MAY 10 1967

UNCLASSIFIED

CLASSIFICATION LEVEL
(S, C OR U)

~~CPSTI PRICES~~

~~H.C. \$ 3.00, MN. 65~~

ATOMICS INTERNATIONAL
A Division of North American Aviation Inc.

NAA-SR-MEMO COVER SHEET

REPORT TITLE

S8DS VARIABLY SPACED CORE, EVALUATION AND DESIGN

AUTHOR

R. H. Tromel

NAA-SR-MEMO 12295

(This Document Contains _____ Pages.)
(This is Copy _____ of _____ Series _____)

CLASSIFICATION TYPE
(RD OR DI)

MASTER

NAA-SR-MEMOs are working papers and may be expanded, modified, or withdrawn at any time, and are intended for internal use only.

THIS REPORT MAY NOT BE PUBLISHED WITHOUT THE APPROVAL OF THE PATENT BRANCH, AEC.

LEGAL NOTICE

This report was prepared as an account of Government sponsored work. Neither the United States, nor the Commission, nor any person acting on behalf of the Commission:

A. Makes any warranty or representation, express or implied, with respect to the accuracy, completeness, or usefulness of the information contained in this report, or that the use of any information, apparatus, method, or process disclosed in this report may not infringe privately owned rights; or

B. Assumes any liabilities with respect to the use of, or for damages resulting from the use of information, apparatus, method, or process disclosed in this report.

As used in the above, "person acting on behalf of the Commission" includes any employee or contractor of the Commission, or employee of such contractor, to the extent that such employee or contractor of the Commission, or employee of such contractor prepares, disseminates, or provides access to, any information pursuant to his employment or contract with the Commission, or his employment with such contractor.

UNCLASSIFIED

CLASSIFICATION LEVEL
(S, C OR U)

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

DO NOT REMOVE THIS SHEET

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.

ATOMICS INTERNATIONAL A Division of North American Aviation, Inc.		NAA-SR-TDR- XXXXXX 12295		APPROVALS	
TECHNICAL DATA RECORD		PAGE 1 OF 19			
AUTHOR R. H. Tromel <i>R.H. Tromel</i>		DEPT. & GROUP NO. 731 14		DATE 1-5-67	
TITLE S8DS Variably Spaced Core, Evaluation and Design		GO NO. 7695		S/A NO. 13330 TWR	
PROGRAM SNAP 8		SUBACCOUNT TITLE S8DS Engineering and Analysis		SECURITY CLASSIFICATION	
DISTRIBUTION D/715 Cano 2 R. A. Johnson L. M. Maki D. G. Mason W. J. Roberts R. F. Wilson D/731 Cano 2 R. F. Audette K. R. Birney D. J. Cockeram E. J. Donovan R. J. Gimera R. B. Harty R. I. Jetter H. Rood J. Susnir L. D. Swanson C. A. Willis Heat & Mass Transfer Unit (12)		(CHECK ONE BOX ONLY) UNCL. ☒ AEC ☐ CONF. ☐ DOD ☐ SECRET ☐		(CHECK ONE BOX ONLY) RESTRICTED DATA ☐ DEFENSE INFO. ☐	
		AUTHORIZED CLASSIFIER SIGNATURE		DATE 1/4/67	
		STATEMENT OF PROBLEM Develop a design technique for shaping coolant flow with variable flow area.			
		ABSTRACT: In the current S8DR, design flow is shaped by a baffle to optimize reactor performance. Pressure drop of the core is large due to the relatively high coolant velocities required. An alternate flow shaping technique involves varying the element spacing to obtain a flow area variation. When a uniform inlet and outlet pressure is provided for all channels, the flow rates are calculable from channel area relations. The variable area technique has been applied to the S8DR core and core pressure drop can be reduced from 4.9 to about 1.2 psi. Implementation of the variable area core requires that S8DR lower plenum flow asymmetry be smoothed to obtain the uniform pressure condition. This flow shaping technique offers the potential of considerably reduced reactor pressure drop and an analytical method of designing flow shaping.			

ATOMICS INTERNATIONAL

A Division of North American Aviation, Inc.

NO. NAA-SR-TDR-12295

DATE 1-5-67

PAGE 2 OF 19

Flow shaping is a significant factor in obtaining maximum performance from the S8DS reactor. In the current design a centrally peaked velocity profile is provided by a baffle below the lower grid plate. Since the flow channels are interconnected, crossflow tends to flatten the profile as it passes through the core. The baffle has two important features; one, because the restriction is severe, it eliminates flow asymmetry from the lower plenum and two, it produces the radial pressure profile, which in turn results in the radial velocity gradient. In Figure 1 the current design is shown along with inlet, midplane and outlet velocity profiles. These profiles are obtained by extrapolation of experimental data which covers the core axis from $z/L = 0.9$. Also shown is the inlet plenum geometry with the single radial inlet nozzle which is responsible for the asymmetric plenum flow patterns. Approximate velocities in the plenum and baffle region are indicated. The pressure drop of a baffled core is relatively large due to the high velocities required. The reactor pressure drop of 4.8 ± 0.3 psi was obtained from a hydraulic experiment and compares well to a calculated value of 4.9 psi. If element spacings larger than the current 0.010 in. are used, the crossflow will increase and exceptionally high peaked inlet velocity profiles will result in higher pressure drops. The current baffle was developed from a series of hydraulic tests with a full scale core model (Reference 1). Subsequent core analysis shows that the flow profile does not optimize reactor lifetime and that the profile overcools the center of the core. An updated flow profile is desirable; however, design of baffles has elluded analysis and further experimentation would be required to verify a change of the baffled core. Some objections in addition to the high pressure drop and difficult design have been mentioned including: pressure forces large enough to lift fuel elements off the grid plate and small clearances between the baffle and grid plate subject to obstruction. Alternates to the single baffle core include: the use of a second baffle above the core to reduce maximum velocities, orificing of the grid plates and variable spacing of the elements. This study

ATOMICS INTERNATIONAL

A Division of North American Aviation, Inc.

NO. NAA-SR-TDR-12295

DATE 1-5-67

PAGE 3 OF 19

deals with variable spacing since it appears to be the most attractive method.

With a variably spaced core flow, variation is achieved with a nearly uniform velocity and a variable flow area. Crossflow is absent because the radial pressure gradient is nonexistent. It is first necessary to provide a uniform radial pressure gradient at the inlet of the core so that all channels will have equal pressure drops. In the present reactor, this would require a flow distribution device since, as previously indicated, flow in the lower plenum is highly asymmetric. Channels are varied by spacing the elements to have larger channels in the center of the core. The flow rate in each channel is then found using the relation

$$\Delta p = \left(\frac{w}{A}\right)^2 \frac{1}{2 g_c \rho} \frac{4 f L}{D_h}$$

and assuming equal pressure drop. This relation indicates the analytical advantage of the variable area core. Flow is now one dimensional, a function of radius only.

The optimum flow profile is found by adjusting flow to each of the elements to obtain maximum lifetime as S8DS operating conditions. Multiple LOAFER cases have shown that a uniform radial peak fuel temperature distribution will optimize reactor lifetime. Therefore, the optimum flow profile was generated by adjusting flows to each of the nine fuel rings for peak fuel temperature at EOL (end of life) conditions. All rings were so adjusted except the ninth where the bypass flow boundary condition requires a flow higher than optimum. In this study, the ninth ring flow was assumed to be 1.25 times the optimum value. This factor was derived from previous experience with S8DS core designs. The resultant flow profile is shown in Figure 2 and compared with an average radial profile from the current design.

ATOMICS INTERNATIONAL

A Division of North American Aviation, Inc.

NO. NAA-SR-TDR-12295

DATE 1-5-67

PAGE 4 OF 19

Determination of the spacing required to achieve a desired flow profile is basically by trial and error. Starting with the present rod centered core of 211 elements, a radial spacing with large spacing at the center and a minimum of 10 mils at the outside was laid out. A restriction of the study is that the current vessel be utilized. This limits the vessel internal diameter to 9.214 in. or to 9.274 in. if shaving of the vessel is permitted. The final spacing, Figure 3, indicates that only 199 elements are accommodated. The extreme radius of the eliminated corner element is 4.678 in. making an interference of 0.071 in. with a core vessel 9.215 in. in diameter. These elements are 0.560 in. in diameter. Spacings on the "c" radius are assumed and "a" and "b" spacings are calculated from the 30-60° triangle geometry. Spacings on the "a" leg are assumed equal but because of the geometry are considerably larger than the radial spacings in outer element rings. In the ninth ring, for instance, the radial spacing is 10 mils while the "a" spacing is 22.5 mils. Since crossflow is absent, this variation in spacing for a given channel should cause no concern. Individual channel areas can be calculated from the spacings. A useful expedient is to average the three spacings for a given channel and find the channel area corresponding to the average spacing, Figure 4. Irregular flow areas are located between the internal reflectors or fillers and the ninth ring elements. In the present example these components are designed to reduce the bypass area to a minimum with no consideration given to using present reflectors. A minimum spacing of 10 mils is maintained in this area. The flow distribution calculation is carried out neglecting the bypass and will subsequently be corrected when a calculation of the bypass is available. Once the distribution of channel area is obtained, the flow can be calculated. The method adopted first normalizes the area to the minimum channel area, Table I. Assuming a friction factor dependence

$$f = f(Re)^{-0.2} \propto W^{-0.2}$$

ATOMICS INTERNATIONAL

A Division of North American Aviation, Inc.

NO. NAA-SR-TDR-12295

DATE 1-5-67

PAGE 5 OF 19

and noting that

$$D_n \propto A$$

the pressure drop equation becomes

$$\Delta p \propto \left(\frac{W}{A}\right)^2 \frac{W^{-0.2}}{A}$$

and rearranging the flow area relation is found

$$\frac{W}{A} = \left(\frac{A}{A}\right)^{1.67}$$

The normalized flow distribution based on minimum area must then be normalized to satisfy continuity. This has been done by plotting flow versus r^2 , where r is the radius to the center of the channel and using the area under the curve to reduce the flows. The assumption here is that the number of channels per unit area is nearly constant and that the core can be treated as homogeneous. Supporting calculations, where each channel is considered, show that these assumptions are justifiable.

The final flow profile, Table I and Figure 5, show that good agreement between the desired profile and the derived profile has been achieved. Bypass flow has been considered and found negligible. Details of this calculation are included in the appendix.

The final test of the profile is the computation of resulting peak fuel temperatures. The UPSTART (Reference 3) model, which considers all channels and elements in the 300° symmetric segment of the core has been used. All typical elements use the calculated normalized flow as a "flow factor" except ninth ring elements. Ninth ring channel flow factors must account for the unheated internal reflector surfaces which partly bound the channel. Thus, a channel bounded by two elements has a flow factor equal to 3/2 the normalized flow and in a channel bounded by one element the flow factor equals 3/1 times the normalized flow. When ring models such as LOAFER or TEMPR8 (Reference 4) are used, the ninth ring flow factor must account for

ATOMICS INTERNATIONAL

A Division of North American Aviation, Inc.

NO. NAA-SR-TDR-12295

DATE 1-5-67

PAGE 6 OF 19

decreased heated periphery and ninth ring flows should be increased by 1.45 to obtain flow factors. Peak fuel temperatures for the 199 element, rod centered core are plotted in Figure 6. They form a band of temperatures flat to within $\pm 15^{\circ}\text{F}$ when the power profile corresponding to average life is used. This model has not used the varying gas gap width resulting from fuel swelling which tends to reduce temperatures in the center of the core.

A similar layout was made of a channel centered core, Figure 7. The symmetrical segment must now be 60° and since there is no radial row of elements, the row closest to a radius was selected for spacings. The total number of elements which fit in the current vessel is 198 although an additional three elements may fit if the vessel is shaved. The extreme radii of three outer elements in the 60° segment, their interference with the current vessel and the total number of elements in the core if they are accommodated is listed in Table II. This element arrangement offers the possibility of slightly increasing the number of elements at the expense of a larger number of internal reflector designs. The flow profile is similar to that of the rod centered core since spacings are equal and only the location radii of the channels is changed.

Pressure drop of the variably spaced core is computed from the same relation that was used to size the core. The core average mass velocity is computed from the total flow and flow area. The channel corresponding to the core average mass velocity is found at the point where the normalized flow is 1.0. Pressure drop is computed from that channel's dimensions and the core average flow. If grid plates are not to introduce additional shaping, they will have to have holes proportional to the channel area. Details of the pressure drop calculation are included in the appendix. The total pressure drop of this core assuming that plenum asymmetry can be removed with no increase in pressure drop over the current inlet nozzle is 1.23 psi at design flow.

ATOMICS INTERNATIONAL

A Division of North American Aviation, Inc.

NO. NAA-SR-TDR-12295

DATE 1-5-67

PAGE 7 OF 19

Uncertainty in flow in a given channel is due primarily to variation in channel area. With a 10 mil tolerance assumed for the spacing, the flow in the smallest channel may be a maximum of 40% low. This is comparable to individual channel uncertainty in the current S8DS core. Coolant temperatures in the channel are not increased in proportion to the decreased channel flow since the energy tends to redistribute to neighboring channels.

The implementation of a variable area core utilizing the current S8DS core vessel without shaving would require:

1. Reduction of the number of elements from 211 to 199.
2. Redesign of the grid plates, internal reflectors and fillers.
3. Design and testing of a flow distribution device for the lower plenum.
4. Testing of a full scale hydraulic model of the proposed variably spaced core to verify its performance.

The hydraulic tests of the final core would involve the mass collection procedure that was used for the S8ER core. Measurement of in core velocities is not required or desirable since the flow areas vary and flow rates in a given channel could not be obtained. Since axial flow dependence has been eliminated, measurement of the outlet flow profile is satisfactory. The question of how well the lower plenum flow smoothing device is working can be answered by a similar mass collection test using only the lower grid plate. In the mass collection technique, the core is inverted and flow is collected from individual channels.

The variable area core offers the following advantages for S8DS:

1. Potential of considerably reduced reactor pressure drop assuming that plenum asymmetry can be removed with low pressure drop.
2. An analytical method of designing core flow shaping.
3. Elimination of the axial dependence of flow.

ATOMICS INTERNATIONAL

A Division of North American Aviation, Inc.

NO. NAA-SR-TDR-12295DATE 1-5-67PAGE 8 OF 19

TABLE I

Flow Profile Parameters for a 199 Element Rod Centered Core

Channel Number ¹	Location r/R^2	Spacing "c"	Channel Area	$a/a_{\min}$	$(a/a_{\min})^{1.67}$	Normalized Flow ³
1	0.076	35	0.0299	1.45	1.86	1.43
2	0.207	35	0.0299	1.45	1.86	1.43
3	0.345	30	0.0282	1.37	1.69	1.30
4	0.476	25	0.0266	1.29	1.53	1.18
5	0.610	20	0.0247	1.20	1.36	1.05
6	0.745	15	0.0229	1.11	1.19	0.92
7	0.875	10	0.0211	1.03	1.05	0.81
8	1.010	10	0.0206	1.00	1.00	0.77

- Notes: 1. Channel number is shown on Figure 3.
2. Location r/R is radius r from center of core to center of channel divided by $R = 4.347$.
3. Normalized flow is normalized by 1.30 to satisfy continuity.

ATOMICS INTERNATIONAL

A Division of North American Aviation, Inc.

NO. NAA-SR-TDR-12295DATE 1-5-67PAGE 9 OF 19

TABLE II

Outer Element Dimensions for Channel Centered Core

Element	Extreme Radius	Interference 9.214 in. dia.	Total Elements
1	4.638	0.031	201
2	4.646	0.039	207
3	4.676	0.069	213

Element numbers correspond to those in Figure 7.

ATOMICS INTERNATIONAL

A Division of North American Aviation, Inc.

NO. NAA-SR-TDR-12295

DATE 1-5-67

PAGE 10 OF 19

REFERENCES

1. T. E. Horne, "S8DS Baffle Development," NAA-SR-TDR-11406, July 13, 1965.
2. K. R. Birney, "LOAFER," NAA-SR-TDR-12237, to be published.
3. P. M. Magee and R. W. Winson, "Three-Dimensional Transient Thermal Model of a SNAP Reactor," NAA-SR-TDR-11822, February 10, 1966.
4. P. M. Magee, "TEMPR8," NAA-SR-TDR-12218, October 28, 1966.

Figure 1. Coolant Velocities in the Current S8DS Reactor

W 122-8-2

UNCLASSIFIED
 Classification
 RD/DI
 Group
 Date: 1/4/67
 Authorized Classifier Signature

PREPARED BY:	ATOMICS INTERNATIONAL A DIVISION OF NORTH AMERICAN AVIATION, INC.	PAGE NO. 12 OF 19
CHECKED BY:		NAA-SR-TDR-12295 REPORT NO.
DATE: 1-5-67		MODEL NO.

Figure 2. Optimized S8DS Flow Profile

UNCLASSIFIED		
Classification	RD/DI	Group
Date: 1/7/67
Authorized Classifier Signature		

PREPARED BY:	ATOMICS INTERNATIONAL A DIVISION OF NORTH AMERICAN AVIATION, INC.	PAGE NO. 13 OF 19
CHECKED BY:		NAA-SR-TDR-12295
DATE: 1-5-67		REPORT NO.
		MODEL NO.

Figure 3. Element Layout of a Red Centered Core

Classification	RD/DI	Group
Date: 1/7/67		
Authorized Classifier Signature		

PREPARED BY:	ATOMICS INTERNATIONAL A DIVISION OF NORTH AMERICAN AVIATION, INC.	PAGE NO. 14 OF 19
CHECKED BY:		NAA-SR-TDR-12295 REPORT NO.
DATE: 1-5-67		MODEL NO.

Figure 4. Channel Area as a Function of Element Spacing

UNCLASSIFIED	RD/DI	Group
Date: 1/9/67
Authorized Classifier Signature		

PREPARED BY:	ATOMICS INTERNATIONAL A DIVISION OF NORTH AMERICAN AVIATION, INC.	PAGE NO. 15 OF 19
CHECKED BY:		NAA-SR-TDR-12295 REPORT NO.
DATE: 1-5-67		MODEL NO.

Figure 5. Flow Profile, Rod Centered Core

UNCLASSIFIED		
Classification	RD/DI	Group
Date: 1/4/67
Authorized Classifier Signature		

PREPARED BY:	ATOMICS INTERNATIONAL A DIVISION OF NORTH AMERICAN AVIATION, INC.	PAGE NO. 16 OF 19
CHECKED BY:		NAA-SR-TDR-12295 REPORT NO.
DATE: 1-5-67		MODEL NO.

UNCLASSIFIED		
Classification	RD/DI	Group
Date: 1/4/67
Authorized Classifier Signature

Fig 6. Peak Fuel Temperatures for Variable Area Core

Scale 2/1

ATOMICS INTERNATIONAL

A Division of North American Aviation, Inc.

NO. NAA-SR-TDR-12295

DATE 1-5-67

PAGE 18 OF 19

APPENDIX

Bypass Flow, Rod Centered Core

Average Channel Area	$\frac{\sqrt{3}}{4}(\text{Pitch})^2 - \frac{\pi}{8}(d)^2$	0.0241 sq. in.
Average Channel Hydraulic Diameter	$8A/\pi d$	0.110 in.
Approximate Bypass Area	$\pi (9.204)(0.010)$	0.289 sq. in.
Approximate Bypass Hydraulic Diameter	$2(0.010)$	0.020 in.

$$\left(\frac{W}{A}\right)^2 \frac{1}{D_n} \left(\frac{A}{D_n W}\right)^{0.2} = \text{Constant} = \frac{W^{1.8}}{D_n^{1.8} A^{1.8}}$$

$$W_{BP} = W_A \left(\frac{D_{nBP}}{D_{nA}}\right)^{0.445} \left(\frac{A_{BP}}{A_A}\right) = W_A \left(\frac{0.02}{0.11}\right)^{0.445} \left(\frac{0.289}{0.0241}\right) = 4.64 W_A$$

There are 450 average channels so the bypass is

$$\frac{4.64 W_A}{4.64 W_A + 450 W_A} = 0.01$$

1% of the total flow.

This is small enough to be neglected.

Pressure Drop, Rod Centered Core

$$\Delta p = \left(\frac{W}{A}\right)^2 \frac{1}{2g_c \rho} \left\{ \frac{4fL}{D_n} + \sum K \right\}$$

$$\text{Average Channel Mass Velocity} \quad \frac{(13.58)(144)}{450(0.0241)} = 180 \text{ lb/sq ft sec}$$

K factors

Lower Grid: inlet 0.05, channel 0.10, exit 0.70

Channel Inlet: 0.40 (element assumed off grid plate)

Channel Exit: 0.70 (element assumed off grid plate)

Upper Grid: inlet 0.05, exit 0.05 (diffuser)

ATOMICS INTERNATIONAL

A Division of North American Aviation, Inc.

NO. NAA-SR-TDR-12295DATE 1-5-67PAGE 19 OF 19

$$\Delta p = (180)^2 \frac{1}{2(32.2)(45)(144)} \left\{ \frac{4(0.007)(17)}{0.110} + 2.05 \right\}$$
$$= 0.5 \text{ psi}$$

Inlet plenum 0.67 (current value)

Outlet plenum 0.06 (current value)

Total Δp = 1.23 psi