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DEVELOPMENT OF AN ACTIVE WELL COINCIDENCE COUNTER FOR U-AL BILLET ASSAY (U)

by

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DEVELOPMENT OF AN ACTIVE WELL COINCIDENCE COUNTER FOR U-AL BILLET ASSAY* (U)

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ABSTRACT

The Savannah River Site (SRS) has completed an experimental evaluation of the application of an active well (neutron) coincidence counter (AWCC) to the assay of ^{235}U in U-Al coextrusion billets of the Savannah River Site fuel fabrication area. Using U-Al coextrusion core standards for the experimental measurements, the AWCC was tested in several different source/sample configurations. As a result of this work, a new configuration was identified for billet assay. This configuration, using a moderated AmLi source placed in the central hole of the billet, yielded a two-standard-deviation precision of 0.6-1.0% for a twenty-minute assay. This precision is a factor of 2-3 better than that obtained from the operation of the AWCC in the standard configuration, i.e., with the interrogation sources located above and below the billet. A dedicated Billet AWCC, using the new center-source configuration and custom-built to accommodate coextrusion billets, is being acquired for use in the fuel fabrication area of SRS. This paper will present details of the experimental work, as well as a description of the resulting AWCC design.

INTRODUCTION

The Savannah River Site (SRS) fuel fabrication area produces reactor fuel tubes via a multi-step coextrusion process. With the increasing emphasis on nuclear material control and accountability programs, it has become desirable to make confirmatory measurements of the ^{235}U content at several stages in the fuel tube production process. These confirmatory measurements are needed to provide assurance that the ^{235}U content remains constant throughout the process, i.e., that no material has been lost or diverted.

As part of the effort to add to the confirmatory measurement capability in the SRS fuel production process, the Analytical Development Section (ADS) undertook an experimental evaluation of the use of an active well coincidence counter (AWCC) for confirmatory measurements of the ^{235}U content of U-Al coextrusion billets (Figure 1) in the fuel tube production area. Although a Californium Shuffler procurement project is currently underway to meet this measurement need, the shuffler is not expected to arrive until April 1990. The relative simplicity and low cost of an AWCC would allow it to be acquired and used well in advance of the arrival of the shuffler. Once the shuffler arrived, the AWCC would serve as a backup instrument. Thus, the AWCC experiments were designed to: 1) evaluate the instrument response and precision for billet assay, and 2) identify design and/or configuration modifications that would enhance the billet assay capabilities of the instrument.

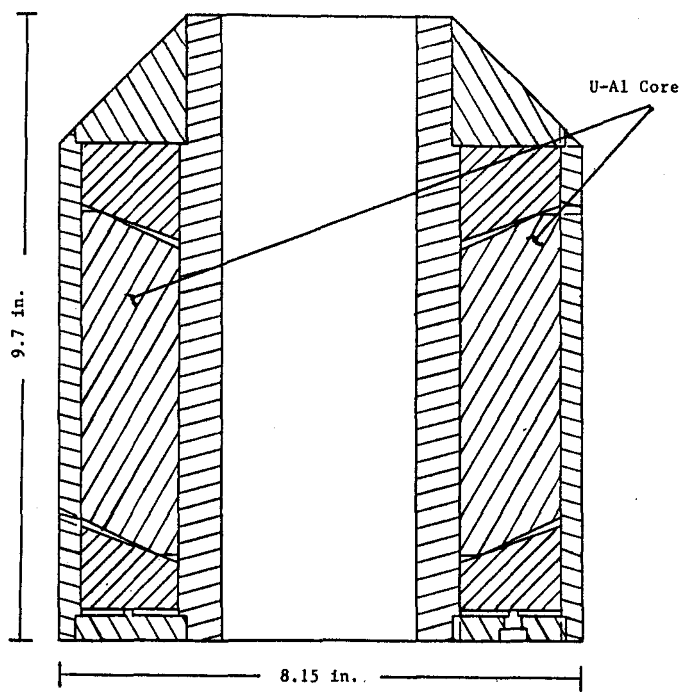

Figure 1. Cross-section of a typical SRS coextrusion billet

DESCRIPTION OF THE AWCC

The AWCC is a commercially available neutron coincidence counter specifically designed to assay ^{235}U in metallic or oxide form (1). The instrument operates on the principle of active neutron interrogation, in which one or more random neutron sources induce fission events in the ^{235}U of the assay sample. The resulting fission neutron signal rate is then taken to be proportional to the ^{235}U content of the sample.

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The AWCC (see Figure 2) consists of a 19" diameter by 24" high polyethylene barrel surrounding a cylindrical sample cavity (well). The two AmLi random neutron sources (5×10^4 n/sec each) are mounted in polyethylene end caps immediately above and below the sample cavity to allow a uniform irradiation of the sample. Thin cadmium shielding between each source and the sample reduces the non-uniform irradiation from thermal neutrons. The irradiation uniformity is further enhanced by the presence of a removable 1" thick Ni annulus around the sample. This Ni liner selectively reflects intermediate energy neutrons to provide a more penetrating neutron irradiation of the sample.

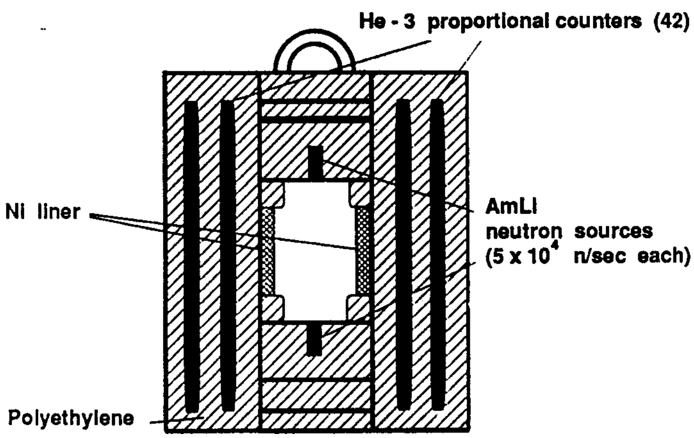

Figure 2. Standard configuration of AWCC (not to scale)

The AWCC has a standard sample cavity configuration height of about 8" and a diameter of 6.7" with the Ni liner. To accommodate larger samples, however, the AWCC incorporates removable pieces to allow some flexibility in adjusting the sample cavity size. As shown in Figure 2, the top and bottom end caps contain several polyethylene pieces that can be removed individually or as a group to expand the sample cavity height to a maximum of 13.8". In addition, the Ni liner can be removed to increase the maximum sample diameter to 8.7". Additional details on the AWCC and its operation can be found in Reference 1.

Operation of the AWCC is controlled by an external shift register coincidence module (2). The shift register module provides: 1) high voltage for the detectors, 2) low voltage power for the preamplifier/amplifier boards, and 3) coincidence circuitry for processing the neutron signals. The shift register allows front panel control of the high voltage, coincidence gate width, counting time, and Start/ Stop of counting. Front panel displays indicate the accidental coincidence counts (A), real + accidental coincidence counts (R + A), and total counts (T), for each counting period. The real coincidence count rate (R), the difference between the counts in the R + A and A scalers, is proportional to the fission rate (and thus the ^{235}U content) of the sample.

Optionally, the shift register can be interfaced to a computer and controlled by an assay program. In this case, the computer provides on-screen and printed displays of the R, R + A, and T values for each run, as well as the calculated standard deviations for the R and T values. The printout also provides the average rates for R and T and a place for descriptive comments. The experiments at SRS were conducted with a HP-85B computer used to control the AWCC counts and to display and print the results.

DETAILS OF EXPERIMENTS

General Information

All of the experiments were carried out in the billet assembly area of the fuel fabrication area at SRS with an AWCC on loan from Los Alamos National Laboratory. Because of AWCC sample cavity size limitations, and because of a lack of suitable, well-characterized U-Al billet standards, the majority of the assay tests were performed on a set of nine U-Al core standards. These U-Al core standards, prepared at SRS as Californium shuffler standards, were produced from U-Al melts using virgin enriched uranium metal and aluminum. The molten alloys were cast into hollow, cylindrical ingots which were then machined to the proper core dimensions. The use of a casting process, rather than the coextrusion process, allowed multiple "grab" samples to be obtained from each melt as it was poured. These "grab" samples were then analyzed at SRS and at New Brunswick Laboratory to determine U-Al and U isotopic concentrations for each core standard.

The U-Al core standards covered the 1400 - 1800 gram ^{235}U mass range for three ^{235}U enrichments: 50%, 59%, and 68%. Table 1 lists the core standard numbers and their New Brunswick Laboratory (NBL)-determined ^{235}U mass and enrichment values. SRS-determined mass and isotopic values were quite similar. Table 2 contains the dimensions of the cores. Because the coextrusion billets are simply coextrusion cores sheathed in aluminum (as illustrated in Figure 1), the experimental results obtained with the core standards should be valid for the coextrusion billets.

All AWCC assays were 20 minutes (1200 seconds) long, divided into 12 x 100 second runs to reduce data loss in the

Table 1. U-235 Compositions of U-A1 Core Standards

CORE NUMBER	U-235 (WT%)	U-235 (g)
WT 3001	58.99	1443
WT 3004	58.88	1627
WT 3005	67.95	1667
WT 3006	50.03	1752
WT 3007	59.00	1756
WT 3009	50.07	1451
WT 3010	68.08	1487
WT 3011	50.11	1609
WT 3012	67.96	1739

Table 2. Machined Core Dimensions

	O. D. (1) (INCHES)	WALL (2) THICKNESS (INCHES)	OVERALL LENGTH (INCHES)
WT 3001	7.492	1.552	5.067
WT 3004	7.503	1.552	5.096
WT 3005	7.497	1.554	5.079
WT 3006	7.467	1.540	5.083
WT 3007	7.471	1.539	5.096
WT 3008	7.468	1.542	4.834
WT 3009	7.499	1.563	5.059
WT 3010	7.497	1.557	5.108
WT 3011	7.450	1.558	5.068
WT 3012	7.469	1.537	5.078

(1) Average of two measurements taken 90^o apart.

(2) Average of four measurements taken 90^o apart.

event of system transients. Since 1200 seconds is a reasonable assay time in a production environment, all quantities that were measured are representative of the actual production use of the instrument.

To ensure that the AWCC and the shift register electronics were operating in a stable manner, the coincidence response of a single core was measured repeatedly throughout the evaluation program. This included multiple measurements over the course of a single day, as well as measurements at the beginning of each day. No system drifts were observed during the course of the work.

Results for Standard Source Configuration

The initial SRS AWCC studies on the U-Al core standards were performed with the AWCC in its standard configuration (see Figure 2), but without the Ni liner. Table 3 lists the observed coincidence response and two-standard-deviation precision for each of the nine coextrusion core standards. Figure 3 shows the least squares fit of the coincidence responses and two sigma error bars against ^{235}U mass for each core standard. The core standards are separated by enrichment value in this plot. The results show an average coincidence response of 360 cps and an average precision (two sigma) of 2-3% for a twenty minute assay in this configuration. The corresponding sensitivities (ability to distinguish between two different ^{235}U masses of the same enrichment) are: about 80 grams for the 50% cores, 80 grams for the 59% cores, and 140 grams for the 68% cores.

Table 3. AWCC Assay Results for U-Al Core Standards. Standard Configuration

CORE NUMBER		U-235 (g)	COINCIDENCE RESPONSE (CPS)	(1)
WT 3009		1451	338.7	+/- 7.6
WT 3011	50%	1609	360.1	+/- 7.4
WT 3006		1752	396.3	+/- 7.5
WT 3001		1443	337.2	+/- 7.2
WT 3004	59%	1627	369.7	+/- 7.3
WT 3007		1756	395.9	+/- 7.3
WT 3010		1487	349.8	+/- 7.2
WT 3005	68%	1667	375.9	+/- 7.3
WT 3012		1739	376.9	+/- 7.3

NOTE: All results are based on twenty-minute assay times.

(1) Uncertainties are two-standard-deviation statistical errors.

Results for the Center Source Configuration

An alternative configuration, with improved source-sample coupling, was evaluated next. In this configuration, called the "center source" configuration, one of the AmLi sources was placed in a polyethylene capsule inside the central hole of the U-Al core. The other source was not used in this configuration. Figure 4 is a schematic illustration of the center source configuration.

Using a polyethylene capsule with a 1.32" wall thickness, results were obtained for each of the core standards. Table 4 lists the real coincidence rate and two-standard-deviation precision results for each of the core standards, as obtained in the center source configuration. The observed response (real coincidence rate) for each core is approximately five times greater than with the standard configuration. The corresponding two-standard-deviation statistical errors were improved by a factor of three to yield values of 0.6 to 1.0%. Figure 5 is a least squares fit of coincidence response versus ^{235}U mass for all core standards in the center source configuration. The improvements in response and precision resulted in sensitivity improvements to: 40 grams for the 50% cores, 50 grams for the 59% cores, and 60 grams for the 68% cores. These values are approximately a factor of two better than observed in the AWCC standard configuration.

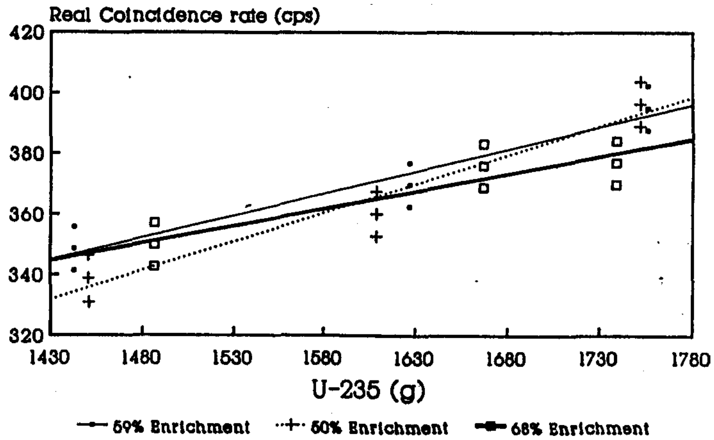

Figure 3. Least-squares fit of AWCC coincidence response vs. ^{235}U mass for cores of various enrichments. Data obtained with AWCC in standard configuration.

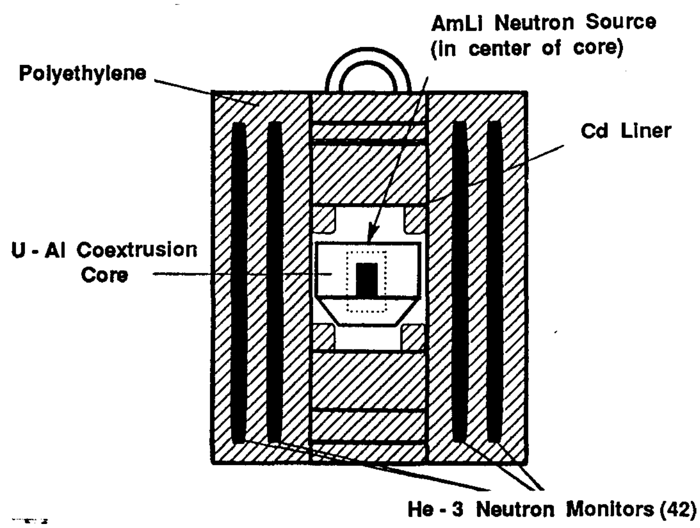

Figure 4. Center source configuration of AWCC (not to scale)

The improved response observed in the center source configuration (versus the standard AWCC configuration) occurs for two reasons:

1) improved coupling between the AmLi interrogation source and the sample, and

2) increased moderation of the interrogation neutrons by the polyethylene source holder. The lower-energy interrogation neutrons have a much higher interaction cross-section with the ^{235}U, resulting in an increase in the fission signal.

Table 4. AWCC Assay Results for U-Al Core Standards. Center Source Configuration

CORE NUMBER		U-235 (g)	COINCIDENCE RESPONSE (CPS)	(1)
WT 3009		1451	1497.9	+/- 10.8
WT 3011	50%	1609	1572.1	+/- 11.4
WT 3006		1752	1677.8	+/- 11.2
WT 3001		1443	1508.1	+/- 10.8
WT 3004	59%	1627	1590.4	+/- 11.0
WT 3007		1756	1641.8	+/- 11.1
WT 3010		1487	1534.8	+/- 10.8
WT 3005	68%	1667	1614.9	+/- 10.9
WT 3012		1739	1623.5	+/- 11.0

NOTE: All results are based on twenty-minute assay times.

(1) Uncertainties are two-standard-deviation statistical errors.

Subsequent tests of the center source configuration with two smaller polyethylene source holders (0.80" and 0.35" wall thicknesses) produced correspondingly lower coincidence responses and poorer precision than obtained with the large source holder, indicating that moderation of the interrogation neutron energy is a large factor in the improved response observed in the center source configuration. Figure 6 illustrates the experimental coincidence response and corresponding relative standard deviation values as a function of the polyethylene source holder wall thickness.

The final measurement of the AWCC evaluation was the assay of a complete coextrusion billet in the center source configuration. For this measurement, one of the U-Al core standards was temporarily clad in aluminum to produce a complete billet. Back-to-back assays were made using the same polyethylene source holder and the same sample cavity configuration (fully expanded to accommodate the billet) for both the bare core and the billet. The results showed very similar coincidence responses for the core and the subsequent billet, implying that the use of the core standards in place of the billets for the AWCC evaluation program was indeed a valid substitution. This finding is also in agreement with earlier SRS AWCC tests [3].

SUMMARY AND FUTURE WORK

The experimental work has demonstrated the feasibility of using an AWCC for the assay of ^{235}U in SRS U-Al fuel billets. The results further indicate that the center source configuration of the AWCC is clearly superior to the standard configuration for this particular application, yielding a factor of 5 improvement in response and a factor of 2-3 improvement in precision over the standard configuration. Assay accuracy was not determined, but should be comparable to the precision if representative, well-characterized billet standards are used.

As a result of the AWCC evaluation program, SRS is pursuing the development of an AWCC that is custom-built for the assay of U-Al coextrusion billets. The Billet AWCC will use the center source configuration and will have special billet-handling equipment for loading and unloading the instrument.

For production use of the AWCC in the center source

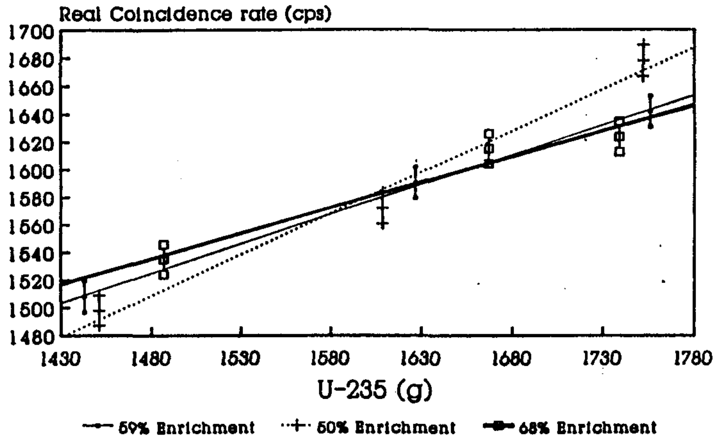

Figure 5. Least-squares fit of AWCC coincidence response vs.^{235}U mass for cores of various enrichments. Data obtained with AWCC in center source configuration.

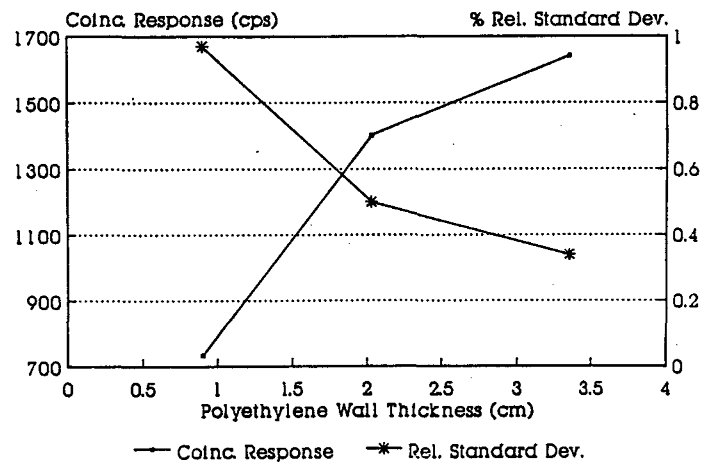

Figure 6. Coincidence response and one sigma standard deviation of response vs.polyethylene source holder wall thickness. Data from AWCC center source configuration.

configuration, the interrogation neutron moderation must be designed very carefully to achieve the proper balance between good response (real coincidence rate/gram ^{235}U) and the ability to interrogate the entire sample. With increasing moderation, the interrogation neutrons are more likely to be thermalized. This results in increased response, but also in more severe self-attenuation of the neutrons in the sample, meaning that a smaller portion of the sample is interrogated by the neutrons. The optimum moderation requirements can best be determined through neutron Monte Carlo calculations. These calculations have been initiated to address these and other design considerations.

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