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LA-5078-MS

INFORMAL REPORT

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Interrogation System (Random Driver)
at the Oak Ridge Y-12 Plant.
Preliminary Results

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Printed in the United States of America. Available from
National Technical Information Service
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Price: Printed Copy \$3.00; Microfiche \$0.95

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ISSUED: November 1972

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APPLICATION OF THE RANDOM SOURCE INTERROGATION SYSTEM (RANDOM DRIVER)

AT THE OAK RIDGE Y-12 PLANT---PRELIMINARY RESULTS

by

J. E. Foley

ABSTRACT

Preliminary results of measurements made with the Random Source Interrogation System ("Random Driver") at the Oak Ridge Y-12 plant are presented. Samples of highly enriched uranium in 2-liter and larger containers have been assayed with the system. Results indicate that fast neutron interrogation, as opposed to thermal interrogation, is required for good penetrability of the samples.

I. INTRODUCTION

The Random Source Interrogation System^{1, 2} or "Random Driver" is a compact, nondestructive assay instrument used principally to determine the ^{235}U content of containers up to 5-gal capacity (Fig. 1). An AmLi random neutron source (of

strength $\sim 5 \times 10^5$ n/sec) is used to induce fissions in the ^{235}U present in an unknown sample. The induced fissions are observed by coincidence counting the time-correlated fission neutrons with two fast plastic scintillation detectors (Pilot F); by requiring the detection of neutrons in both detectors within a time interval of ~ 50 nsec, it is possible to distinguish the time-correlated induced fission neutrons from the randomly produced source neutrons. The interrogation neutrons from the AmLi (α, n) source are subthreshold (< 1 MeV), therefore they produce fissions in the ^{235}U and not in ^{238}U . The source moves vertically up and down inside the counter to uniformly scan the rotating sample. The amplitude of the source motion is determined by the position of adjustable limit switches (Fig. 2). The source neutrons are not thermalized, and the sample counting well (cf. Fig. 1) is lined with boral to preserve a "hard" spectrum of interrogating neutrons, thus ensuring good neutron penetrability through the sample.

Fig. 1. Random Source Interrogation System for assay of fissionable material in containers up to 5-gal capacity.

Fig. 2. Interior view of Random Driver showing source motion limit switches.

The detectors are shielded with lead, typically two inches thick, to reduce sensitivity to fission gamma rays (which do not readily penetrate dense samples) and to reduce unwanted γ - γ coincidence background events (e.g. as may arise from ^{208}Tl cascade gamma rays, nowadays frequently present in enriched uranium feed material). Further gamma ray coincidence rejection is accomplished by proper fast timing; i.e. coincidence gamma rays are detected within a few nanoseconds of each other, while neutron-neutron coincidences are more widely separated in time because of their lower speed and the finite die-away time of the neutrons within the system. By discarding the first few nanoseconds of the coincidence counting time, it is possible to reduce the gamma-gamma coincidences with little loss of neutron-neutron coincidences. A ^3He or BF_3 detector mounted inside the counter corrects for changes in neutron flux

within the sample due to the presence of nonfissionable matrix material in the sample. In samples containing considerable amounts of hydrogenous material, for example, thermal neutron flux is increased and the induced fission rate is increased accordingly. The ^3He detector monitors the flux and corrects for this effect. The coincidence logic system (Fig. 3) consists of (1) a prompt coincidence counting channel that records coincidence neutrons from the induced fission events along with accidentally produced coincidences from the random source, and (2) a delayed coincidence channel that records accidentally produced coincidences from the source. The difference between the count rate of the prompt and delayed channels is the true coincidence rate, which is proportional to the ^{235}U content of the sample.

Fig. 3. Coincidence logic system used with the Random Driver.

II. RANDOM DRIVER MEASUREMENTS AT Y-12

Two major categories of samples have been investigated: (1) samples in ~ 5 in. diam containers, containing large quantities (many kg) of enriched uranium, and (2) 3-gal "cream cans" with a low uranium density--up to ~ 600 g uranium. In all measurements the interrogation source was ~ 3×10^5 n/sec, consisting of a 2×10^5 n/sec AmLi source and a 1×10^5 n/sec PoLi source. Both sources were used to give a larger source strength; however, results of these measurements indicate a larger source strength (5×10^5 to 10^6 n/sec) would be desirable.

A. Dense Samples in 5 In. Diam Containers

For all measurements made on these samples, the detector configuration was kept fixed (Fig. 4):

- Two in. of Pb on inner surfaces of detectors
- $\frac{1}{4}$ in. BORAL on inner surfaces of Pb shielding
- Source moved ± 6 in. about centerline of counter

1. Metal Turnings. These samples consisted of metal turnings of 93% enriched uranium contained in ~ 5 in. O.D. by ~ 12 in. high stainless steel "hospital cans." Five samples were available, containing from 1500 g ^{235}U to 4000 g ^{235}U . In all cases the cans were full, the density depending on how tightly the material was pressed into the cans. The calibration curve for these samples is shown in Fig. 5. The ^3He flux monitor showed essentially constant value for all of these samples, indicating a very low thermal neutron component.

The linear calibration curve for these samples demonstrates an important feature of this counter. Since these samples have constant volume, but different masses, the uranium density differs considerably. The linear calibration curve demonstrates we are getting good penetrability of

the samples. A softer neutron spectrum would produce a nonlinear calibration curve.

Fig. 4. Counting configuration used at Y-12.

Fig. 5. Calibration curve for 5 in. O.D. by 12 in. high hospital cans of uranium metal turnings.

2. UF_4 . These samples were also contained in 5 in. O.D. by 12 in. high stainless steel hospital cans. The depth of the material in the cans (measured by gamma scanning) ranged from ~ 2 in. for the can containing 1743 g ^{235}U to $\sim \frac{1}{2}$ full for the 7377 g sample. In all cases the material was positioned in the center of the counter. There are a significant number of neutrons emitted by the samples themselves; thus, they "self-random-drive" to a considerable extent. These samples were measured both with and without the random source; the results are shown in Fig. 6. The difference between the curve with the source and the curve without the source gives a calibration curve that is nearly identical with the curve for the metal chips (Fig. 5). Above 4 kg ^{235}U it appears that multiplication within the sample can be observed. The measured multiplication is about what would be expected from simple calculations, presented in Appendix A. Here, as with the metal chips, the ^3He flux monitor shows no significant thermal neutron flux.

Fig. 6. Calibration curve for 5 in. O.D. by 12 in. high hospital cans of "Green Salt"-- UF_4 .

Fig. 7. Calibration curve for 2-liter bottles of UNH crystals.

3. UNH Crystals. These hydrated crystals were contained in polyethylene bottles ~ 5 in. O.D. by 8 in. high. The ^3He flux monitor gave approximately twice the response of the metal chips and UF_4 samples, thus indicating a considerable increase in thermal neutron flux. The calibration curve of Fig. 7 reflects this increase with a much steeper slope.

4. Metal Turnings Using Thermalized Source. The metal turnings in item 1 above were also assayed using a thermalized source. A 2 in. thick polyethylene block was placed between the random source and the sample, and the $\frac{1}{4}$ in. BORAL sheets were removed from the inside of the counter. The results of the thermal interrogation are shown in Fig. 8, along with the hard spectrum interrogation of Fig. 5. Thermal interrogation produces a very nonlinear calibration curve, but it does give ~ 5 times the count rate. This nonlinearity produces serious assay problems: for example, suppose one-half of the material was removed from the 4 kg sample such that the remaining material occupied one-half of the volume of the container (thus, the uranium density is held constant). The observed coincidence rate would

then be one-half that of the 4 kg sample, or ~ 160 coinc. counts/sec. From Fig. 8, however, this would assay as less than 700 g ^{235}U , rather than 2 kg. If the material were then allowed to expand to fill the entire volume of the can, rather than one-half of it, the coincidence rate would then increase to ~ 260 cps, resulting in the correct assay of 2 kg. Self-shielding is very dramatic at these concentrations of ^{235}U . Assays using thermal interrogation depend strongly on the uranium density, while assays using a linear calibration curve do not have this problem. This same density problem using thermal interrogation was also seen in the 3-gal cream cans, to be described in the next section.

Fig. 8. Thermal neutron interrogation of uranium metal turnings.

B. 3-Gal Cream Cans

The 3-gal cream cans were ~ 9 in. diam by 13 in. high. These samples were difficult to assay with the Random Driver because: (1) the source strength of 3×10^5 n/sec was too weak for this large volume, and (2) many of the samples contained ^{208}Tl which gave a considerable coincidence background from high energy cascade gamma rays.

A calibration curve (see Fig. 9) was generated using standards supplied by Y-12. The counter configuration was identical to that used for the dense samples, except the detector spacing was larger (~ 11 in.) and only 1 in. of Pb shielding was used. Fifteen cans were counted that had been previously measured in MONAL by both active and passive techniques. Fig. 10 shows the comparison with the average MONAL results with the Random Driver measurements. There appears to be agreement between the Random Driver data and MONAL data, but the standard deviation of the data is much larger than one would like. The standard deviation of these samples is ~ 40 g (count time was 400 sec). By using a source strength of 1×10^6 n/sec, it would be possible to reduce the standard deviation to ~ 25 g.

Calibration curves were also made on the 3-gal standards using a thermalized source (1 in. of polyethylene placed between the source and sample). The results for two different density samples are shown in Fig. 11. One set of standards contained 2% uranium by weight and the other 7% by weight. We see a considerable difference in response for the different uranium densities, a difference that is not seen with the hard spectrum interrogation (Fig. 9).

III. CRITICALITY PROCEDURES

The criticality procedures followed at Y-12 are given in Appendix B. It is extremely important that such procedures be developed and followed for each application of the Random Driver.

Fig. 9. Calibration curve for 3-gal "cream cans".

Fig. 10. Comparison of Random Driver results with MONAL for 3-gal cream cans containing acid leached residues and process residues.

Fig. 11. Thermal interrogation of 3-gal "cream cans".

ACKNOWLEDGMENTS

The author acknowledges the professional help of many people in the design, construction, and deployment of the Random Driver at Y-12: John Watkins of Y-12, Lew Fields of ORO, Leo Cowder and Ed Whitted of LASL. Special thanks also go to D. B. Smith, LASL, for generating the criticality procedures given in Appendix B.

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APPENDIX A

ESTIMATE OF MULTIPLICATION IN DENSE SAMPLES

- (1) We see from Fig. 6 that the observed coincidence rate from ~ 7 kg of ^{235}U is ~ 140 cps. This was produced by a random source strength of $\sim 3 \times 10^5$ n/sec.
- (2) Since the coincidence efficiency of the instrument is $\sim 1\%$, we see that the source strength of 3×10^5 n/sec induces $\sim 1.4 \times 10^4$ fissions/sec in a 7 kg sample.
- (3) Since each fission results in an average of ~ 2.5 neutrons, then the source strength of 3×10^5 n/sec results in $\sim (2.5) (1.4 \times 10^4) = 3.5 \times 10^4$ induced fission neutrons/sec.
- (4) This induced neutron production rate of 3.5×10^4 n/sec is approximately 1/10 the random interrogation source strength of 3×10^5 n/sec. Thus, it would be reasonable to expect the observed coincidence rate for a 7 kg sample to be $\sim 10\%$ higher than what would be expected from the interrogation source alone.

APPENDIX B*

CRITICALITY SAFETY OF U (93.5%) ASSAY IN THE RANDOM SOURCE INTERROGATION SYSTEM - MODEL 2

This appendix establishes criticality procedures for the assay at the Y-12 Oak Ridge facility of highly enriched ($\leq 93\%$ ^{235}U) uranium scrap in the random driver neutron counter. This scrap is typically stored in 6 in. diam by 9.5 in. high (~ 4.4 liter) poly bottles and 8.75 in. diam by 12.5 in. high (~ 12.3 liter) "cream" cans. The following procedures shall be followed.

- (1) Any container having a gross weight of 15 lbs (6.8 kg) or less may be placed in the counting geometry.
- (2) Any container having volume less than 4.5 liters and gross weight less than 40 lbs (18 kg) may be placed in the counting geometry.
- (3) Any container having volume greater than 6 liters and gross weight greater than 15 lbs (6.8 kg) must be shown by prior gamma counting to contain no more than 900 grams of ^{235}U .

This gamma screening will be performed in either the Oak Ridge gamma assay system which is based on reliable standards or in the LASL Ge(Li) segmented gamma system.

- (4) It is our understanding that criticality safety procedures are also being generated by Oak Ridge. If the Oak Ridge procedures differ from the LASL procedures, the more restrictive of the two will be followed.

These procedures are based primarily on data taken from W. R. Stratton, LA-3612, p. 16. It was assumed that for volumes under consideration, the $\text{H}_2\text{O} + \text{U}$ system is undermoderated (i.e., removal of hydrogen increases the critical mass of ^{235}U). The values of the critical mass of ^{235}U and the critical radius of the $\text{H}_2\text{O} + \text{U}$ sphere given in LA-3612 were used to compute the total weight of the system.

*This appendix written by Darryl B. Smith, A-1 (LASL).