Atomics International Division
Rockwell International

U

CLASSIFICATION LEVEL
(S, C OR U)

DOCUMENT NO.

TI-759-200-001

COVER SHEET

DOCUMENT TITLE

Conceptual Core Model for the Reactor Core Test

AUTHOR

L. D. Swenson

NOTICE

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Energy Research and Development Administration, 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 IS AN INTERNAL WORKING
DOCUMENT AND MAY BE
EXPANDED, MODIFIED, OR
WITHDRAWN AT ANY TIME.

~~IT IS INTENDED FOR
INTERNAL USE ONLY.~~

CLASSIFICATION TYPE
(RD OR DI)

~~THIS REPORT MAY NOT BE PUBLISHED WITHOUT THE APPROVAL OF THE PATENT BRANCH, AEC.~~

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.

U

CLASSIFICATION LEVEL
(S, C OR U)

MASTER

DO NOT REMOVE THIS SHEET

DISTRIBUTION OF THIS DOCUMENT UNLIMITED

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.

Atoms International
14000 1st Avenue, Suite 100, San Diego, CA 92128

SUPPORTING DOCUMENT

NUMBER TI-759-200-001		REV LTR/CHG NO. SEE SUMMARY OF CHG
DOCUMENT TYPE Technical Information		
KEY NOUNS Conceptual Model, Fuel Element Dimensions		
ORIGINAL ISSUE DATE 11/16/70		
GO NO. 7759	S/A NO. 13450	PAGE 1 OF 8 TOTAL PAGES REL. DATE 11/19/70
SECURITY CLASSIFICATION		
(CHECK ONE BOX ONLY)		(CHECK ONE BOX ONLY)
UNCL ☒	AEC ☐ DOD ☐	RESTRICTED DATA ☐
CONF. ☐		DEFENSE INFO. ☐
SECRET ☐		
AUTHORIZED CLASSIFIER <i>E. Donovan</i>		DATE 11/17/70

PROGRAM TITLE ZrH Core Test Reactor Program		
DOCUMENT TITLE Conceptual Core Model for the Reactor Core Test		
PREPARED BY DATE L. D. Swenson/11/17/70	DEPT 731	MAIL ADDR LB25
APPROVALS <i>E. Donovan</i>		DATE 11/17/70

DISTRIBUTION			ABSTRACT
*	NAME	MAIL ADDR	
	J. G. Asquith	LB02	Several design options for the ZrH Flight System Reactor were investigated which involved tradeoffs of core excess reactivity, reactor control, coolant mixing and cladding thickness. A design point was selected which is to be the basis for more detailed evaluation in the preliminary design phase. The selected design utilizes 295 elements with 0.670 inch element-to-element pitch, 32 mil thick Incoloy cladding, 18.00 inches long fuel meat, hydrogen content of 6.3×10^{22} atoms/cc fuel, 10.5 w/o uranium, and a spiraled fin configuration with alternate elements having fins with spiral to the right, spiral to the left, and no fin at all (R-L-N fin configuration). Fin height is 30 mils for the center region of the core and 15 mils for the outer region.
	J. A. Beoletto	LB27	
	D. S. Bost	LB22	
	J. E. Brunings	LB41	
	D. C. Campbell	LB45	
	N. F. Davies	LB45	
	W. F. Dennison	LB45	
	R. L. Detterman	LB03	
	E. J. Donovan	LB25	
	R. E. Forrester	LB45	
	R. B. Harty	LB27	
	L. M. Maki	LB02	
	A. B. Martin	LA12	
	D. G. Mason	LB02	
	J. R. Miller	LB45	
	T. A. Moss	LB02	
	T. G. Parker	LB45	
	R. B. Paulson	LB15	
	W. A. Rhoades	LB22	
	R. Roberts	LB22	
	W. J. Roberts	LB36	
	H. Rood	LB22	
	K. L. Rooney	LB22	
	J. H. Walter	LB23	
	Reactor Engineering Unit (13)	LB25	

* TITLE PAGE ONLY

Summary

The ZrH Core Test Reactor conceptual design review held October 7-12 made it clear that a change in the then current reference design was necessary to alleviate difficulties in providing adequate stress margins, to improve coolant mixing, and adequate margins of excess reactivity and control drum worth. A number of design options were investigated from the perspective of determining whether adequate excess and control margins were provided while incorporating features to increase the stress design margin and coolant mixing. Based on these studies, a recommendation for new reference configuration is presented.

The new recommended configuration has 0.670" element-to-element pitch, 0.032" thick Incoloy 800 cladding, fin heights of 30 and 15 mils in the inner and outer zones, respectively, and fin-on-tube element support with elements arranged in a triangular pitch having one element with fins spiraled right, one spiraled left, and one with no fins (R-L-N configuration). The core has an uncoated clad I.D. of 0.576 in. (inner zone) and 0.591 in. (outer zone), fuel meat diameter of 0.560 in. (inner zone) and 0.575 in. (outer zone), a active fuel length of 18.00 inches. A six drum void-backed reflector configuration is recommended with control drums which are full core length, 6.25 in. thick, and have a 6.25 in radius of curvature. The recommended design employs a fin geometry which inherently promotes high interchannel mixing efficiency through elimination of flow opposition characteristic of prior designs. The core excess reactivity and control provided by the selected geometry is currently considered adequate to meet design requirements. The .032 in. thick Incoloy cladding with a .0025 in. glass coating thickness provides a 43% margin in the cold, assembled condition and 50% in the hot operating condition based on cladding proportional limit stresses. The stress analysis does not currently include core "clamping" loads, thermal gradients incurred in startup, effect of fin undercutting to provide needed clearances for element bowing or the effect of "loose" neutral elements which may be involved due to zone boundary geometry mismatch. Evaluation of these effects is to be conducted in the near future.

Pre-Conceptual Design

The design basis for conceptual design review was based on a pre-conceptual design selection that evolved from the first six weeks analysis of the core test reactor configuration. Subsequent detailed analysis of the configuration plus the results from hydraulic tests and fuel element and stress testing provided the input for conceptual design review. Thus, by the time the design review was held, it had become apparent that the pre-conceptual core design would not satisfy the stress margin and hydraulic performance requirements.

The pre-conceptual design had an element-to-element pitch of 0.650", 25 mil thick Incoloy 800 cladding, fin-on-fin element spacing, and uniform fin spiral with 20 mil high fins in the inner zone of the core and 10 mil high fins in the outer zone of the core. The uniform fin spiral did not provide the desired degree of mixing and the 25 mil Incoloy 800 cladding did not provide a positive design margin for the fabrication and assembly stresses.

Design Alternatives

Several design alternatives were investigated from the standpoint of excess reactivity and control worth. The results of the scoping study are given in Table I. The base point for the calculations is the 0.650" pitch core described above. APC-II transport theory cases were used to determine available excess reactivity and control drum worth for that case. Previous parametric results were then used as the basis for extrapolation to the other cases shown. The cladding thickness was increased and the right-left-neutral (R-L-N) fin configuration was considered. The core with the Flight System reflector was the basis for the calculations. A flight configured core which will meet the performance requirements will also meet the requirements and provide an increased margin on both excess reactivity and control when coupled with the 6-drum core test reflector.

The data presented in Table I for the flight configured core show that each of the designs considered is close to providing required excess and exceeds the requirements for control drum worth when fully enriched $B_4^{10}C$ poison inserts are used in the Ta/10W poison backing. However, stress calculations indicated a minimum Incoloy 800 cladding thickness of 0.032 in. with a maximum glass thickness of 0.0025 in. was required to provide a

TABLE I
 COMPARISON OF AVAILABLE EXCESS AND CONTROL
 REQUIREMENTS FOR FLIGHT CONFIGURATION ZrH CORE

ELEMENT PITCH (in.)	0.650	0.670	0.670	0.670	0.670
CLAD MATERIAL	INC 800	INC 800	INC 800	INC 800	INC 800
CLAD THICKNESS (mils)	25	30	32	32	35
FIN HEIGHT (mils)	10/20	15/30	15/30	15/30	15/30
FIN SPIRAL	UNIFORM	R-L-N	R-L-N	R-L-N	R-L-N
W/O U	10.5	10.5	10.5	11.5	11.5
AVAILABLE EXCESS	\$17.46	\$18.52	\$17.44	\$18.70	\$17.08
AVAILABLE CONTROL*	\$10.80	\$10.29	\$10.48	\$10.48	\$10.77
REACTIVITY REQUIREMENTS					
RECOVERABLE LOSSES	3.65	3.65	3.65	3.65	3.65
FISSION PRODUCTS & BURNUP	8.23	7.73	7.82	7.24	7.37
HYDROGEN LOSS	2.75	2.49	2.40	2.40	2.30
BOL PREPOISON	1.33	1.52	1.49	1.60	1.57
EOL MARGIN	2.00	2.00	2.00	2.00	2.00
TOTAL	\$17.96	\$17.39	\$17.36	\$16.89	\$16.89
CONTROL REQUIREMENTS					
RECOVERABLE LOSSES	3.65	3.65	3.65	3.65	3.65
REACTIVITY MISMATCH	2.00	2.01	2.09	2.50	2.44
MOL SHUTDOWN MARGIN	2.00	2.00	2.00	2.00	2.00
EOL MARGIN	2.00	2.00	2.00	2.00	2.00
TOTAL	\$9.65	\$9.66	\$9.74	\$10.15	\$10.09

* WITH FULLY ENRICHED $B_4^{10}C$ INSERTS IN Ta/LOW POISON BACKING

reasonable design margin on the fabrication and assembly stresses. It was also decided, in the interest of minimum system perturbations, to keep the uranium weight percent at 10.5. By this point in time, preliminary data from the hydraulic tests indicated that the R-L-N fin configuration did give the desired degree of coolant mixing. Thus, the design shown in Table II was tentatively selected as the reference for the preliminary design phase studies.

Fuel Element "Rattle"

When the new fuel element configuration was laid out, it was found that a problem existed at the zone boundary between the elements with different fin heights. The nature of the problem is illustrated in Table III. Since the fin envelope was no longer identical with the fuel element pitch (center-to-center spacing) as it was in the fin-on-fin configuration, a combination of finned element interference and neutral element looseness existed at the boundary. The extent of the "interference" and looseness is shown in Table III as positive and negative mismatch, respectively.

Several alternate design approaches were investigated to alleviate the element mismatch problem at the zone boundary. Return to a fin-on-fin arrangement but with R-L-N fins and with the neutral elements having "pads" to maintain their external envelope requirements was considered. This option was constrained to maintaining a nominal fin height in the outer zone of 0.010 in.; the necessary increase in element spacing being achieved by increasing the core diameter. Other options were the retention of R-L-N fin-on-tube arrangement while shaving some fins and padding other fins or neutrals. Also, retaining the R-L-N fin-on-tube arrangement while shaving some fins to eliminate interference but allowing the loose elements to "rattle" was considered. Neither of the latter two alternatives present reactivity or control perturbations. The reactivity and control effects associated with the fin-on-fin configuration are indicated in Table IV relative to the base case configuration of Table II. These values are extrapolations from the base case and require the benefit of verifying calculations but they should properly show the trends. The effect of considering Hastelloy-X-280 cladding is also shown.

TABLE II

REACTOR CORE TEST CONCEPTUAL MODEL DESIGN SUMMARY

DESIGN

• NOMINAL THERMAL POWER	600 Kwt
• NUMBER OF ELEMENTS	29
• LATTICE PITCH	0.670 in.
• INLET TEMPERATURE	1065 °F
• OUTLET TEMPERATURE	1200 -20 °F
• REFLECTOR TYPE	VOID BACKED Be
• INNER REFLECTOR TYPE	CLAD BeO
• CORE DIAMETER	12.580 in.
• CORE LENGTH (ACTIVE FUEL)	18 in.
• FUEL ROD DIAMETER (INNER/OUTER)	0.560/0.575 in.
• FUEL CLADDING	0.032 in. INCOLOY 800
• BARRIER	SCB
• GAP	6 mils (RADIAL)
• FIN HEIGHT	30/15 mils
• FUEL ELEMENT SPACING - NOMINAL (INNER/OUTER)	30/15 mils
• POISON	Eu ¹⁵¹ + Gd ¹⁵⁵
• FUEL	ZrH + 10.5 wt% U235, N _H = 6.3
• FUEL ELEMENT DIMENSIONS	
I.D. (INNER ZONE)	0.576 in.
(OUTER ZONE)	0.591 in.
O.D. NEUTRAL ELEMENTS (INNER ZONE)	0.640 in.
(OUTER ZONE)	0.655 in.
FIN O.D. (INNER ZONE)	0.700 in.
(OUTER ZONE)	0.685 in.
• FIN LENGTH	15.5 in.
• FIN SPIRAL	R-L-N
• FIN PITCH	5.25 in/turn
• FIN RELIEF CUT	
HOT END 6.5 in.	12 mils
CENTER 2.0 in.	0 mils
COLD END 7.0 in.	8 mils

TABLE III

FUEL ELEMENT DIMENSIONS AND PITCH MISMATCH

<u>Outer Zone</u>		<u>Inner Zone</u>
168	Number of Elements	127
0.670	Pitch*	0.670
-0.015	Element-to-Element Spacing	-0.030
0.655	Cladding O.D.	0.640
-0.064	Cladding Thickness	-0.064
0.591	Cladding I.D.	0.576
0.016	Glass plus Gap Thickness	0.016
0.575	Fuel Diameter	0.560
0.655	Cladding O.D.	0.640
0.030	2* Fin Height	0.060
0.685	Fin Envelope	0.700
0.655	Neutral Envelope	0.640
1.340	2* Pitch	1.340
0.670	Pitch	0.670
<u>At Zone Interface</u>		
0.685	Fin Envelope	0.700
0.640	Neutral(other zone)	0.655
1.325	2* Pitch	1.355
0.6625	Pitch at Boundary	0.6775
0.6700	Nominal Pitch	0.6700
-0.0075	Mismatch	+0.0075

* All dimensions in inches, diametral.

TABLE IV

REACTIVITY AND CONTROL PENALTIES FOR FIN-ON-FIN ELEMENT SPACING

<u>Pitch</u> (inches)	<u>Fin</u> (mils)	<u>Spacing</u> (mils)	<u>Cladding</u> <u>Material</u>	<u>Thickness</u> (mils)	<u>Excess Reactivity</u> <u>Change (\$)</u>	<u>Control Worth</u> <u>Change (\$)</u>
0.670	15/30	FOT*	Inc 800	32	0	0
0.670	10/20	FOF**	Inc 800	32	-1.54	+0.33
0.680	10/20	FOF	Inc 800	32	-0.54	-0.02
0.690	10/20	FOF	Inc 800	32	+0.46	-0.37
0.670	15/30	FOT	Hast-X-280	20	+3.88	-1.14

* fin-on-tube

** fin-on-fin

Conclusions and Recommendations

It is necessary to choose a new reference design as soon as possible so that the preliminary design phase of the core design may proceed in an orderly fashion. This design must be based on our current best knowledge. The actual effect on element cladding stresses resulting from neutral element looseness at the zone boundary is currently unknown but eventual padding of these elements remains a relatively simple option. Discussion with personnel in Fuel Element Engineering and Development Group has indicated that the additional shaving of the fins on those elements which cause overlap is feasible. Relocating the Ring 8 neutral element end-pin holes in the grid plates would have the effect of taking the 7.5 mil "slop" on the Ring 7 side of the Ring 8 neutral elements and placing it equally on both sides of the element is another option, but has not yet been quantitatively evaluated.

For purposes of the current design effort, Program Office direction is to use the design given in Table II assuming fins will be shaved at the zone boundary as required. The consequences of the "loose" neutral elements are to be evaluated before any decision to incorporate support pads is made.