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Informal AEC Research
and Development Report

MARITIME LOOP IRRADIATION PROGRAM

SAVANNAH I FUEL IRRADIATION

QUARTERLY PROGRESS REPORT

April 1, 1962 - July 31, 1962

by

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The GETR operations engineer supervising the loop operation during the report period was B. E. Underwood. Physics calculations of neutron flux and power generation based on neutron flux were performed by J. G. Keppler.

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SECTION I

INTRODUCTION

This report covers the S-I-5-B-M fuel irradiation in the GETR Maritime Loop during the final quarter of fiscal year 1962 plus the month of July 1962 to conclude the irradiation program. The data are summarized in Section II. Discussions on fuel performance, fuel environment (water chemistry), and loop operations are included. For detailed data reports for this report period, refer to Loop Operation Data Summary Reports #14, #15, #16, and #17. These individual cycle reports include summary graphs of significant loop operation parameters and water chemistry data.

SECTION II

SUMMARY

2.1 Irradiation Summary

	Summary Report No.	Reactor Cycle No.	Reactor Operation Dates	Reactor MWD	S-I-5-B-M Average Burnup* MWD/Tonne U
Previous Reports	1	18	12/2/60-12/12/60	266.3	141
	2	19	No reactor operation	0.0	0
	Total as of December 31, 1960			266.3	141
	2	20	1/6/61-2/5/61	815.0	427
	3	21	3/21/61-3/26/61	163.7	93
	4	22	3/28/61-3/31/61	90.8	49
	Total as of March 31, 1961			1335.8	710
	4	22	4/1/61-4/20/61	533.1	287
	5	23	5/7/61-6/4/61	615.0	431
	6	24	6/11/61-6/30/61	562.9	307
	Total as of June 30, 1961			3246.8	1735
	6	24	7/1/61-7/9/61	238.3	130
	7	25	7/14/61-8/13/61	864.3	454
	8	26	8/18/61-9/17/61	884.0	490
	9	27	9/23/61-9/30/61	151.0	79
	Total as of September 30, 1961			5384.4	2888
	9	27	10/1/61-10/22/61	551.0	292
	10	28	10/30/61-11/26/61	749.5	367
	11	29	12/2/61-12/31/61	860.2	421
	Total as of December 31, 1961			7545.1	3968
	11	29	1/1/62	30.0	15
	12	30	1/10/62-2/4/62	702.4	326
	13	31	2/19/62-3/11/62	567.1	271
	14	32	3/17/62-3/31/62	293.1	149
	Total as of March 31, 1962			9137.7	4729

*Revised (See Section 3.2)

	Summary Report No.	Reactor Cycle No.	Reactor Operation Dates	Reactor MWD	S-I-5-B-M Average Burnup MWD/Tonne U
This Report	14	32	4/1/62-4/15/62	424.3	216
	15	33	4/24/62-5/19/62	727.0	374
	16	34	5/31/62-6/24/62	689.1	341
	17	35	7/2/62-7/19/62*	458.0	247
	Total as of July 31, 1962			11436.1	5907

The irradiation corresponds to the equivalent of 9149 hours (381 days) reactor operation at full power.

2.2 Typical Operating Conditions

Total power generation in facility (at 30 MW reactor power)	118 KW
Gamma heating in facility outside fuel	9 KW
Total heat generation in fuel	109 KW
Gamma heating in fuel	6 KW
Fission heating in fuel	103 KW
Average heat flux (at 30 MW power)	105,000 BTU/hr-ft^2
Peak to average heat flux	2.10
Peak heat flux (Cycle #34)	223,000 BTU/hr-ft^2
Average thermal neutron flux (from Physics calculation)	1.33×10^{13} nv
Total flow	52 gpm
Flow inside fuel channel	48 gpm (6.5 ft/sec)
Pressure	1300 psi
Temperature, facility tube inlet	505°F
Temperature, facility tube outlet	521°F
Differential pressure across facility tube	1.5 psi
Cleanup loop flow	0.3 gpm

*Includes reactor operation before loop fuel removal only.

2.3 Typical Coolant Conditions

		Maritime Specifications
Conductivity	0.2 μmho cm^{-1}	--
Ionic dissolved solids (from conductivity)	0.1 ppm	< 1 ppm
Turbidity	< 5 Nephelos	--
pH	6.8-7.4	6.5-8.5
Chloride	< 0.02 ppm	< 0.1 ppm normal 1.0 ppm, 24 hr. max.
Dissolved oxygen	< 0.01 ppm	< 0.01 ppm normal 0.05 ppm max.
Dissolved hydrogen	1.8-3.6 ppm	1.8-3.6 ppm

2.4 Operation Summary

The loop operated continuously during the report period for the full duration of reactor operation (i.e., no loss of irradiation exposure hours). All water chemistry conditions with the exception of the dissolved hydrogen were maintained within specifications during reactor operation (dissolved hydrogen within specification approximately 90% of the time). The S-I-5-B-M fuel was removed subsequent to the July 19, 1962 shutdown concluding the fuel irradiation.

SECTION III

MARITIME FUEL OPERATION

3.1 Heat Generation and Peak Heat Flux

The total heat generation in the fuel can be calculated by two methods, that is, either from the experimentally observed loop coolant flow and temperature measurements, or from the reactor core neutron flux calculations extended out to the loop fuel position in the reactor pool. The first method yielded an average fuel heat generation for the report period of 109 KW whereas the latter method yielded an average of 99 KW (see Appendix). The data represent improved agreement between the two methods resulting from the use of new techniques in calculating the neutron flux in the loop fuel.

The peak heat flux during the report period occurred during reactor Cycle #34 when the peak to average ratio was 2.20 (radial peaking factor 1.39 and start of cycle vertical peaking of 1.58 at 18 inch reactor control rod bank position). For Cycle #34, the average heat flux was 101,000 BTU/hr-ft^2 with the peak heat flux at 223,000 BTU/hr-ft^2.

3.2 Burnup

The S-I-5-B-M fuel burnup through the previous quarter (ending March 31, 1962) was increased to 4729 MWD/Tonne U from a previously reported value of 4376 MWD/Tonne U. Previously the burnup was calculated from computer programmed physics calculations scaled to the experimentally observed heat generation. The new value was determined by simplified calculation utilizing the definition of burnup directly as follows:

$$\text{Average Burnup } \frac{\text{MWD}}{\text{Tonne U}} = \frac{\text{MWD Fuel Element Fission Power Output}}{\text{Tonne U in Assembly}}$$

$$= \frac{\left(\frac{\text{Test Assembly}}{\text{Fission Power, KW}}\right)\left(\frac{1 \text{ MW}}{1000 \text{ KW}}\right)\left(\frac{\text{GETR MWD}}{\text{30 MW GETR Power Level}}\right)}{\frac{\text{6680 gm U in Assembly}}{10^6 \text{ gm U/Tonne U}}}$$

$$= 0.0050 \left(\frac{\text{GETR}}{\text{MWD}}\right)\left(\frac{\text{Test Assembly}}{\text{Fission Power, KW}}\right)$$

The test assembly fission power is taken as the total power calculated from the loop flow and differential temperature measurements (reactor at 30 MW) minus the 15 KW calculated gamma heating in the loop from reactor core radiations.

The average burnup during the report period was 1178 MWD/Tonne U bringing the total to 5907 MWD/Tonne U for the complete irradiation. The peak burnup can be estimated based on time weighted peaking factors (averaged over a reactor cycle as a function of reactor control rod position). The estimated vertical peaking factor is 1.4 which, with a radial peaking factor of 1.39, results in a time weighted peak-to-average ratio of 1.95. The peak burnup is therefore estimated to be (1.95)(5907) = 11,500 MWD/Tonne U.

3.3 Differential Pressure Across Facility Tube

The differential pressure across the facility tube has remained within the range of 1.0-2.0 psi throughout the fuel irradiation. The variations from cycle to cycle have not shown a trend toward increased differential pressure.

3.4 Fission Product Check of Cladding Integrity

The fission product levels during each cycle since the irradiation began have remained essentially constant. A sample taken July 6 gave the iodine-133 level of 210 disintegrations per minute per milliliter of loop coolant (dpm/ml) and the iodine-131 at 14 dpm/ml. The levels are consistent with those expected from background surface contamination of the fuel.

SECTION IV

MARITIME FUEL ENVIRONMENT - COOLANT CONDITIONS

4.1 Conductivity

The conductivity was in the range of 0.13-0.60 μmho cm^{-1} during reactor operation with a typical value of 0.20 μmho cm^{-1}. The corresponding ionic dissolved solids were typically 0.10 ppm. The conductivity during loop startup for Cycle #34 was temporarily as high as 3 μmho cm^{-1} with a gradual decrease to a final value of 0.13 μmho cm^{-1} at the end of the cycle.

4.2 pH

The pH remained in the range of 6.8-7.4 as measured by the colorimetric method at the loop location.

4.3 Chlorides

The chlorides as measured daily by nephelometry at the loop location were less than 0.1 ppm during loop operation with the typical value less than 0.02 ppm. Weekly laboratory analyses yielded less than 0.02 ppm chloride by the Hellige turbidimeter method except for one analysis at 0.036 ppm.

4.4 Dissolved Oxygen

The typical dissolved oxygen concentration was less than 0.01 ppm (indicated range of 3-8 ppb) as measured by the thallium column method at the loop location. The oxygen was highest during startup of Cycles #33 and #34 with the data at a maximum of 20 ppb and 30 ppb respectively.

Data on the loop oxygen were obtained from three sample points, the main loop separator (valve SSV-121), the cleanup loop ion exchanger inlet (valve SSV-123), and the cleanup loop ion exchanger effluent (valve SSV-124). Data obtained from the three sample points generally agreed within 2 ppb oxygen during the normal loop operation with the

conductivity at 0.2 μmho cm^{-1}. During the early part of the loop operation for Cycle #34 where the conductivity was somewhat greater than 1 μmho cm^{-1}, the best results were obtained with the ion exchanger effluent sample point SSV-124 since the best accuracy is obtained when the inlet conductivity for the analyzer is low.

The dissolved oxygen in the demineralized and deaerated makeup water was monitored routinely and the data varied between 3 and 60 ppb oxygen. The oxygen in the makeup water had little (if any) observable effect on the oxygen in the main loop.

A new dissolved oxygen analysis panel was installed in the sample station during the April shutdown prior to reactor startup for Cycle #35. The new panel utilizes the same type thallium column as previously used but incorporates provision for direct readout in terms of ppb O_2 and for sample temperature compensation. The new sample analysis panel has proven to be highly satisfactory and the thallium method used is believed to be the most sensitive and accurate method known in the observed oxygen range.

4.5 Dissolved Hydrogen

The dissolved hydrogen was within specification (1.8-3.6 ppm) for approximately 90% of the loop operation time during the report period. The hydrogen was maintained by nearly continuous operation of the hydrogen addition compressor. During startup of reactor Cycle #34 from May 28 to June 1, the indicated dissolved hydrogen was below specification, generally less than 0.5 ppm. The hydrogen addition compressor was in operation during this period, however, suggesting that the hydrogen was within specification. The absolute pressure gauge on the total gas sampler was later found to be sluggish in operation and may have given a false low indication of the dissolved hydrogen concentration.

A new total gas sampler panel was installed prior to reactor start-up for reactor Cycle #33. The new panel operates on the same basic principle as the original equipment but is designed for simpler operation.

The sampler is designed to degas a sample by introducing the sample into an evacuated chamber partially filling the chamber with a known volume of sample. Gas coming out of solution contributes a gas pressure inside the sampler which is measured with an absolute pressure gauge. The absolute pressure is proportional to the amount of gas originally dissolved in the sample (corrections are required for water vapor pressure and temperature). The calibration of the sampler was determined by calculation based on an equilibrium between the gas and water phases of the sampler (partial pressure of gas in liquid phase of sample volume equal to partial pressure of gas in gas phase). Calibration tests using water saturated with air show that somewhat more gas remains dissolved in the water phase of the sampler than is calculated on the basis of equilibrium conditions thus limiting the accuracy of the method. The method is sufficiently accurate however for operational control of the dissolved hydrogen concentration and the procedure has the advantage of being simple, reliable, and easily performed by loop operators at the loop location.

SECTION V

LOOP OPERATION

The loop operated continuously during the report period for the full duration of reactor operation (i.e., no loss of irradiation exposure hours). The new equipment for the sample station briefly described in the quarterly report for the second quarter 1962 (October-December 1961) (GEAP-3905) was installed during the between cycle shutdown in April 1962. The equipment provides better accuracy for the conductivity and dissolved oxygen measurements and is simpler and more reliable for use at the loop location.

SECTION VI

FUEL INTERIM EXAMINATION

The first interim examination of the S-I-5-B-M fuel assembly was performed in September, 1961, after 2809 MWD/Tonne Uranium exposure (Ref. 3). The second interim examination was performed on June 27, 1962 after 5660 MWD/Tonne Uranium exposure and the results are presented in a separate report (Ref. 6). The fuel was removed after the reactor shutdown on July 19 to conclude the fuel irradiation.

SECTION VII

CRUD DEPOSITION PROGRAM

The coupons were removed following the shutdown on July 19 terminating the coupon exposure period. The coupons were monitored individually for gross radiation levels with a "CP" type instrument on July 31 but there was insufficient time to obtain coupon weights and the more accurate radiation level determinations before the program termination. The additional analyses are planned subject to customer authorization to proceed with a final report on the chemistry program.

The preliminary data obtained indicate little difference in activity levels with respect to surface finish but considerable difference related to exposure period. A total of 5 groups of coupons have now been exposed with 6 coupons in each group (3 coupons of 125 μ inch surface roughness and 3 coupons of 250 μ inch surface roughness in each group). The gross gamma results on all groups are as follows:

		Average Activity (3 Coupons) mR/hr @ 2"	
Group	Group Exposure	125 μ inch Surface	250 μ inch Surface
1	First 865 hours only	1	1
2	First 4735 hours only	9.2	9.5
3	Full program 9149 hours	15.2	15.8
4	Last 4414 hours only	16.7	16.9
5	Last 8284 hours only	47	47

As shown above, of the coupons removed at the end of the program, the coupons that had been exposed for the complete program had the least amount of surface contamination (group 3 had least activity of groups 3-5). It is obvious from the data that many factors are involved in the rate of contamination buildup and that only a thorough review of factors such as initial

coupon corrosion rate, type of scale formation, activity in transport, water chemistry, etc., can yield an accurate interpretation of the data.

APPENDIX

A. Total heat generation in fuel calculated from flow and temperature measurements.

1. Apparent coolant temperature rise across facility tube (facility tube outlet minus facility tube inlet temperature) - average for report period with reactor at 30 MW — 15.7°F

2. Apparent coolant temperature loss across facility tube with loop at normal operating temperature but with reactor at 0 MW (average of 5 points on 1-31-62) — 0.7°F

3. Temperature rise due to reactor operation — 16.4°F

4. Heat absorbed by coolant from tables (h_f at 521.4°F minus h_f at 505°F). — 19.8 $\frac{BTU}{lb}$

5. Flow 8.13 scale units at 505°F equals 52.1 gpm from instrument calibration curves.

$$52.1 \text{ gpm} \frac{1}{7.48} \frac{ft^3}{gal} \frac{1}{0.0205} \frac{lb}{ft^3} 60 \frac{min}{hr} = 20{,}400 \text{ lb/hr}$$

6. Total heat generation

$$19.8 \frac{BTU}{lb} 20{,}400 \frac{lb}{hr} = 404{,}000 \text{ BTU/hr}$$

$$= 118 \text{ KW}$$

7. Gamma heating outside fuel from reactor gamma radiation based on estimate of 0.6 watts average per gram from physics calculations.

Facility tube	10,300 gm
Zr shroud tube	3,040 gm
Coolant	2,200 gm
	15,540 gm

$$(15{,}540 \text{ gm})(0.60 \text{ watts/gm})\left(\frac{1}{1000}\right) = 9 \text{ KW}$$

8. Total heat generation in fuel

   116 KW - 9 KW = 109 KW

B. Total heat generation in fuel calculated from neutron flux (from physics data).

1. Average thermal neutron flux for report period with reactor at 30 MW = 1.33×10^{13} nv

   $\Sigma_f = 0.3087$ cm^{-1} (@ 5000 hours)

   Volume/inch of one fuel rod = 2.33 cc

2. Fission power $\frac{KW}{in} = \frac{\Sigma_f \cdot V}{3.35 \times 10^{13}} \frac{\text{fiss/sec in}}{\text{fiss/sec KW}}$

$$= \frac{(0.3087)(1.33 \times 10^{13})(2.33)}{3.35 \times 10^{13}}$$

$$= 0.286 \frac{KW}{inch}$$

3. Fission heat generation in fuel

   = (9 rods)(36 in length)$(0.286 \frac{KW}{in})$

   = 93 KW

4. Gamma heating inside fuel from reactor gamma radiation based on estimate of 0.6 watts average per gram from physics calculations.

UO_2	7,578 gm
SS	2,180 gm
	9,758 gm

(9,758 gm)(0.6 watts/gm $\frac{1}{1000}$ = 6 KW

5. Total heat generation in fuel

   93 KW + 6 KW = 99 KW

C. Average Heat Flux.

1. Heat generation in fuel.	109 KW 372,000 BTU/hr
2. Heat transfer surface.	3.54 ft^2
3. Average heat flux.	105,000 BTU/hr ft^2

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1	January 20, 1961	18
2	February 20, 1961	19-20
3	April 25, 1961	21
4	May 29, 1961	22
5	July 14, 1961	23
6	August 14, 1961	24
7	September 11, 1961	25
8	October 18, 1961	26
9	November 17, 1961	27
10	December 29, 1961	28
11	January 31, 1962	29
12	March 12, 1962	30
13	May 4, 1962	31
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16	July 31, 1962	34
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GEAP-3808	April 1961-June 1961	August 25, 1961	D. W. Danielson
GEAP-3869	July 1961-September 1961	December 21, 1961	D. W. Danielson & R. S. Gilbert
GEAP-3905	October 1961-December 1961	January 31, 1962	D. W. Danielson & R. S. Gilbert
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