Conf-9209266--6

ANALYTICAL ANALYSES OF STARTUP MEASUREMENTS ASSOCIATED WITH THE FIRST USE OF LEU FUEL IN ROMANIA'S 14-MW TRIGA REACTOR*

ANL/EP/CP--77812

DE93 004152

M. M. Bretscher and J. L. Snelgrove
Argonne National Laboratory
Argonne, Illinois 60439 USA

and

M. Ciocanescu
Institute for Nuclear Research
Pitesti, Romania

To be presented at the

XV International Meeting on
Reduced Enrichment for
Research and Test Reactors

September 27 to October 1, 1992
Roskilde, Denmark

*Work supported by the U.S. Department of Energy, Office of Arms Control and Nonproliferation under Contract No. W-31-109-ENG-38.

ANALYTICAL ANALYSES OF STARTUP MEASUREMENTS ASSOCIATED WITH THE FIRST USE OF LEU FUEL IN ROMANIA'S 14-MW TRIGA REACTOR

M. M. Bretscher and J. L. Snelgrove
Argonne National Laboratory
Argonne, Illinois 60439 USA

and

M. Ciocanescu
Institute for Nuclear Research
Pitesti, Romania

ABSTRACT

The 14-MW TRIGA steady state reactor (SSR) is located in Pitesti, Romania. Beginning with an HEU core (10 wt% U), the reactor first went critical in November 1979 but was shut down ten years later because of insufficient excess reactivity. Last November the Institute for Nuclear Research (INR), which operates the SSR, received from the ANL RERTR program a shipment of 125 LEU pins fabricated by General Atomics and of the same geometry as the original fuel but with an enrichment of 19.7% ^{235}U and a loading of 45 wt% U. Using 100 of these pins, four LEU clusters, each containing a 5 x 5 square array of fuel rods, were assembled. These four LEU clusters replaced the four most highly burned HEU elements in the SSR. The reactor resumed operations last February with a 35-element mixed HEU/LEU core configuration.

In preparation for full power operation of the SSR with this mixed HEU/LEU core, a number of measurements were made. These included control rod calibrations, excess reactivity determinations, worths of experiment facilities, reaction rate distributions, and themocouple measurements of fuel temperatures as a function of reactor power. This paper deals with a comparison of some of these measured reactor parameters with corresponding analytical calculations.

INTRODUCTION

The 14-MW TRIGA Steady State Reactor (SSR) is located in Pitesti, Romania, and is operated by the Institute for Nuclear Research. Initially, the beryllium-reflected core contained 29 HEU fuel clusters each consisting of a square 5x5 array of Incoloy-clad uranium-zirconium hydride-erbium fuel pins enclosed within an aluminum shroud. As burnup proceeded, the core size increased until the complete inventory of 35 fuel clusters was in use. After about 13,600 MWD's of operation, the SSR was shut down in 1990 because of insufficient excess reactivity.

At the time of the 1991 International RERTR Meeting in Jakarta, Indonesia, the Institute for Nuclear Research received a shipment of 125 LEU TRIGA pins from the ANL RERTR program for use in the SSR. These pins are of identical geometry as the original HEU fuel. After a detailed series of inspections and measurements performed by SSR personnel, four LEU fuel clusters were assembled.

In preparation for full-power operation of the SSR with a mixed HEU/LEU core consisting of 31 burned HEU and 4 fresh LEU elements, a series of measurements was undertaken last February at which time the ANL authors of this paper were present. This paper deals with a comparison of some of these measured reactor parameters with corresponding analytical calculations.

The first set of measurements was made in the 35-cluster HEU core shown in Fig. 1. Based on ^{137}Cs gamma-scanning measurements of the irradiated fuel pins together with an absolute ^{137}Cs standard, cluster-averaged burnups had been assigned to each fuel element. Table 1 summarizes these results. This tables differs somewhat from that given in Ref. [1] because of the rearrangement of some fuel pins so as to maximize the burnup of those clusters which were to be replaced with four fresh LEU fuel elements.

Experiment loops are normally located in grid positions G7 (A Loop), D6+E6 (C1 Capsule), and E4 and E9 (standard natural uranium experiments) and may be replaced with water. These loops are described in Ref. [2]. The A Loop includes six zircaloy-clad CANDU type UO_2 rods with 5% enrichment while the C1 Capsule is loaded with a single 5% enriched UO_2 rod. The standard experiments in E4 and E9 each contain three natural uranium UO_2 rods.

The methods used to determine atom densities in fresh HEU and LEU fuel as well as burnup- and axially-dependent atom densities for the fuel described in Table 1 are discussed in detail in Ref. [1]. This reference also describes the structure of the 8-group cross section sets used in this study and the modeling methods needed for diffusion and burnup calculations.

EXCESS REACTIVITIES FOR 13 SSR CORE CONFIGURATIONS WITH FRESH HEU FUEL

It is useful to test multigroup cross sections, modeling procedures, and computational methods by comparing calculated and measured excess reactivities for relatively simple core configurations. The initial approach-to-critical measurements in the SSR and the cluster-by-cluster expansion from the just critical 17-element fresh HEU core configuration to the 29-element standard core provides a very useful set of data for testing computational techniques. A reactivity computer was used to measure the excess reactivity of each of these 13 core configurations. The results of these measurements, including control rod elevations at critical, are recorded in the SSR logbook [4].

The reactivity computer determines the excess reactivity by analyzing the shape of the time-dependent amplitude of a detector signal, proportional to the instantaneous reactor power, during a small positive reactivity transient. Table 2 lists the kinetic parameters used by the reactivity computer (see Ref. 3, p. 17). They are based on the properties of fresh HEU fuel. For comparison, Table 2 includes a calculated set of delayed neutron parameters for the 35-cluster core with 31 burned HEU fuel elements and 4 fresh LEU clusters. The loading sequence for expanding the fresh core from 17 to 29 fuel clusters is shown in Fig. 2.

Table 3 summarizes the results of measured and calculated excess reactivities for each of the 13 HEU core configurations. This table also shows that both measurements and calculations indicate that the 16-cluster assembly is subcritical. For these measurements all eight control rods were banked together and operated as a unit. Fully inserted and fully withdrawn control rods correspond to 100 and 900 units of withdrawal, respectively, which represents a total rod displacement equal to the height of the fuel column (55.88 cm). The intermediate rod bank positions shown in Table 3 are the experimentally

SSR 35 HEU CLUSTER CORE CONFIGURATION
(with experiment loops)

K	J	I	H	G	F	E	D	C	B	A	
H_2O	H_2O	H_2O	H_2O	H_2O	H_2O	H_2O	H_2O	H_2O	Be-H	Be	12
H_2O	Be-H	Be-H	Be-H	Be-H	Be-H	Be	Be	Be	H_2O	Be	11
H_2O	Be-H	C07	CR-8	C13	CR-7	C04	C25	Be	H_2O	Be	10
H_2O	Be-H	C03	C15	C20	C08	Std. Exp.	C02	Be	H_2O	Be-H	9
H_2O	Be-H	CR-4	C37	CR-2	C14	C27	C26	Be	H_2O	Be	8
H_2O	Be-H	C29	C31	A Loop	C34	C09	C17	Be	H_2O	Be	7
H_2O	Be-H	C06	C30	C36	C33	C1 Capsule		Be	H_2O	Be	6
H_2O	Be-H	CR-1	C28	CR-3	C16	C23	C10	Be	H_2O	Be	5
H_2O	Be-H	C18	C24	C19	C21	Std. Exp.	C12	Be	H_2O	Be	4
H_2O	Be-H	C05	CR-6	C22	CR-5	C01	C11	Be	H_2O	Be	3
H_2O	Be-H	Be-H	Be-H	Be-H	Be-H	Be-H	Be	Be	H_2O	Be	2
H_2O	H_2O	H_2O	H_2O	H_2O	H_2O	H_2O	H_2O	H_2O	Be	Be	1

POOL

Be-H = Beryllium reflector element with central water hole

FIGURE 1

TABLE 1
SSR HEU FUEL CLUSTER EXPOSURES AND ^{235}U BURNUPS
(Based on Gamma-Scanning Measurements)

Fuel Cluster	MWD's Exposure	% ^{235}U Burnup
C11	498	62.7
C05	487	61.4
C04	485	61.2
C25	482	60.8
C01	475	59.9
C23	448	56.6
C22	447	56.5
C21	444	56.2
C02	440	55.6
C12	436	55.1
C18	433	54.8
C24	433	54.7
C26	431	54.6
C03	431	54.5
C07	430	54.3
C13	429	54.2
C17	428	54.1
C27	427	54.0
C29	426	53.9
C19	426	53.8
C08	425	53.8
C15	422	53.4
C10	421	53.2
C20	418	52.9
C28	416	52.7
C06	411	52.0
C09	402	51.0
C16	399	50.5
C14	393	49.8
C31	246	31.4
C34	245	31.3
C33	195	24.9
C37	35	4.5
C30	33	4.2
C36	29	3.7

TABLE 2
SSR DELAYED NEUTRON PARAMETERS FOR THE 29-CLUSTER FRESH HEU CORE AND FOR THE 35-CLUSTER BURNED HEU/LEU MIXED CORE

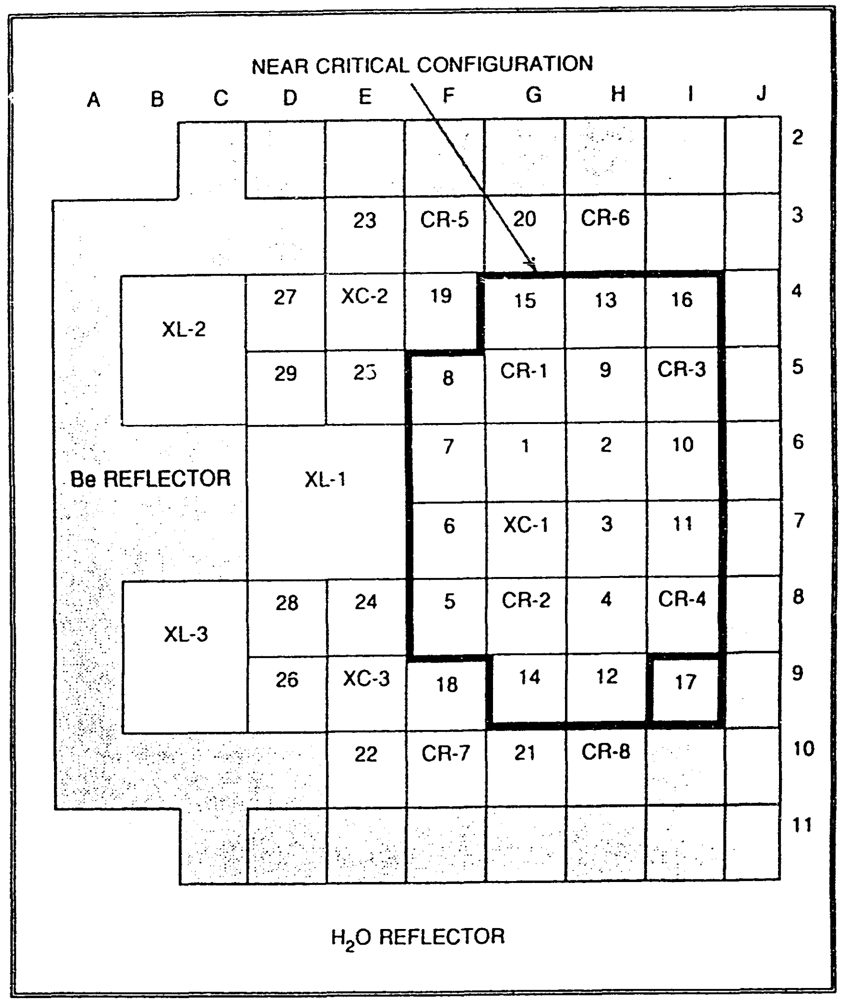
	29-Cluster Fresh HEU Core*				35-Cluster Burned HEU/LEU Mixed Core**			
Group	λ_i(sec^{-1})	β_i	a_i	ℓ_p-μs	λ_i(sec^{-1})	β_i	a_i	ℓ_p-μs
1	1.244-2	2.31-4	0.033		1.2722-2	2.7961-4	0.038241	
2	3.051-2	1.533-3	0.219		3.1737-2	1.5497-3	0.21195	
3	1.114-1	1.372-3	0.196		1.1617-1	1.3732-3	0.18780	
4	3.013-1	2.765-3	0.395		3.1137-1	2.9748-3	0.40684	
5	1.1362	8.05-4	0.115		1.4001	9.4171-4	0.12879	
6	3.0135	2.94-4	0.042		3.8706	1.9297-4	0.026390	
TOTAL		7.00-3	1.000	22.0***		7.3120-3	1.0000	27.90

* See Ref. 3, p. 17.

**These parameters were generated using ENDF/B-V delayed neutron data.

***This value was obtained from Ref. 5, p. 2-224.

SSR GRID LOCATIONS FOR THE INITIAL CORE LOADING SEQUENCE



ALL EXPERIMENT LOCATIONS (XL-1, 2, 3; XC-1, 2, 3; AND THE HOLES IN THE BERYLLIUM REFLECTOR) ARE FILLED WITH WATER

FIGURE 2

TABLE 3

ROOM TEMPERATURE EXCESS REACTIVITIES FOR 13 SSR CORE CONFIGURATIONS WITH FRESH HEU FUEL

No. of Clusters	Rod Bank Units	$K_{eff}(C)$	$K_{eff}(E)$	$\rho_{ex}(C)$ \$	$\rho_{ex}(E)$ \$	C/E
16	900	0.9975				
17	900	1.0097	1.0101			
	775	1.0010	1.0000	1.23	1.43	0.86
18	900	1.0137	1.0133			
	748	1.0026	1.0000	1.56	1.88	0.83
19	900	1.0201	1.0188			
	708	1.0014	1.0000	2.62	2.64	0.99
20	900	1.0299	1.0266			
	664	1.0021	1.0000	3.84	3.70	1.04
21	900	1.0347	1.0303			
	647	1.0052	1.0000	4.05	4.20	0.96
22	900	1.0369	1.0317			
	640	1.0045	1.0000	4.45	4.39	1.01
23	900	1.0403	1.0339			
	631	1.0033	1.0000	5.06	4.69	1.08
24	900	1.0444	1.0386			
	610	1.0032	1.0000	5.62	5.31	1.06
25	900	1.0509	1.0458			
	581	1.0044	1.0000	6.30	6.26	1.01
26	900	1.0525	1.0476			
	575	1.0026	1.0000	6.75	6.49	1.04
27	900	1.0548	1.0503			
	565	1.0015	1.0000	7.20	6.84	1.05
28	900	1.0563	1.0532			
	555	1.0010	1.0000	7.46	7.21	1.03
29	900	1.0585	1.0576			
	539	1.0004	1.0000	7.84	7.78	1.01

SSR RHO–EXCESS IN DOLLARS FOR FRESH HEU CLUSTERS

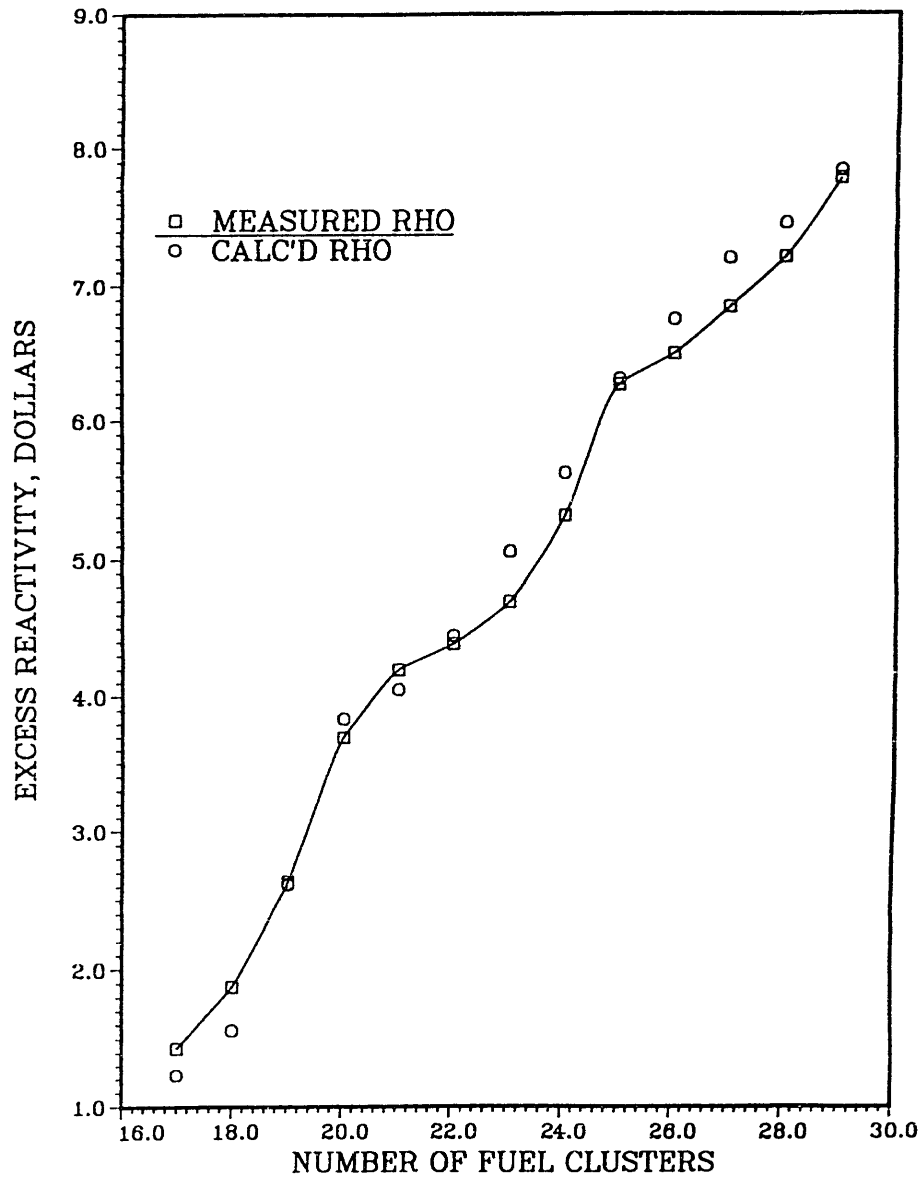


FIGURE 3

determined elevations for which the reactor cores are critical. A total delayed neutron fraction of 0.0070 (Table 2) was used to convert excess reactivities from absolute units to dollars and vice versa. The calculated-to-experiment (C/E) ratios given in Table 3 show that the analytical results are in reasonable agreement with the measured values, which lends credence to the computational methods used in this study. Note too the good agreement between the calculated value of k_{eff} for the critical rod positions and unity. For the 13 cores at critical the average calculated eigenvalue is 1.0026 ± 0.0015. Figure 3 provides a graphical display of this data.

EXCESS REACTIVITIES FOR THE SSR CORE WITH 35 BURNED HEU FUEL CLUSTERS

The purpose of this set of measurements was to determine the reactivity worth of each of the experiment loops relative to water as well as that for a fresh LEU fuel element and a near-fresh HEU cluster. Figure 1 shows the core configuration used for these determinations. Before beginning these measurements, the reactivity computer was used to calibrate each of the control rods. Excess reactivities were obtained from the observed control rod elevations at critical and the rod calibration data. Since the measurements were made at low power (about 500 W), the analytical results are based on cross sections generated at 296K. As before, a value of $\beta_{eff} = 0.0070$ was used to compare measured and calculated excess reactivities.

The results of these measurements are summarized in Table 4. The calculated k_{eff}'s for the critical rod positions are consistent but below unity (0.9929 ± 0.0020). Improved modeling of the experiment loops may reduce some of the C/E ratios for the excess reactivities. Particularly disturbing is the large C/E ratio (1.48) for the case where the C36 HEU cluster (3.7% burnup) in grid location G6 was replaced with water. The consistency of the calculated critical k_{eff}'s for the three experiments involving the G6 location suggests that the banked rod position is correct in each case. One suspects that the discrepancy might be due to inaccuracies in the rod calibration curves, especially near the upper ends of travel. No errors in the measurements or in the calculations have been identified.

EXCESS REACTIVITIES FOR THE 35-CLUSTER SSR CORE WITH FOUR FRESH LEU ELEMENTS REPLACING FOUR HIGHLY BURNED HEU ELEMENTS

In preparation for the first use of LEU fuel in the SSR, some of the HEU clusters in Fig. 1 were relocated while all the experiment loops were removed and replaced with water. This modified core configuration is shown in Fig. 4. The highly burned fuel clusters C25, C01, C11, and C05 (see Table 1) were replaced, one at a time, with the fresh LEU clusters C42, C40, C38, and C39, respectively. With each fuel cluster replacement the control rod bank elevation at critical was determined. With the four LEU clusters in place at the end of these measurements, the control rods were recalibrated again making use of the reactivity computer. This calibration data was used to evaluate the measured excess reactivities. Later, the C1 Capsule was placed in grid positions D6+E6, the standard natural uranium experiments in E4 and E9, and a 5x5 stainless steel (SS) shim bundle in G7.

Table 5 summarizes the results of these measurements and the corresponding calculations. Except for the first case, measured and calculated excess reactivities are in good agreement. As in the last section, all these measurements were carried out at low power and so the analytical results are based on 296K cross sections. Also, a value of $\beta_{eff} = 0.0070$ was used.

TABLE 4
EXCESS REACTIVITIES FOR THE SSR FIGURE 1 CORES

Deviation from Fig. 1 Core	Rod Bank Units	$K_{eff}(C)$	$K_{eff}(E)$	$\rho_{ex}(C)$ \$	$\rho_{ex}(E)$ \$	C/E
None	900	1.03885	1.04570			
	545	0.99240	1.00000	6.436	6.243	1.03
	900	1.00880	1.01153			
G6: C36→H_2O	728	0.99187	1.00000	2.417	1.629	1.48
G6: C36→C38 (LEU)	900	1.04360	1.05226			
	517	0.99256	1.03000	7.039	7.095	0.99
D6+E6: C1→H_2O	900	1.03442	1.04045			
	568	0.98994	1.00000	6.205	5.554	1.12
G7: A Loop→H_2O	900	1.03214	1.03606			
	588	0.99547	1.00000	5.098	4.972	1.03
G7: A Loop→H_2O	900	1.03114	1.03349			
D6+E6: C1→H_2O	600	0.99538	1.00000	4.997	4.629	1.08
E4, E9: Std Exp's→H_2O						
G7: A Loop→H_2O	900	1.02756	1.03101			
D6+E6: C1→H_2O	612	0.99281	1.00000	4.866	4.297	1.13

SSR 35 HEU CLUSTER CORE CONFIGURATION
BEFORE THE ADDITION OF FOUR FRESH LEU ELEMENTS

K	J	I	H	G	F	E	D	C	B	A	
H_2O	H_2O	H_2O	H_2O	H_2O	H_2O	H_2O	H_2O	H_2O	Be-H	Be	12
H_2O	Be-H	Be-H	Be-H	Be-H	Be-H	Be	Be	Be	H_2O	Be	11
H_2O	Be-H	C02	CR-8	C15	CR-7	C18	C07	Be	H_2O	Be	10
H_2O	Be-H	C19	C24	C28	C06	H_2O	C12	Be	H_2O	Be-H	9
H_2O	Be-H	CR-4	C37	CR-2	C25	C09	C20	Be	H_2O	Be	8
H_2O	Be-H	C11	C31	H_2O	C34	C23	C10	Be	H_2O	Be	7
H_2O	Be-H	C05	C30	C36	C33	H_2O		Be	H_2O	Be	6
H_2O	Be-H	CR-1	C29	CR-3	C01	C27	C08	Be	H_2O	Be	5
H_2O	Be-H	C21	C17	C16	C14	H_2O	C26	Be	H_2O	Be	4
H_2O	Be-H	C22	CR-6	C04	CR-5	C03	C13	Be	H_2O	Be	3
H_2O	Be-H	Be-H	Be-H	Be-H	Be-H	Be-H	Be	Be	H_2O	Be	2
H_2O	H_2O	H_2O	H_2O	H_2O	H_2O	H_2O	H_2O	H_2O	Be	Be	1

POOL

Be-H = Beryllium reflector element with central water hole

FIGURE 4

TABLE 5
EXCESS REACTIVITIES FOR THE SSR FIGURE 4 CORES

Deviation from Fig. 4 Core	Rod Bank Units	$K_{eff}(C)$	$K_{eff}(E)$	$\rho_{ex}(C)$ \$	$\rho_{ex}(E)$ \$	C/E
None	900 636	1.02196 0.99116	1.02598 1.00000	4.344	3.618	1.20
F8: C25→C42 (LEU)	900 602	1.03204 0.99814	1.03282 1.00000	4.701	4.539	1.04
F8: C25→C42 (LEU) F5: C01→C40 (LEU)	900 572	1.03975 1.00100	1.03933 1.00000	5.319	5.406	0.98
F8: C25→C42 (LEU) F5: C01→C40 (LEU) I7: C11→C38 (LEU)	900 542	1.04603 1.00124	1.04621 1.00000	6.110	6.310	0.97
F8: C25→C42 (LEU) F5: C01→C40 (LEU) I7: C11→C38 (LEU) I6: C5→C39 (LEU)	900 517	1.05298 1.00119	1.05214 1.00000	7.018	7.079	0.99
F8: C25→C42 (LEU) F5: C01→C40 (LEU) I7: C11→C38 (LEU) I6: C5→C39 (LEU) D6+E6: H_2O→C1 Capsule E4, E9: H_2O→Std. Nat. U Exp. G7: H_2O→SS Shim Bundle	900 569	1.04769 1.00641	1.04000 1.00000	5.593	5.494	1.02

INTEGRAL CONTROL ROD WORTHS FOR THE SSR 35-CLUSTER CORE WITH FOUR FRESH LEU FUEL ELEMENTS

This core configuration is shown in Fig. 4 but with the highly burned HEU fuel clusters in grid locations F5, F8, I6, and I7 replaced with fresh LEU fuel elements. Each control rod was calibrated using the reactivity computer [3] to measure the reactivity worth associated with small outward displacements of the control rod assembly. Measurements covered the full range of control rod motion from the fully inserted to the fully withdrawn position. The integral worth is the sum of the measured worths for each segment of rod withdrawal.

SSR control rod assemblies consist of an upper poison section and a lower aluminum follower section. The poison section (Ref. 5, p. 2-127) consists of a 58.42 cm stack of pressed B_4C (natural boron) pellets in the form of a square annulus with water at the center. For some initial diffusion calculations the poison section of the control rod was represented by a set of group-dependent internal boundary conditions (current-to-flux ratios) applied at the surface of the B_4C absorber and calculated by the methods described in Ref. [6]. It was soon learned, however, that nearly the same results for control rod worths are obtained by using normal diffusion theory with cross sections homogenized over the entire control rod cell. This more approximate method has the advantage of significantly reducing the number of mesh intervals needed. Use of the internal boundary conditions increases the calculated rod worth by about 0.3%.

The output from the reactivity computer is based on the delayed neutron parameters for fresh HEU fuel shown in Table 2. Probably a better set of parameters for this particular core is the second set also listed in Table 2. An estimate of the reactivity computer's response based on this second set of parameters resulted in a correction which tends to reduce the experimental results by about 1% or less. Because of uncertainties in this calculation, this small correction was not applied to the experimental data.

Table 6 compares the measured and calculated integral control rod worths. The calculations are based on the eigenvalues obtained for the fully withdrawn rod (900 units) and the fully inserted rod (100 units). For these calculations the remaining 7 rods are banked together and withdrawn to the position where the reactor was observed to be critical for the the rod in question located at its mid withdrawal point (500 units). As before, a value of $\beta_{eff} = 0.0070$ (Table 2) was used to convert absolute worths to dollars.

Table 6 shows that the calculations and measurements are in satisfactory agreement for the relatively high worth rods (rods 1-4), but that the low worth rods (5-8) are significantly under-calculated. These low worth rods are located adjacent to the beryllium reflector and perhaps a different set of cross sections are needed for the evaluation of their worths. Since eigenvalue changes of only about 0.0004 would bring these calculated results into reasonable harmony with the measurements, the diffusion calculations require the eigenvalues to converge to within 1.0E-5. Figure 5 displays these results by showing the C/E ratio for each control rod and the % ^{235}U burnup for each fuel cluster.

CONCLUSION

The 14-MW TRIGA research reactor in Pitesti, Romania, was shut down in 1990 because the fuel was too highly burned to continue operations. Last November they received a shipment of 125 unirradiated LEU fuel pins from the ANL RERTR program. After a number of preliminary measurements, the SSR resumed operations last February with a mixed 31 HEU/4 LEU core. Our calculations indicate that the SSR should be able to operate for about 2450 MWD's with this core configuration. Based on current operating schedules, this will allow the SSR to continue running until

TABLE 6
CONTROL ROD WORTHS FOR THE SSR 31 HEU/4 LEU CORE CONFIGURATION
(without experiment loops)

Control Rod	Units of Elevation Rod	Units of Elevation Bank	$K_{eff}(C)$	W(C) $	$W_c(C)$* $	W(E) $	C/E
1	900	519	1.00766				
	100	519	0.99612	1.642	1.648	1.798	0.92
2	900	523	1.01529				
	100	523	0.98757	3.949	3.962	3.851	1.03
3	900	525	1.01810				
	100	525	0.98510	4.553	4.568	4.803	0.95
4	900	519	1.00786				
	100	519	0.99598	1.691	1.696	1.664	1.02
5	900	505	1.00258				
	100	505	0.99861	0.566	0.568	0.782	0.73
6	900	518	1.00395				
	100	518	1.00105	0.412	0.414	0.566	0.73
7	900	517	1.00572				
	100	517	1.00011	0.797	0.799	1.018	0.79
8	900	519	1.00398				
	100	519	1.00064	0.475	0.476	0.535	0.89

*Based on the use of internal boundary conditions for the B_4C.

$W_c(C) = 1.003175\ W(C)$.

CONTROL ROD WORTH C/E RATIOS AND % U-235 BURNUPS FOR THE SSR 31 HEU/4 LEU CORE CONFIGURATION

K	J	I	H	G	F	E	D	C	B	A	
H_2O	H_2O	H_2O	H_2O	H_2O	H_2O	H_2O	H_2O	H_2O	Be-H	Be	12
H_2O	Be-H	Be-H	Be-H	Be-H	Be-H	Be	Be	Be	H_2O	Be	11
H_2O	Be-H	C02 55.6	CR-8 0.89	C15 53.4	CR-7 0.79	C18 54.8	C07 54.3	Be	H_2O	Be	10
H_2O	Be-H	C19 53.8	C24 54.7	C28 52.7	C06 52.0	H_2O	C12 55.1	Be	H_2O	Be-H	9
H_2O	Be-H	CR-4 1.02	C37 4.5	CR-2 1.03	C42 0.0	C09 51.0	C20 56.5	Be	H_2O	Be	8
H_2O	Be-H	C38 0.0	C31 31.4	H_2O	C34 31.3	C23 56.6	C10 53.2	Be	H_2O	Be	7
H_2O	Be-H	C39 0.0	C30 4.2	C36 3.7	C33 24.9	H_2O		Be	H_2O	Be	6
H_2O	Be-H	CR-1 0.92	C29 53.9	CR-3 0.95	C40 0.0	C27 54.0	C08 53.8	Be	H_2O	Be	5
H_2O	Be-H	C21 56.2	C17 54.1	C16 50.5	C14 49.8	H_2O	C26 54.6	Be	H_2O	Be	4
H_2O	Be-H	C22 56.6	CR-6 0.73	C04 61.2	CR-5 0.73	C03 54.5	C13 54.2	Be	H_2O	Be	3
H_2O	Bc-H	Be-H	Be-H	Be-H	Be-H	Be-H	Be	Be	H_2O	Be	2
H_2O	H_2O	H_2O	H_2O	H_2O	H_2O	H_2O	H_2O	H_2O	Be	Be	1

POOL

Be-H = Beryllium reflector element with central water hole

FIGURE 5

they receive a shipment of LEU fuel pins, now being fabricated by General Atomics, for 14 fresh fuel clusters.

To test ANL's analytical methods, a series of 13 fresh HEU core configurations was analyzed and excess reactivities were compared with directly measured values. Calculated results were found to be in good agreement with the measured ones.

In preparation for full power operation of the SSR with a mixed HEU/LEU core, a number of low power measurements were undertaken last February. Many of these measured values have been compared with calculated results. Generally speaking, the calculations agree rather well with the corresponding measurements. However, there are some notable exceptions. For the core shown in Fig. 1 the worth of the C36 fuel cluster, relative to water, is significantly overpredicted. The integral worths of the low worth control rods (rods 5-8) in the 31 HEU/4 LEU mixed core are underpredicted by 12 to 37%. These differences are being investigated, but no completely satisfactory explanation is currently available.

LEU fuel pins, sufficient in number for 14 additional clusters, are being fabricated by General Atomics. These pins are expected to be available for use in the SSR before the end of life of the current 31 HEU/4 LEU mixed core.

REFERENCES

1. M. M. Bretscher and J. L. Snelgrove, "Transition From HEU To LEU Fuel In Romania's 14-MW TRIGA Reactor," 14th International RERTR Meeting, Jakarta, Indonesia, November 4-7, 1991.

2. C. Iorgulis and C. Costescu, "Tridimensional Neutronic Calculation Methods Used In Romanian 14 MW TRIGA-SSR Fuel Management and Irradiation Experiments Evaluation," Eleventh European TRIGA Users Conference, Heidelberg, Germany, September 11-13, 1990, GA TOC-22.

3. "R-20A Reactivity Computer Operation and Maintenance Manual ELE 313-0000-2," General Atomic Company, E-115-569, February 1976.

4. The measured excess reactivities and critical control rod elevations for the fresh HEU core configurations were recorded in the SSR logbook on December 12, 1979.

5. "Safety Analysis Report of the TRIGA Steady-State Research/Materials and Testing Reactor for the Institute of Nuclear Technologies, Bucharest, Romania," General Atomic Company, E-117-323, Vol. II, February 1974.

6. M. M. Bretscher, "Blackness Coefficients, Effective Diffusion Parameters, and Control Rod Worths for Thermal Reactors," ANL/RERTR/TM-5 September 1984.

END

DATE FILMED

2 / 19 / 93