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FINAL REPORTS ON PT 105-551-A AND SUPPLEMENT A, "HIGH EXPOSURE THORIUM" AND PT 105-516-A,
"EFFECTS OF IRRADIATION OF THORIUM SLUGS"

INTRODUCTION

(7)
Production Test 105-516-A was written to determine the stability by both measurement and visual examination, of thorium slugs as used in flattening columns to exposures in excess of 400 MWD/AT. Both rolled and extruded thorium slugs were used; the highest exposures reached were about 1000 MWD/AT.

(1)
Production Test 105-551-A was written to demonstrate the stability of thorium slugs as used in flattening columns at exposures up to approximately 1500 MWD/AT; the supplement authorized exposures up to 3000 MWD/AT. Six tubes of 10-66 material already in the pile were chosen; these have been discharged at exposures varying from ~1230 to ~2000 MWD/AT.

All material used in both the above tests was canned by the old "B" process in which no mechanical sizing or metallurgical bonding was performed. All 10-66 material is presently being canned by the "C" process using mechanical sizing to insure better heat transfer; thicker can walls are also used. Except for the 13-tube block of J-C columns charged in H Pile under PT 105-567-A, all thorium used in the present J-Q program was canned by the "C" process.

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SPECIAL REVIEW
FINAL DETERMINATION
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SUMMARY

The burned spots found under PT 105-516-A and the ruptures produced under PT 105-551-A have demonstrated that the "B" process canning is not adequate for thorium exposures over approximately 1000 MWD/AT in flattening columns. Further testing will be necessary to determine an exposure limit for thorium canned by the "C" process; thorium slugs canned by the "C" process are presently being tested under PT 105-579-A Revised. The maximum calculated thorium slug power for tubes operating under PT 105-551-A was 7.75 KW or 15.5 KW/ft. of thorium.

Under PT 105-551-A two primary failures occurred by swelling. Examination of the ruptured slug from 3480-B showed large compacted masses of whitish powder under the raised portions of the can wall. This is assumed to be thorium oxide (thoria) produced by the reaction of water with the heated metal. The primary rupture in 1371-B showed a long raised or swelled ridge opposite the ribs and extending from the weld for about five inches along the can-wall. The can was split along this ridge. The secondary rupture from this same tube showed only a fine stream of bubbles (presumed to be hydrogen) coming from a tiny hole in the weld-bead. Two slugs from 2180-D were found to have the end-caps distended -- in one this amounted to about 1/8 to 3/16 inch. One slug from 3179-D had a similarly bulged end-cap. While sorting slugs, another piece with a bulged end-cap was found. This was discharged from 2374-D at an exposure of about 1000 MWD/AT.

Heat generation data vs. exposure were obtained and are presented on Figure I. These data have a rather large probable error due to exposure uncertainties and the inherent difficulties involved in getting accurate heat generation data when the heat generation is of the same order of magnitude as the heat removed from the graphite.

DETAILS

PT 105-551-A was issued 12-3-53 and at that time the exposures of the six selected tubes were as follows:

Tube No.	No. of Pcs.	Lot No.	Date Charged	Exposure 12-7-53
1371-B	35 (6" pieces)	M-24-R	3-18-53	650 MWD/AT
3480-B	25 "	M-24-R	3-18-53	720 "
2180-D	25 "	M-12	3-26-53	950 "
3179-D	20 "	M-12	7-13-53	550 "
1984-H	15 "	M-11	2-17-53	680 "
2872-H	15 "	M-14	5-21-53	410 "

Figure II gives a rough history of tube exposure vs. time. The responsibility for exposure accounting on this material was transferred from Special Irradiations to Production Scheduling in May 1953; the data show some inconsistencies during the change-over period. Immediately following this transfer, a new technique was developed whereby the reactivity effect of flattening columns was adjusted by displacing the column from the pile center line.⁽³⁾ Therefore, the uncertainty in the exposure is rather large. It is estimated to be ± 20 per cent. All tubes have now been discharged; the dates, exposures, and comments are listed below.

Tube No.	Date Discharged	Exposure	Comments
1371-B	9-20-54	1650 MWD/AT	Ruptured and Stuck
3480-B	4-27-54	1230	Ruptured and Stuck
2180-D	7-23-54	2000	Scheduled out. (2 slugs swelled)
3179-D	10-4-54	1330	Scheduled out. (1 slug swelled)
1984-H	8-30-54	1480	Scheduled out. - looked good
2872-H	9-30-54	1500	Scheduled out. - looked good.

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• Tube 1371-B remained centered (front-to-rear) for all the time it was in the pile. Since this charge was about 223" long, it provided very reliable heat generation vs. exposure data over the range of exposure experienced (~ 1650 MWD/AT). Initial rupture indications were first noticed on the beta-monitor at 3:00 a.m. on 9-20-54. Over a period of three hours it was noticed that header samples from 1 1/2 header gave activity readings from two to three times as great as the adjacent headers. The panellit pressure reading on 9-19-54 had been 45; half-hourly readings starting at 4:00 a.m. on 9-20-54 were 50.5, 51.0, 51.5, 52.0, 53.0, 56.0. At 6:30 the unit was shut down and it was necessary to remove the process tube with the rupture stuck inside. The primary rupture was canned (#438) for shipment to the metallurgical laboratory. D.P. O'Keefe will issue a report on the examination. The secondary rupture (can #439) may also be examined. The primary rupture was #12 from the front; the position of the secondary rupture is not known. Just prior to rupture the observed power removed from 1371-B was ~ 196 KW (calculated to be 151 KW from U-233 fission and 35 KW from the graphite) and the surrounding tubes averaged ~ 510 KW. The calculated average relative power of the thorium was 31.6 per cent of the adjacent uranium. (See below) Assuming a cosine flux distribution gives a slug power at the #12 position of ~ 6.9 KW due to fissioning of the U-233. The maximum slug power was 7.75 KW. This assumes a cosine distribution of U-233 since the column was centered at all times. The slug power then follows a cosine squared distribution. The minimum slug power was then 1.55 KW and the average was 4.6 KW.

Visual examination showed rather heavy scale formation on the slug ends; most pieces showed moderate to heavy weld-bead attack and a line of small pits along the line of contact with the tube ribs. All pieces had only light to moderate film deposits on the can wall surface. One piece showed virtually no film over approximately one-half of the can wall; prominent flow-lines, and only one line of pits normally associated with the ribs. This piece may have been "cocked" or "rolled" off one rib and against the tube wall. The piece showed no unusual pitting otherwise.

• Tube 3490-B also remained centered; good heat generation data were thus provided until the time of rupture at ~ 1230 MWD/AT. On 4-26-54 it was noticed that the panellit pressure had increased 4 psi over the preceding day; by 4-27-54 the increase was 16 psi. It was recommended that the column be discharged. The charge was stuck; the tube and charge were pushed out together requiring a force of 6500 pounds. Just prior to discharge the tube power was 124 KW of which 30 KW was calculated to come from the graphite. The surrounding tube power was 518 KW. The calculated relative power was 24.5 per cent of the adjacent uranium. The maximum slug power was 5.5 KW, assuming a cosine squared slug power distribution. The position of the rupture in the tube is not known. The ruptured piece was transferred to the metallurgical laboratory and examined by D.P. O'Keefe. (4) The piece had three prominent "lumps" under the can which had raised sufficiently to contact the tube wall. The can-wall was split on top of these lumps. Two were in a line opposite the ribs and one was adjacent to a rib and nearly diametrically opposite to one of those above. After stripping, the lumps were found to be hard compacted masses of whitish powder -- assumed to be thorium oxide. Between the two opposed lumps the thorium was split or cracked. It is conjectured that the two lumps may be joined through the slug center and that the internal pressure built up as the less dense oxide was formed caused the splitting. It is planned that the piece will be sectioned through this region in the near future. No point of initial water entry was found; however, the can was so badly damaged by the rupturing process and subsequent removal from the tube that the evidence was probably destroyed.

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Tube 2180-D was discharged at the scheduled exposure of ~2000 MWD/AT. Subsequent examination showed that two pieces had the end-caps bulged outward. The worst case was estimated to be 1/8" to 3/16". In general all the slugs (25) were very slightly filmed to clean and bright. Most were dented and many of the dents appeared to have been made prior to charging or during charging. Most pieces showed moderate to heavy rib marks and some corrosion attack in and near the rib marks. The slugs had been displaced periodically as follows:

3-26-53	charged centered
12-29-53	displaced to 80" downstream
3-9-54	centered
4-9-54	displaced to 80" downstream
4-23-54	centered
5-20-54	displaced to 80" downstream
6-30-54	centered
7-23-54	discharged

Almost every piece showed moderate to heavy pitting of the weld and a ring of pits around the can-wall extending 1/8" to 1/4" down the can-wall from the weld. It is planned that the most severely bulged piece (M-12-172) will be examined in the metallurgical laboratory (can #519). Underwater examination showed one or two pits near the weld which may have penetrated to the thorium. The outlet temperature monitoring thermocouple for 2180-D failed sometime after the shutdown of 7-1-54 and before the shutdown of 7-23-54 when the tube was discharged. The last heat generation data were taken on 6-24-54 at an exposure of about 1840 MWD/AT. The tube power was 101 KW of which 30.5 KW was calculated to come from the graphite. The surrounding tube power was 436 KW. The calculated relative power was 34.4 per cent of the adjacent uranium. Assuming a cosine flux distribution and uniform product distribution the maximum slug power was 3.3 KW. The highest slug power would occur with a cosine distribution of U-233 in the slugs. This yields a slug power of about 4.0 KW. The true maximum slug power was probably between these limits.

Tube 3179-D was displaced periodically as follows:

7-13-53	charged centered
12-5-53	displaced at 80" downstream
4-9-54	displaced to 160" downstream
6-30-54	replaced to 80" downstream
10-4-54	discharged

The discharged pieces were examined and found to be clean and bright or only lightly filmed. Three pieces had some scale on the ends. One piece was found with the end-cap bulged outward 1/8 to 3/16". The last heat generation data were taken 9-30-54 with the column displaced 80" downstream. Assuming a cosine flux distribution and a uniform distribution of U-233 in the pieces, the maximum slug power was 5.3 KW on the most upstream piece. The latter assumption is not valid. The distribution of U-233 in the column has not been calculated, but since the charge was displaced downstream most of the time the upstream piece would have up to about 1.4 times the average U-233 concentration. Therefore, the maximum slug power may have been as high as 7.4 KW.

Tube 1984-E was displaced periodically as follows:

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2-17-53	charged centered
7-17-53	displaced to 104" downstream
10-4-53	displaced to 144" downstream
11-3-53	replaced to 120" downstream
12-7-53	replaced to 64" downstream
1-18-54	displaced to 112" downstream
8-30-54	discharged

The discharged slugs were examined and one slug was found to have a very few deep pits near the weld; otherwise the slugs looked very good and had only moderate film. No useful heat generation data were obtained. The outlet thermocouples at H Pile are in the fitting where the pigtail joins the header; it is believed that heat conducted through the metal piping caused the outlet temperatures to read high. The short (15 pc) columns generated very little heat while displaced so far downstream.

Tube 2872-H was displaced periodically as follows:

5-21-53	charged centered
7-17-53	displaced to 80" downstream
8-2-53	displaced to 120" downstream
9-8-53	displaced to 152" downstream
11-3-53	replaced to 104" downstream
12-7-53	replaced to 32" downstream
2-22-54	displaced to 96" downstream
3-4-54	displaced to 128" downstream
3-28-54	replaced to 96" downstream
4-5-54	replaced to 40" downstream
6-9-54	displaced to 80" downstream
8-30-54	replaced to 40" downstream
9-30-54	discharged

The discharged slugs were examined and found to be lightly filmed to clean and bright. One piece was found with a large, deep, irregular pit near the weld; the pit itself was bright. Another piece had a large nearly hemispherical pit (possibly a dent) half-way down the can-wall. The pit was bright but smooth and about 1/8" in diameter. No useful heat generation data were obtained. It should be noted that the rib marks on these slugs were only moderately deep in spite of the thirteen movements of the slugs on the ribs.

HEAT GENERATION

The relative heat generation obtained under PT 105-551-A is presented on Figure I as heat generation in the thorium-loaded tube, less the heat removed from the graphite divided by the average heat generation in the adjacent uranium, less the heat removed from the graphite. The heat removed from the graphite for a uranium loaded tube was taken as 6 per cent of the tube power. Since the local water temperatures in the thorium-loaded tube were lower than the local water temperatures in the surrounding tubes it was assumed that there would be heat flow to the thorium-loaded tubes. The heat flow to the cooler tube should also be a function of graphite conductivity and pile gas composition. This "background" heat was determined experimentally by observing the heat removed from tubes containing no fissionable material. (S. S. Jones³) found the value to be 4.5 to 5.29 per cent for bismuth and aluminum with outlet temperatures comparable to the surrounding tubes.) Three determinations were made for B Pile and five for D Pile yielding 5.7 per cent and 7.0 per cent

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respectively. The accuracy was not high, but the error is believed small relative to other probable errors. Scattered values as high as 17 per cent were obtained for H Pile.

Two sample calculations will be given; the remaining values are presented on Figure I and in Table I.

Tube 1371-B on 8-31-54 -- Exposure 1570 MWD/AT.

Tube Number	Power
1271	595 KW
1370	627 KW
1371	196 KW
1372	607 KW
1471	609 KW

1. The charge was centered - 35 pcs.
2. Fraction of total tube power in adjacent equal uranium length is 89 per cent (cosine).

Average of 4 surrounding tubes - 610 KW -- less 6% = 573 KW

5.7% of 610 = 34.8 KW (See above)

89 % of 578 = 510 KW (See above)

therefore relative heat generation = $\frac{(196 - 34.8)}{510} 100 = 31.6\%$

When the charge is displaced and shorter, the calculated fraction of total tube power in the adjacent uranium (equal length and same position) becomes smaller and the probable error becomes larger.

Tube 3179-D on 4-19-54 -- Exposure 940 MWD/AT

Tube Number	Power
3079	560 KW
3178	563 KW
3179	74 KW
3180	542 KW
3279	536 KW

1. The charge was displaced 160" (20 pcs)
2. Fraction of total tube power in adjacent equal uranium length is ~15 per cent (cosine)

Average of 4 surrounding tubes = 550 KW - less 6% = 517 KW

7% of 550 = 38.5 KW (See above)

15% of 517 = 78 KW (See above)

therefore the relative heat generation = $\frac{(74 - 38.5)}{78} 100 = 45\%$

All calculated relative heat generations for charges greatly displaced from the pile center were inconsistent with the data from centered charges and theoretical calculations. It is assumed that when the charge is displaced the cosine assumption is considerably in error.

The calculated curve shown on Figure I is based on reference (6) and extensions on this document to exposures of 4000 MWD/AT. The calculations will not be presented here.

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TABLE I

HEAT GENERATION DATA

1371-B

Date	Exp.	Tube Pwr.	Surr. Pwr.	Pos.	Factor	%
12-22-53	630 MWD/AT	96.6 KW	477	cent.	0.89	17.3
2-9-54	810	111	439	"	"	23.4
3-8-54	910	133	462	"	"	27.6
3-30-54	990	114	454	"	"	23.2
4-9-54	1030	108	477	"	"	20.3
5-10-54	1140	152	524	"	"	27.8
6-4-54	1220	165	519	"	"	31.2
7-6-54	1370	188	599	"	"	30.7
8-16-54	1520	180	548	"	"	32.5
8-31-54	1570	196	610	"	"	31.6

3480-B

12-22-53	710	86.4	471	cent.	0.79	17.0
2-9-54	890	96.5	425	"	"	22.9
3-8-54	1010	126	556	"	"	22.8
3-30-54	1100	113	496	"	"	23.0
4-9-54	1140	124	518	"	"	24.5

3179-D

12-18-53	570	74.8	545	80"	0.43	19.6
2-12-54	700	97.0	589	"	"	23.4
3-1-54	740	93.7	562	"	"	24.0
3-29-54	910	98.2	581	"	"	24.5
4-19-54	940	74.0	550	160"	0.15	45.0*
4-29-54	960	73.0	558	"	"	43.0*
7-8-54	1050	93.5	457	80"	0.43	33.4
8-30-54	1220	98.5	519	"	"	29.8
9-30-54	1320	107	502	"	"	34.4

2180-D

12-10-53	970	88.0	561	cent.	0.75	11.7
2-12-54	1180	105	613	80"	0.50	21.6
3-1-54	1230	103	581	80"	0.50	22.8
3-29-54	1480	125	570	cent.	0.75	21.2
4-19-54	1530	105	526	80"	0.50	27.6
4-29-54	1580	130	479	cent.	0.75	28.6
5-25-54	1650	102	489	80"	0.50	29.5
6-24-54**	1830	101	436	80"	0.50	34.4

* Data for greatly displaced columns assumed to be invalid.

**Last data before thermocouple failed.

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RUPTURE RATE

Figure III illustrates the rupture rate for the material exposed under PT 105-551-A. The four points were obtained as follows:

- (a) In the exposure range 1200-1250 one tube (3480-B at 1230 MWD/AT) ruptured out of the six reaching this exposure; the rate is then 0.167.
- (b) In the exposure range 1300-1350 one tube (3179-D at 1330 MWD/AT) ruptured out of the five reaching this exposure; the rate is then 0.200 plus 0.167 or 0.367. (For this analysis 3179-D was considered to be a valid rupture.)
- (c) In the exposure range 1600-1650 one tube (1371-B at 1650 MWD/AT) ruptured out of two reaching this exposure; the rate is then 0.500 plus 0.200 plus 0.167 or 0.867.
- (d) In the exposure range 1950-2000 one tube (2180-D at 2000 MWD/AT) ruptured out of one reaching this exposure; the rate is then 1.867. (For this analysis 2180-D was considered to be a valid rupture.)

The sample (6 tubes) is so small and the estimated probable error in the exposure is so large ($\pm 20\%$) that the calculated rupture rate is of limited validity. It should also be noted that 10-66 slugs are no longer canned by the B-process.

REFERENCES

- (1) HW-29702, "PT 105-551-A, High Exposure Thorium," 10-21-53, R. O. Brugge.
- (2) HW-31468, "PT 105-551-A, Supplement A, High Exposure Thorium," 4-15-54, R. O. Brugge.
- (3) HW-27972, "Modification of Charging Procedures for Flattening Columns", 5-1-53. G. F. Owsley.
- (4) A document covering this examination will be issued in the near future.
- (5) HW-29919, "Relative Heat Generation in the Graphite of a Hanford Pile - Final Report, PT 105-104-P," 11-10-53, S. S. Jones.
- (6) HW-26729, "Reactor Study, U-233 Yield from Thorium Irradiation," 1-7-53, A. W. Halliday.

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FIGURE 1
HEAT GENERATION IN THORIUM VS. EXPOSURE AS A PERCENT OF
ADJACENT URANIUM POWER (EXPOSURE IS IN MW/CAT)

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APPENDIX I

A BRIEF FINAL REPORT ON PRODUCTION TEST 105-516-A

INTRODUCTION

ET-105-516-A was written to determine the stability of rolled and extruded thorium slugs irradiated in flattening columns or centered in uranium columns (7)

SUMMARY

No limit to exposure was found; all slugs reached target exposures and were routinely discharged. Post-irradiation examination indicated no significant dimensional change. Some pieces showed blackened or "burned" spots attributed to areas of high heat transfer surrounded by areas of low heat transfer. No significant difference was found between rolled and extruded pieces.

DETAILS

Fourteen columns containing various quantities of six-inch thorium pieces were controlled by this test. They were charged as follows:

Ref. No.	Tube No.	Date Charged	No. Pcs.	Loc. No.	Date Disch.	Exp.
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A. Flattening Columns - Rolled Slugs (Exposures given in MWD/AT)

1	2680-D*	7-4-52	10	M-9	1-7-53	578
2	2785-DR*	8-5-52	10	M-9	5-25-53	768
3	3581-DR*	8-5-52	10	M-9	6-9-53	1000
4	2379-E*	1-26-52	15	--	1-5-53	1081
5	2374-D*	12-31-51	35	M-4	10-1-52	715

B. Flattening Columns - Extruded Slugs

6	1468-DR*	8-5-52	10	M-10	10-16-52	259
7	1984-E*	8-30-52	10	M-10	2-17-53	655
8	2872-E*	8-30-52	10	M-10	9-27-53	800

C. 10-66 Mixed with Uranium - Rolled Slugs

9	3774-E*	8-13-52	5	M-9	10-20-52	269
10	3185-D*	9-8-52	5	M-9	3-26-53	579
11	2773-DR*	9-6-52	5	M-9	1-23-53	574

D. 10-66 Mixed with Uranium - Extruded Slugs

12	3483-DR*	8-5-52	5	M-10	10-16-52	259
13	1569-E*	8-13-52	5	M-10	1-19-53	626
14	3779-E*	8-30-52	5	M-10	12-24-52	400

* Pre-measured pieces; * Pre- and Post-measured pieces
 † In-pile at time test was written

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Groups C and D were loaded as follows:

- (1) regular downstream dummy charge
- (2) 24 uranium pcs. (4")
- (3) alternate thorium slugs and pairs of uranium slugs, total of 50 thorium slugs spaced with 8 uranium slugs (4")
- (4) 024 uranium pcs. (4")

REFERENCE

- (1) HW-24680, "PW 105-516-A, Effects of Irradiation on Thorium Slugs," 7-8, G.C. Fullmer

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