0315587030

~~CONFIDENTIAL~~

Q

UNCLASSIFIED

MASTER

TIM 795, Supp. 2

GROUP 1

Excluded from automatic
downgrading and
declassification

~~RESTRICTED DATA~~

This document contains restricted data as defined in the Atomic Energy Act of 1954. Its transmittal or the disclosure of its contents in any manner to an unauthorized person is prohibited.

P R A T T & W H I T N E Y A I R C R A F T
D I V I S I O N O F U N I T E D A I R C R A F T C O R P O R A T I O N

C A N E L

M I D D L E T O W N • C O N N E C T I C U T

UNCLASSIFIED

~~CONFIDENTIAL~~

REPRODUCTION OF THIS DOCUMENT IS UNLIMITED

0315587030

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

~~CONFIDENTIAL~~

UNCLASSIFIED

PRATT & WHITNEY AIRCRAFT

CANEL

TECHNICAL INFORMATION MEMORANDUM

MASTER

SUBJECT: One Dimensional Transport Calculations of
Self Shielding Factors For In-Pile Capsule
Tests

TIM NO. 795, Supp. 2

DATE OF REPORT: April 27, 1964

COPIES TO: R. Strough, E. Dytko,
C. Bigelow, G. Parks, W. Fader, R. Doak,
D. Vassallo, M. Zeisser, M. DeCrescenti,
W. Ackermann, V. Scotti, F. Felber, J. Krause,
H. L. Richings

WRITTEN BY: W. G. Alwang
J. Krause
APPROVED BY: E. J. Richings

~~CONFIDENTIAL R.D.~~
~~Classification~~

Group No. 1

Eric V. Sordin Jr.
Authorized Classifier

April 28, 1964
Date

GROUP 1

SPECIAL REVIEW FINAL DETERMINATION	Reviewers	Class.	Date
	RBM	U	12-17-81
Class: U			

Excluded from automatic
downgrading and
declassification

Introduction

The design of inpile tests of SNAP-50 fuel elements requires a knowledge of the depression of the test reactor flux due to the presence of the fuel test capsule. There are three primary effects which contribute to the flux depression as follows:

1. Introduction of the capsule into the test hole displaces water thus reducing the local thermal flux.
2. Since the capsule contains considerable structural material, liquid metal coolant, heaters, etc. some flux depression occurs due to absorption in non-fuel materials.
3. Further flux depression occurs due to the fuel specimen itself.

In this report the results of Sn transport calculations (DTK code) of the effective self shielding factors for in-pile tests of UN and UC fuels are given. Cylindrical mockups were prepared to represent test locations in ETR, MTR and GETR and the effective self shielding factor versus fuel enrichment was determined. The effect of a tungsten diffusion barrier and of changes in fuel specimen diameter were also obtained. All calculations are based on the fuel test capsule design described in TIM 715.

As a check on the validity of the calculated flux spectra, the cadmium ratio as measured with cobalt was compared with values obtained from the DTK calculations.

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

NOTICE
This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Atomic Energy Commission, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

This
Atom
closu

person is prohibited

Classification Cancelled
By Authority Of
Date 11/5/71
UNCLASSIFIED

April 27, 1964

Method and Results

The effective self shielding factor $f_o(\epsilon)$ is defined as follows:

$$f_o(\epsilon) \equiv \frac{\overline{\sigma_f}}{\sum_f \epsilon_h(\epsilon) \phi_{th}^o} \quad (1)$$

where $\overline{\sigma_f}$ = Average fission rate in the fuel test specimen

$\sum_f \epsilon_h(\epsilon)$ = Macroscopic thermal fission cross section for fuel with enrichment

ϕ_{th}^o = Unperturbed thermal flux at the test location

Defined in this way, it is evident that the effective self shielding factor includes not only the thermal flux depression but also the effects of epithermal and fast fissions in U^{235} and U^{238} . It therefore depends on the local flux spectrum as well as on the dimensions and composition of the fuel capsule.

In all cases considered in this study the unperturbed thermal flux is defined as the flux in the test hole when filled with water since this is the flux generally reported by the test reactor operators and is therefore the initial data on which the design of an imple test is based.

A description of the MTR, ETR and GETR test facilities is given in Ref. 1 through 4. In representing these test facilities in an idealized one dimensional cylindrical mockup, the axis of the cylinder is taken as coincident with the axis of the test hole. An attempt is then made to represent the local region of the test by a series of radial zones beginning at the center of the hole and continuing out into the reactor core. A zero gradient boundary condition is then applied at the outer boundary. For core test locations this procedure can be carried out without much ambiguity. For reflector test locations however the cylindrically symmetric geometry does not resemble the actual geometry very well. For this latter case, the thickness of reflector material between the core and the test location was chosen to give approximately the correct spectrum at the test location. It is assumed that if the spectrum is correctly represented, the self shielding factors will also be correct. The validity of the calculated spectrum was checked by a comparison with measured cadmium ratios.

The analytical mockups used are shown in Figs. 8 through 11. For each case a homogeneous DTK calculation was done using the 16 group cross sections given in LAMS 2543. For hydrogen scattering the linear anisotropic approximation was used. The U^{238} capture cross sections were corrected for resonance self shielding in groups 7 through 12.

The corrected cross sections as calculated by the GAM II (Ref. 11) code are given in Table 3. Since during preliminary calculations very little difference was observed between S4 and S8, the study was conducted using S4 only.

As an example of the resulting flux distributions, Fig. 12 shows the thermal flux for a base case i.e. with water in the test hole and the thermal flux for the same hole now containing a fuel test capsule.

Consistent with the definition of $f_0(\epsilon)$ (Eq. 1) the effective self shield factor was obtained from the calculations as follows:

$$f_0(\epsilon) = \frac{S_F}{\bar{\nu} \sigma_f^{16} n^{235}(\epsilon) \phi_0^{16}} \quad (2)$$

where S_F = Total neutron source per unit height in the fuel specimen region (from DIK print out)

$\bar{\nu}$ = Average neutrons per fission in U^{235}

σ_f^{16} = Average microscopic U^{235} fission cross section in the thermal (16th) group.

$n^{235}(\epsilon)$ = U^{235} atomic density in the fuel specimen

ϕ_0^{16} = Total integrated thermal (16th group) flux per unit height in the central region of the test hole before insertion of the capsule (from DIK print out for base case)

The results of these calculations are given in Table 1 for all cases. For purposes of comparison the results are plotted in Figs. 1 - 7.

Comparison of Measured and Calculated Cadmium Ratios

The calculations yielded approximate Cd ratios for the ETR core, the MTR core and reflector which are shown in Table 2, along with ratios obtained for several locations from "Approximate Neutron Flux Spectrum" issued by Phillips Petroleum Co. for MTR cycle 146 and ETR cycle 27.

Table 2 shows reasonable agreement between the values issued by Phillips and the calculations except perhaps in the case of the core filler piece in the ETR. The difference may be due to the fact that for the calculations the filler piece is Be three by three inches in cross section with four one-inch holes containing water. For the value issued by Phillips the filler piece is probably aluminum.

April 27, 1964

Conclusions

It is evident in all the figures that a substantial self shielding effect occurs even at 0.7% enrichment. This is the flux depression due to 1) displacement of the water and 2) absorption in the non-fuel regions of the capsule. As can be seen from the figures, at low enrichment the self shielding factor is essentially independent of the type of fuel or fuel diameter. It does however depend on whether the local moderator is water or beryllium (Figs. 3 and 7).

As expected the effective self shielding factor decreases monotonically with increasing enrichment. The effect of increasing the fuel diameter is to reduce the effective self shielding factor (Fig. 1). The self shielding factor is also reduced by substituting the more dense UN fuel for UC and also by introducing the tungsten diffusion barrier though in both cases the effect is small.

In Fig. 3 the results are shown of a calculation in which water was substituted for beryllium in an MTR reflector mockup. This illustrates the fact that for an identical fuel test capsule the effective self shielding factor depends on the moderator external to the capsule. The tendency toward larger values of the self shielding factor for a water moderator versus a beryllium moderator is also seen in Fig. 7 since the GEMR raft facility is surrounded by water.

The error to be associated with the present results cannot as yet be given since only very limited comparisons with experiment are available. It is planned that, as more impile tests are completed, the validity of the calculated results will be checked and if necessary refinements of the analytical methods will be made.

Of the various assumptions used in this analysis the following three require further investigation:

1. What errors are introduced by assuming infinite cylindrical geometry?
2. Resonance self shielding was corrected for in U^{238} . Is it necessary to apply similar corrections for other materials?
3. Is the assumption of a single thermal group with a Maxwell-Boltzmann spectrum adequate?

W. G. Alwang

J. Krause

Approved:

H. J. Richings

WGA/JK:eak

0315587030

TIM-795, Supp. 2

~~CONFIDENTIAL R.D.~~

April 27, 1964

References

1. IDO-16428, Revision 1 "In-Tank Irradiation Facilities In The MTR and ETR".
2. "Complete Irradiation Services at Vallecitos" from Atomic Power Equipment Department General Electric Co., San Jose, California.
3. AEC-U-3607 (Vol I) "Final Physics Report For The Engineering Test Reactor".
4. Nucleonics, Vol. 15, No. 3, March 1957.

~~CONFIDENTIAL R.D.~~

0315587030

0315587030

April 27, 1964

Table I
Tabulation of Calculations

Series	Capsule Location	Fuel	Fuel Diameter Inches	Diffusion Barrier	Calculated Self Shielding Factor			Fig No. of Mockup Used	Fig. Nos. Where Series Results Appear
					.7% Enrich.	10% Enrich.	30% Enrich.		
1	EIR Core	UC	0.188	-	.627	.374	.202	8	1,2,4,7
2	EIR Core	UC	0.277	-	.617	.298	.145	8 with fuel dia. charge	1
3	EIR Core	UC	0.188	W	.607	.363	.196	8 with 6 mil W sur. fuel	2
4	MTR Refl. (Water)	UC	0.188	-	.771	.453	.236	11	3
5	GEIR RAFT	UC	0.188	-	.727	.439	.232	10	6,7
6	MTR Refl.	UC	0.188	-	.622	.391	.216	9	3,5,7
7	EIR Core	UN	0.188	-	.615	.362	.197	8 with fuel charge	4
8	GEIR RAFT	UN	0.188	-	.710	.424	.225	10 with fuel charge	5
9	MTR Refl.	UN	0.188	-	.609	.381	.210	9 with fuel charge	6

0317220 1070

031507030

TIM-795, Supp. 2

~~CONFIDENTIAL R.D.~~

April 27, 1964

Table II

Cadmium Ratios for Cobalt

	<u>Core</u>		<u>Reflector</u>
	<u>Overall</u>	<u>Center of Core Filler Piece</u>	
ETR			
Phillips	6.9-11.8	7.9	
Calculated	8.1	11.54	
MER			
Phillips	7.6-13.6		10.3-16.8
Calculated	8.2		13.8

~~CONFIDENTIAL R.D.~~

0317281070

0315587030

TIM-795, Supp. 2

~~CONFIDENTIAL - R.D.~~

April 27, 1964

Table III

Non Self Shielded and Self Shielded U-238 Transport Cross Sections

Group	<u>Non-Self Shielded</u>	<u>Self Shielded</u>
	LAMS 2543	GAM II
7	14	13.96
8	15	14.6
9	22	14.44
10	59	15.95
11	65	15.72
12	119	21.54

~~CONFIDENTIAL - R.D.~~

03172201070

UC CYLINDRICAL PIN DIAMETER EFFECT
IN AN ETR CORE LOCATION

○ 0.188" DIAMETER
△ 0.277" DIAMETER

UC CYLINDRICAL PIN DIAMETER = 0.188"
EFFECT OF 6 MIL TUNGSTEN DIFFUSION
BARRIER IN AN ETR CORE LOCATION

○ WITH TUNGSTEN BARRIER
△ WITHOUT TUNGSTEN BARRIER

DC CYLINDRICAL PIN DIAMETER = 0.188"
EFFECT OF REFLECTOR MATERIAL
IN MTR TYPE REFLECTOR

O H₂ REFLECTOR
Δ WATER REFLECTOR

COMPARISON OF UC AND UN DIAMETER = 0.188"
CYLINDRICAL PINS IN AN ETR CORE LOCATION

COMPARISON OF UC AND UN DIAMETER = 0.188"
CYLINDRICAL PINS IN AN MTR REFLECTOR LOCATION

UC CYLINDRICAL PEN DIAMETER = 0.188"
COMPARISON OF BTR CORE, MTR REFLECTOR
AND GTR RAFT LOCATIONS

○ BTR CORE
△ MTR REFLECTOR
□ GTR RAFT

Figure 8

Cylindrical Mock-Up of 10% Enriched 0.188" UC Capsule With Atom
Densities (atoms/cm³ x 10⁻²⁴) and Radii in Cm. in ETR Core Location

CONFIDENTIAL

Figure 9

Cylindrical Mock-Up Of 10% Enriched 0.188" Diameter
UC Capsule With Atom Densities (atoms/cm³ x 10⁻²⁴)
and Radii in Cm. in MTR Reflector Location

		31.66624
	U-235 .00005331, U-238 .000003707, B .00002739	
	Al .006127, H .05992, O .02996	15.63624
	Be	
		5.47624
	Al .06042	
		1.66624
	H .06688, O .03344	
		1.6383
	Al .06042	
		1.5367
	H .06688	
	O .03344	
		1.3950
	Fe .0611, Cr .0158, Ni .00988	
		1.3251
	Void	
		1.2662
	Cb .05332	
		1.1407
	Na .002841, K .001304, Fe .006338	
	Al .01657, O .02485, Cb .01445	.7254
	Cb .05332	
		.4606
	Li ⁷ .03956	
	Li ⁶ .000003956	.3175
	Cb .05332	
		.254
	Void	
		.2388
	U-235 .003153, U-238 .02838, C .03153	
		0

CONFIDENTIAL

0315587030

Figure 10

Cylindrical Mock-Up of 10% Enriched 0.188" Diameter
UC Capsule With Atom Densities (atoms/cm³ x 10⁻²⁴)
and Radii in Cm. in GSTR RAFT Location

GSTR	U-235 .00005331, U-238 .000003707, B .00002739	25.0825
	Al .006127, H .05992, O .02996	
	Al .06042	17.4625
	H .06688, O .03344	9.8425
	Fe .0611, Cr .0158, Ni .00988	2.2225
CAPSULE ASSEMBLY	H .06688, O .03344	1.905
	Fe .0611, Cr .0158, Ni .00999	1.3950
	Void	1.3251
	Cb .05332	1.2662
	Na .002841, K .001304, Fe .006338	1.1407
	Al .01657, O .02485, Cb .01445	.7254
	Cb .05332	.4602
	Li ⁷ .03956	.3175
	Li ⁶ .000003956	.254
	Cb .05332	.2388
	Void	
	U-235 .003153, U-238 .02838, C .03153	0

031712291030

Figure 11

Cylindrical Mock-Up of 10% Enriched 0.188" Diameter UC Capsule With Atomic
Densities (atoms/cm³ x 10⁻²⁴) and Radii in Cm. in MTR with Water Reflector

10 CYLINDRICAL PIN DIAMETER = 0.188"
RELATIVE THERMAL FLUX WITH AND WITHOUT
10% ENRICHED FUEL CAPSULE ASSEMBLY IN THE OUTER RAFT LOCATION

TIM - 795, SUPPL. 2

UNCLASSIFIED

FIG. 12

UNCLASSIFIED