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ABSTRACT

The second generation Research Reactor Fuel Counter (RRFC-II) has been developed to measure the remaining ^{235}U content in foreign spent Material Test Reactor (MTR)-type fuel being returned to the Westinghouse Savannah River Site (WSRS) for interim storage and subsequent disposal. The fuel to be measured started as fresh fuel nominally with 93% enriched Uranium alloyed with Al clad in Al. The fuel was irradiated to levels of up to 65% burnup. The RRFC-II, which will be located in the L-Basin spent fuel pool, is intended to assay the ^{235}U content using a combination of passive neutron coincidence counting, active neutron coincidence counting, and active-multiplicity analysis. Measurements will be done underwater, eliminating the need for costly and hazardous handling operations of spent fuel out of water.

The underwater portion of the RRFC-II consists of a watertight stainless steel housing containing neutron and gamma detectors and a scanning active neutron source. The portion of the system that resides above water consists of data-processing electronics; electromechanical drive electronics; a computer to control the operation of the counter, to collect, and to analyze data; and a touch screen interface located at the equipment rack.

The RRFC-II is an improved version of the Los Alamos-designed RRFC already installed in the SRS Receipts Basin for Offsite Fuel. The RRFC-II has been fabricated and is scheduled for installation in late FY 2001 pending acceptance testing by Savannah River Site personnel.

SYSTEM DESCRIPTION

The RRFC-II measures the remaining ^{235}U content in foreign spent Material Test Reactor (MTR)-type fuel being returned to the Westinghouse Savannah River Site (WSRS) for interim storage in the L-Basin and subsequent disposal. The fuel to be measured started as fresh fuel nominally with 93% enriched Uranium alloyed with Al clad in Al. The RRFC-II is designed to assay fuel with 8 to 22 plates, an initial ^{235}U enrichment of 80%-95%, and an initial ^{235}U loading of 50-400g with a one-standard deviation accuracy of 10%. Irradiation levels of up to 65% burnup can be measured without the use of additional calibration curves. The RRFC-II may also be used to assay control assemblies and other nonstandard items with diminished accuracy. The RRFC-II will assay the ^{235}U content using a combination of passive neutron coincidence counting, active neutron coincidence counting, and active-multiplicity analysis.

Spent fuel will be measured underwater during unloading operations in the interim storage pool. The ability to measure underwater eliminates costly, time consuming, and hazardous handling for above water operations. The underwater portion of the RRFC-II consists of a watertight stainless steel housing containing a neutron source, neutron and gamma detectors, and a scanning active neutron source designed to operate at a 10-meter depth. All data processing electronics, electromechanical drive electronics, and computers are located above water.

The RRFC-II is an improved version of the Los Alamos-designed RRFC [1]. Table I summarizes the differences between the two units.

Table I. Summary of Differences Between the RRFC and RRFC-II

Parameter	***RRFC***	***RRFC-II***
Assay Mode	Active Calibration Curve	Passive (Active-Passive) Calibration Curve Multiplicity (Solve for M)
Interrogation Sources	2 Am-Li at a fixed location	1 Am-Li scanning
Number of He-3 Tubes	12	23
Efficiency	12%	18%
Axial Displacement Limit	$\pm$5 cm (@25% accuracy)	$\pm$5 cm (@10% accuracy)
Max Gamma Dose Rate	12,000 Rad/hr (surface)	>20,000 rad/hr surface
Weight	750 lbs	2000 lbs
Burnup Range with one calibration	0 – 50% 50 – 65%	0 – 65%
MTR assembly U-235 initial mass	80 – 250 g	50 – 400 g
Measurement time	5 minutes	10 minutes (Active-Passive)

Two main components are located underwater: the Fuel Counter (FC) and the Source Transport Mechanism (STM). The FC contains the detectors and preamplifier in a configuration that allows the STM to be inserted in a pass-through hole. The STM contains a stepper motor and drive mechanism for an isotopic neutron source.

The above-water components consist of a pressurizing canister, Advanced Multiplicity Shift Register (AMSR) electronics[2] for neutron data processing, a pico-ammeter for gamma data processing, a motor controller to control the STM, a control computer for data acquisition and instrument control, and a touch screen interface located at poolside. The control computer is located outside the controlled area of the facility with data and control signals being transmitted over long serial links. The touch screen interface is co-located inside the radiological controlled area at the location of the equipment rack containing the AMSR electronics. Neutron coincidence detector data are processed by the AMSR under control of a special version of the Los Alamos Neutron Coincidence Counting Code, INCC, called RRFC/INCC. RRFC/INCC, hosted by the control computer, also commands STM movements, reads the pico-ammeter, and analyzes the data.

UNDERWATER FUEL COUNTER

The underwater FC is shown in Fig. 1. MTR assemblies are loaded into the central cavity of the FC by personnel operating from the edge of the spent fuel pool using manual manipulators. The FC's funnel assists the loading process. A SF assembly-grappling tool can be inserted into the topmost section of the central cavity, which has been enlarged to allow the tool to be easily inserted and withdrawn. The fuel element to be measured is roughly centered both axially and radially inside the counter by a removable basket sized for the specific fuel. While the centering baskets are necessary for the RRFC-II to operate optimally, the sensitivity to axial misalignment of the fuel will be much less for the RRFC-II than for the original RRFC. The RRFC-II design also includes a criticality control provision by a barrier installed surrounding the counter. This barrier is designed to keep a second fuel assembly from coming into close contact (12 inches, approaching from the side) with the fuel inside the cavity.

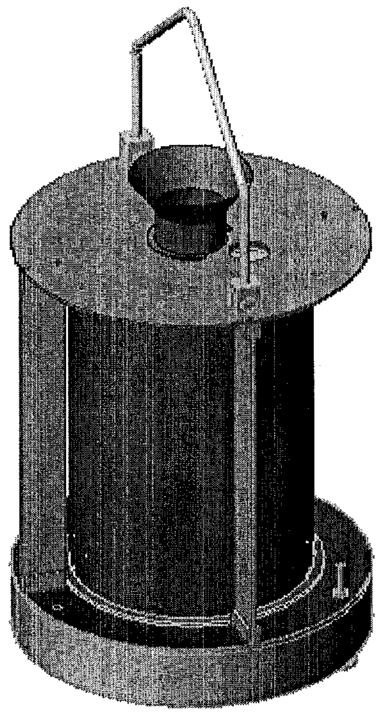

Fig. 1. Drawing of the underwater portion of the RRFC-II referred to as the Fuel Counter. The pass-through hole for the source transport mechanism can be seen on the top partially obscured by the lifting bail.

The FC contains 23 ^3He neutron detectors, shown in Fig. 2, each with its own separate preamplifier, all embedded inside a polyethylene moderator. A cylindrical lead shield surrounding the central cavity shields the neutron detectors from the intense gamma radiation emitted from the MTR spent fuel (SF). The detectors were specially designed through a Los Alamos-GE Reuter-Stokes cooperative research agreement to operate in high gamma environments. These detectors allow the FC to measure fuel with contact dose exceeding 20,000 rad/hr behind only a relatively small thickness of lead. Specifications for the detectors are shown below in Table II.

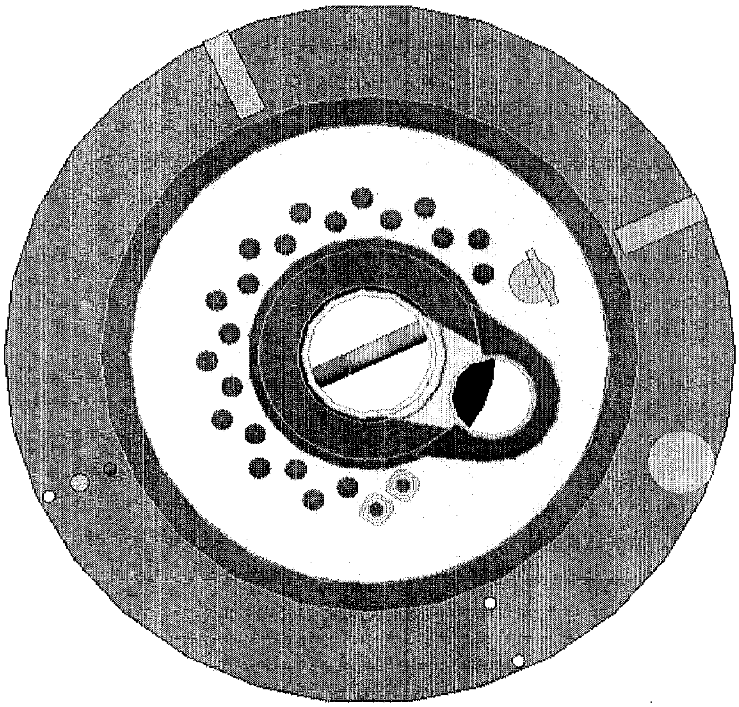

Fig. 2. Cut through the RRFC geometry showing the location of the ^3He tubes, the lead shielding, the ion chamber, and the source pass-through hole.

Table II. ^3He Detector Specifications

Parameter	Feeding and Shearing Cells
Manufacturer	GE Reuter-Stokes
Model Number	RS-P4-0830-105
Max Diameter	26.2 mm
Sensitive Length	30"
Fill Gas	^3He
Fill Pressure	4 atm
Quench Gas	Nitrogen
Wall Material	Aluminum
Wall Coating	Carbon

In addition to the neutron detectors, the FC contains an ion chamber for measurement of SF gross gamma emission. The ion chamber interfaces to an autoranging pico-ammeter, which is automatically read by RRFC/INCC. Specifications for the ion chamber are shown in Table III.

Table III. Ion Chamber Specifications

Parameter	Bare Ion Chamber	Inside LANL Housing
Manufacturer	LND Inc.	""
Model Number	52110	52129
Max Diameter	16 mm	26 mm
Max Length	153.9 mm	218 mm
Sensitive Volume	17 cm^3	""
Fill Gas	Xenon	""
Fill Pressure	7600 Torr	""
Gamma Sensitivity	3.4×10^{-10} amps/R/hr	""
Gamma Flux Range	$10^{-3} - 10^{4}$ R/hr	""
Voltage Range	100 – 3000	""

SOURCE TRANSPORT MECHANISM

An Am-Li neutron source is incorporated into the source transport mechanism (STM), shown in Fig. 3, for active interrogation of SF. The source is normally parked in the home position at the lower extreme of the source travel where it does not interact significantly with the SF. In this position, passive measurements can be made to determine the inherent α, n emission from the fuel. The source can be scanned in steps along the entire axial length of the fuel. The STM incorporates a stepper motor, which is under the control of an external driver/indexer located above water. The STM has been designed so that it can be removed from the FC without the need to open the sealed FC body.

The scanning mechanism provides several benefits in accuracy and operational ease versus the fixed sources in the original RRFC:

- elimination of the need to use separate calibration curves for low and high burnup fuel,
- reduced sensitivity to vertical misalignment,
- ability to do passive as well as active measurements,
- better accuracy on fuels with uneven burnup profiles, and
- ability to perform active multiplicity analysis to directly determine multiplication.

PRESSURIZING CANISTER

The pressurizing canister, connected to the facility instrument air supply or a pressurized cylinder of nitrogen or dry air, keeps a net positive air pressure on the underwater components, preventing water from entering the FC in the case of a small leak of an oring seal. All cables from the FC to the above-water components are contained in high-pressure tubing connected to the pressurizing canister. The tubing protects the cables from chafing, water damage, and transmits the air pressure to the FC. The pressurizing canister also provides a bulkhead for all cables coming up from the fuel counter.

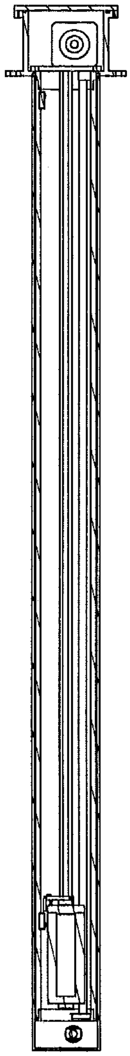

Fig. 3. Schematic diagram of the source transport mechanism.

INSTRUMENT OPERATION

The RRFC-II provides two interfaces for instrument operation: a simple touch screen panel located on the instrument rack by poolside, and a remote computer interface. The touch screen is to be used by facility personnel for initiating a limited set of operations without the need for an expert's attention. The touch screen allows the operator to conduct routine operations such as initiating a control measurement and performing an assay. The remote interface, located outside the controlled area in clean office space about 100 meters from the spent-fuel pool, is to be used by expert users to set up measurement campaigns, calibrate the instrument, and perform measurement control.

To initiate a measurement campaign, the expert user formulates an "Operator Declaration" file containing item IDs, declared original ^{235}U mass, declared remaining ^{235}U mass, declared burnup, and the material type for each assembly to be measured. The original mass and declared burnup are only stored for reference purposes.

By pushing a button, the remote interface allows the expert user to select the desired operation: "Setup," "Measurement Control," "(Active-Passive) Calibration Curve Assay," "Active Multiplicity," "Display Summary," or "Exit." The remote interface starts RRFC/INCC on the selected path and remotely operates the equipment.

The "Setup" function is used to import the operator declaration file into RRFC/INCC, which implicitly starts a new campaign. This function is also used to access a detailed interface allowing the user to enter new calibration parameters or change instrument settings.

The "Measurement Control" function manages an active-mode measurement on the measurement control assembly with the source positioned at the center of the assembly. This function will be invoked at the start and completion of each measurement campaign. After the control measurement, the RRFC/INCC code will drive the source to the home position and present the singles, doubles, and triples results for comparison with previous measurements.

"(Active-Passive) Calibration Curve Assay" is the primary measurement method to be performed on every assembly. After selecting this option, the remote interface prompts the user to select an item ID to be measured from a drop-down list based on the operator declarations. The user is prompted to insert the proper assembly into the counter and press OK. The RRFC-II automatically takes a passive measurement with the interrogation source stowed in the home position, where it doesn't interact significantly with the fuel. The ion chamber is read during this interval (a series of point measurements is taken and averaged).

For noise suppression during ion chamber measurements, RRFC/INCC commands the stepper motor to shut off its holding current. A series of active measurements, nominally 9, is then taken with the interrogation source scanning the entire fuel assembly in steps. During measurement, RRFC/INCC displays the current source position and the time remaining for the entire measurement. RRFC/INCC automatically analyzes the data after subtracting the passive from the active results, analyzes the measurements, and calculates the ^{235}U mass remaining in the assembly. The difference between the measured and the declared mass is displayed. If the difference exceeds the preset tolerance, both interfaces (the touch screen and the remote computer) present the user with options on how to proceed: a remeasurement of the same assembly, a multiplicity analysis, or continue on to the next measurement.

The "Active Multiplicity" function is used to determine assembly multiplication for confirmation of assembly geometry. This mode is seldom used. In this mode, the RRFC-II automatically takes a passive measurement with the interrogation source stowed in the home position. An active multiplicity measurement is then taken with the interrogation source located at the center of the fuel. RRFC/INCC automatically analyzes the data, subtracting the passive results from the active results and converts the net result to the multiplication of the assembly. An expert user will compare the multiplication of the assembly to the expected multiplication taken from a list provided with each calibration curve. Based on the difference between the expected multiplication and the measured multiplication, the user will decide if a new calibration curve is necessary.

A summary table of measurements can be displayed and printed. The summary contains a list of all item IDs measured in the current campaign, the date and time of the measurement, the declared mass, the measured mass, the error in the measured mass, the percent difference (declared – measured), and the ion chamber reading. For any measurements that were reanalyzed, the reanalyzed measurements appear in the summary table.

ACKNOWLEDGMENT

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SUMMARY

The RRFC-II was designed with the explicit goal of simplifying MTR-type spent fuel measurement operations and accommodating facility needs. Underwater operations eliminate the need for hazardous above-water, spent fuel handling. Facility personnel can use the counter without assistance from an expert user, and it provides performance sufficient to accurately measure fuel in a short, 10-minute interval.

REFERENCES

[1] M. E. Abhold; S. Holt; G. Walton; H. Menlove; and S. T. Hsue, "The design and performance of the research reactor fuel counter," *Nucl. Mater. Manage.* **XXV** (Proc. Issue/CD-ROM) (1996).

[2] M. E. Abhold, M. R. Sweet, S. C. Bourret, W. J. Hansen, J. M. Audia, M. S. Krick, S. D. Salazar, and J. E. Stewart, "Advanced Multiplicity Shift Register with Networking Capability," Nucl. Mater. Manage. **XXVIII** (Proc. Issue/ CD-ROM) (1999).