate these misidentifications.

The second problem is that fuzes A5, B2, and D6 were found to have leaking power supplies by HDL but there is no evidence for that in the NBS measurements. However, Dr. J. Nelson found that these supplies only started to leak recently and concluded that they were forced to the leaking stage by the bakeout at NBS. Consequently, the methylene bromide probably had not had time to absorb into the plastic case. Again, further experimental tests would be required to determine how long one should wait after baking before doing neutron transmission tests.

TABLE 2. Summary of results for M732 fuze power supplies of unknown status.

Fuze Number	Transmission Before Bake Out	Transmission After Bake Out	Status NBS	Status HDL
25 A1	0.992	1.011		
A2	0.998	1.004		
A3	0.991	0.991		
A4	1.020	1.005		
A5	1.002	1.012		L
A6	0.830	0.695	L	L
A7	--	0.997		
A8	--	0.987		
25 B1	0.588	0.307	L	L
B2	1.001	0.982		L
B3	0.902	0.925	L	
B4	0.973	0.961	L	
B5	0.988	0.990		
B6	--	0.982		
B7	--	0.998		
B8	--	0.995		
25 C1	0.899	0.901	L	
C2	0.936	0.383	L	L
C3	0.989	0.990		
C4	1.008	0.991		
C5	1.008	0.994		
C6	--	0.994		
C7	--	0.990		
C8	--	1.001		
25 D1	0.968	0.994		
D2	1.001	0.994		
D3	1.007	1.018		
D4	1.002	1.000		
D5	0.982	0.993		
D6	--	0.995		L
D7	--	1.010		
D8	--	0.995		

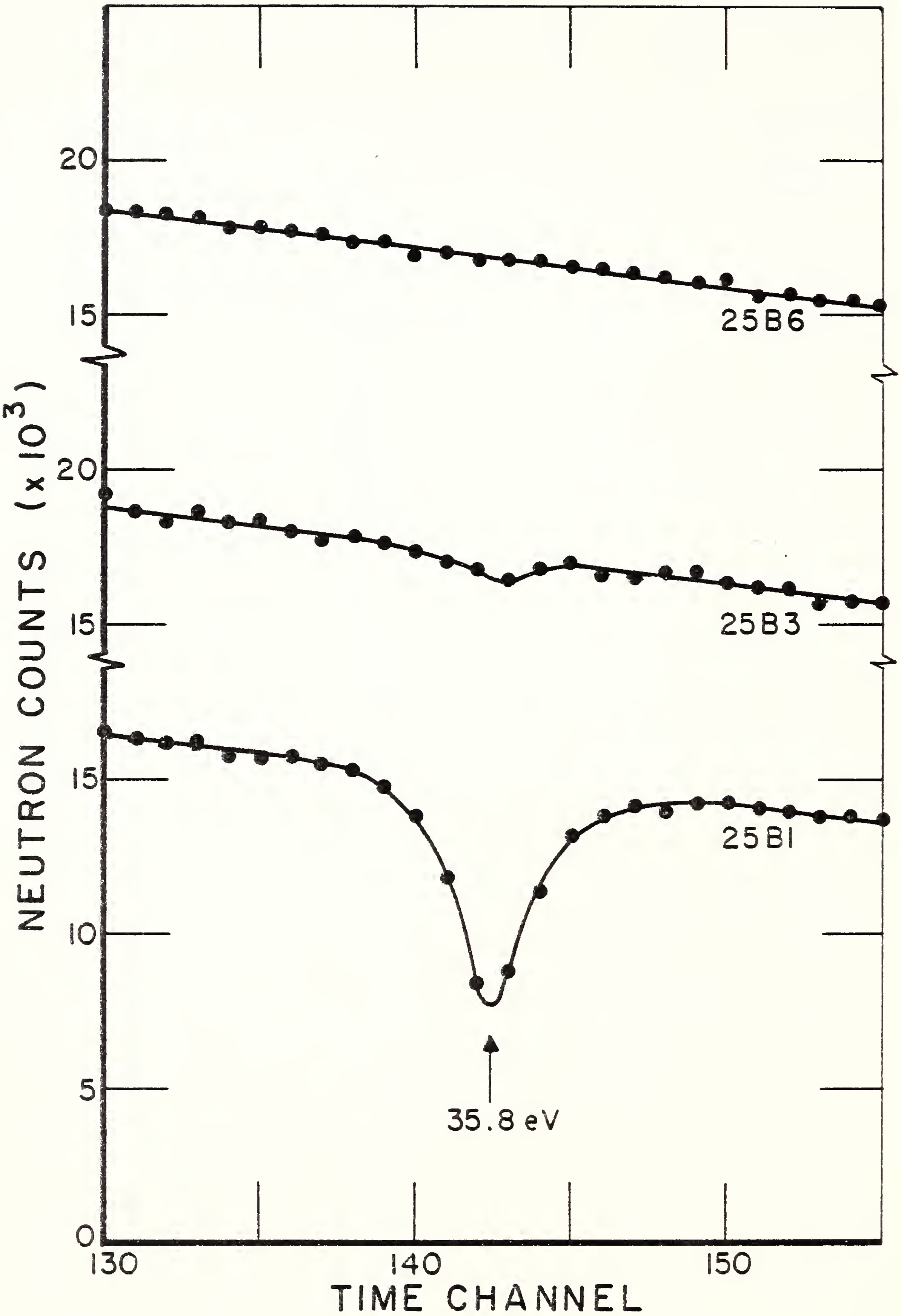

Figure 4. Typical results for NRTA on M732 proximity fuze of unknown status. See text and table 2 for the s[illegible]us of these fuzes.

Assuming the proposed solutions to the problems described above are viable, which seems quite likely, NRTA appears to be a technically feasible method to nondestructively evaluate M732 fuzes.

5. Portable Electron Linac for NRTA

At NBS the 150-MeV electron linear accelerator (linac) operating at a power level of 3.5 kW was used as a source of neutrons. There are several similar linacs in the United States (Oak Ridge National Laboratory and Lawrence Livermore National Laboratory) suitable for this application. Accelerators which use proton spallation to produce neutrons are at Los Alamos National Laboratory and at Argonne National Laboratory. Outside the U.S. suitable pulsed-neutron sources exist in Belgium, England, and Japan. All of the sources listed typically provide 4 to 10 times the neutron production of the NBS linac.

However, a portable linac which provides nearly the source strength of the NBS linac would be more convenient for the purpose of examining a large number of fuzes at their place of storage. It has been pointed out by Bowman[3] that a low energy accelerator with a low atomic number neutron production target can be as efficient as a high energy (high atomic number target) linac.

Electron linear accelerators generally can produce an acceleration of about 5 MeV per meter. A portable linac of about 10 MeV would then easily fit inside a truck trailer body. Such a device was, in fact, built about twenty years ago and just recently declared surplus. This device could be rebuilt but it would be better to take advantage of new technology and start from scratch.

We propose a portable linac having a total average power of 10 kilowatts and an electron beam energy of 10 MeV. The electron beam should be pulsed, having a repetition rate of 1000 Hz and a pulse length $\leq$ 0.5 μs. The target should be beryllium deuteride. We have discussed the availability of such a machine with a number of vendors and consultants. The cost of such a machine would be 1.0 to 1.5 million dollars and the delivery time would be about 12 months. In addition to the linac itself, the complete analysis system would require detectors and data analysis equipment as well as a mechanical system to handle the fuzes. This additional equipment and the associated development would add about $300,000 to the cost.

The proposed portable linac would have from 1 to 3 times the neutron production as that used in the measurements described above. Assuming that a statistical precision of ~ 5% is needed for the transmission measurements, the required exposure time per fuze is 5-15 minutes. However, many fuzes can be tested at the same time, easily twenty. This reduces the effective time per fuze to 15-45 seconds. A conceptual design of how such a measurement system might look is shown in figure 5.

Because of the radiation field associated with the linac, there would have to be some shielding placed around the system. This could be made of concrete and not necessarily transported with the linac.

6. Nondestructive Evaluation by X-Ray Fluorescence

As an alternate to the nuclear technique, NRTA, an atomic physics technique, x-ray fluorescence, was investigated for possible application to nondestructive evaluation of M732 fuzes. In this technique the characteristic K_α x-ray (11.9 keV) lines in bromine would be excited by the continuous

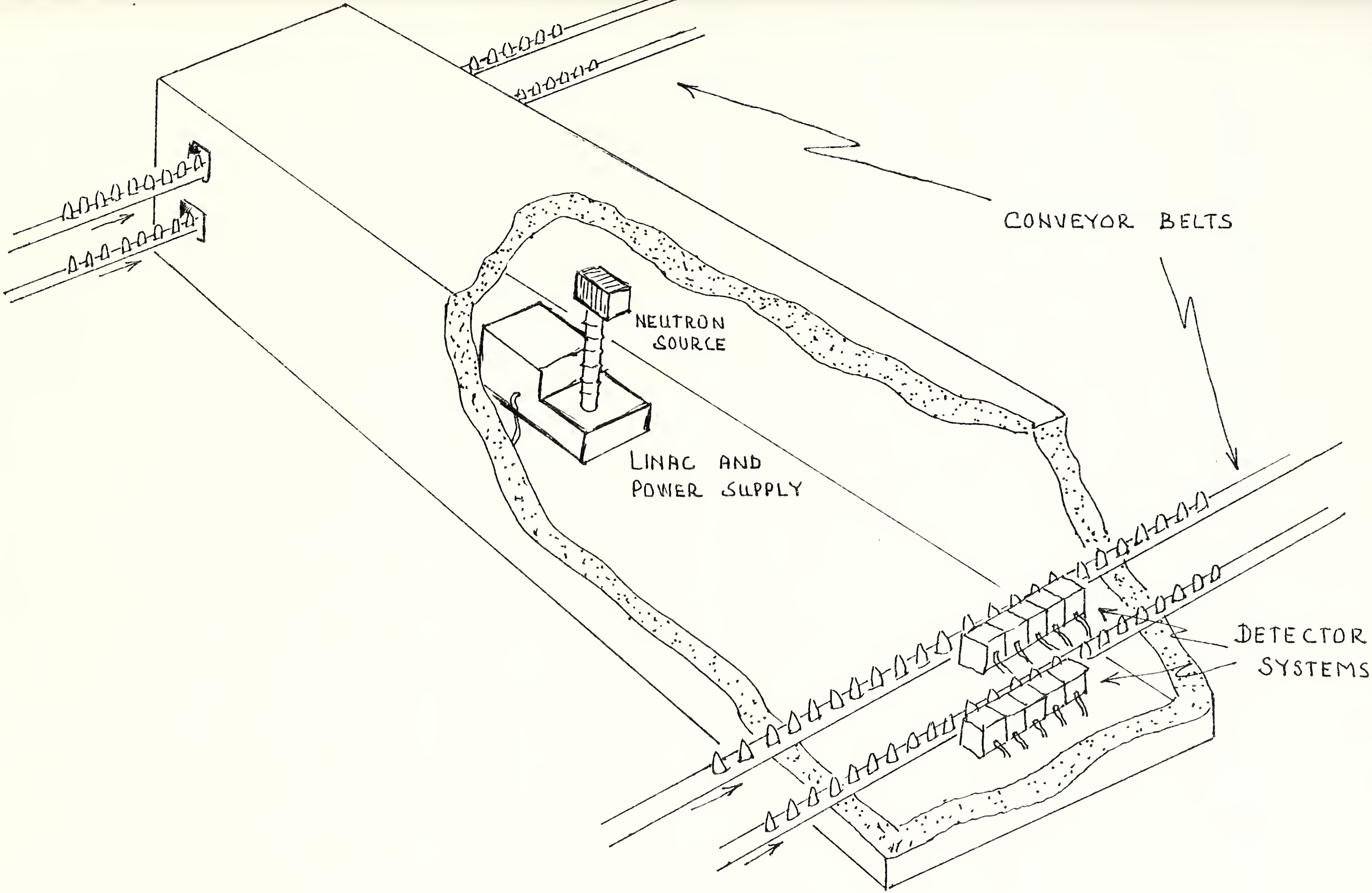

Figure 5. Conceptual design of a portable linac with detector and handling systems for NRTA on M732 proximity fuzes.

spectrum from an x-ray generator. Photoelectric cross sections are quite large, > 10^4 b/atom, and x-ray production is also large so that measurement times can be short, on the order of a few seconds in principle.

However, there are two major problems in this technique. The first problem is that a few millimeters of steel are essentially opaque to 12-keV x rays; so that each fuze would have to be disassembled to expose the bottom of the battery case. Transmission of the 1.5-mm thick plastic case is 80% for 12-keV x rays.

The second problem is that lead has many L x-ray lines in this same energy region which would dominate the x-ray spectrum. One would be required to subtract the contribution by the lead plates. This procedure extends the measurement time and increases the uncertainty in the results.

Because of these problems it was decided not to proceed with experimental tests of this technique.

7. Conclusions

The three tasks in this program of nondestructive evaluation for M732 proximity fuzes have been successfully completed. Neutron resonance transmission analysis has been shown to be better than expected as a NDE technique for testing these fuzes for leaking power supplies. It was discovered that methylene bromide was being absorbed by the plastic case of the power supply, increasing the signal for NRTA by a factor of ~ 50. In a test of the method using M732 fuzes of unknown status, both false positive and false negative results were seen. Methods to eliminate both of these false results were proposed but perhaps need to be further tested experimentally.

To implement NRTA for screening the M732 fuze stockpile, a portable linac was proposed. This device could be placed in a semi-trailer and moved to the storage locations. M732 fuzes could be examined at an effective rate of 15-45 seconds per fuze. The cost of the linac and associated experimental equipment was estimated to be 1.3 to 1.8 million dollars.

Although no experimental tests were performed using x-ray fluorescence, two problems were foreseen in using this as a NDE technique. First, each fuze would need to be partially disassembled because of the low transmission of x rays through steel. Secondly, the L x rays from lead would be expected to dominate the spectra severely complicating the measurement.

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10. SUPPLEMENTARY NOTES

☐ Document describes a computer program; SF-185, FIPS Software Summary, is attached.

11. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here)*

A study on nondestructive evaluation (NDE) of M732 proximity fuzes to test for leaking power supplies has been performed. Neutron resonance transmission analysis (NRTA) is shown to be a viable method for NDE in this application. The method could be further developed for NDE of the M732 fuze stockpile. The technique of x-ray fluorescence is shown to have some severe limitations in this application.

12. KEY WORDS *(Six to twelve entries; alphabetical order; capitalize only proper names; and separate key words by semicolons)*

bromine; electron linac; neutron resonance; neutron time-of-flight; nondestructive evaluation; power supply; proximity fuze; transmission analysis

13. AVAILABILITY

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