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SM-2 TASK 3
MECHANICAL DESIGN REPORT

OCTOBER 1958 TO MARCH 1960

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ALCO PRODUCTS, INC.
NUCLEAR POWER ENGINEERING DEPARTMENT
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**SM-2 TASK 3
MECHANICAL DESIGN REPORT
OCTOBER 1958 TO MARCH 1960**

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29	W. K. Stromquist	40	W. M. S. Richards
30	H. L. Hoover	41	G. P. Pancer
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32	J. G. Gallagher	43	R. E. Williams
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ABSTRACT

Progress on design studies under Task 3, the mechanical design portion of the SM-2 Core and Vessel design, is summarized for the period October 1958 to March 1960. Task 3 covers the mechanical design of the reactor vessel, vessel closure, nozzle penetrations, steel reflector, core support structure, flow divider, control rods, absorbers, and fuel elements.

Layouts showing the basic designs, major dimensions, and materials of construction are presented. Stresses for the reactor vessel selected were within ASME Code limits. The report does not contain final results of Task 3 work.

TABLE OF CONTENTS

	<u>Page</u>
ABSTRACT - - - - -	vii
1.0 SUMMARY - - - - -	1
2.0 DESIGN REQUIREMENTS - - - - -	3
3.0 BASIC DESIGN EVALUATION - - - - -	5
3.1 Single Pass, Up Flow - - - - -	5
3.2 Single Pass, Down Flow - - - - -	5
3.3 Two-Pass, Up-Down Flow - - - - -	6
3.4 Two-Pass, Down-Up Flow - - - - -	6
3.5 Two-Pass, Up-Up Flow - - - - -	6
4.0 REACTOR VESSEL - - - - -	7
5.0 REACTOR VESSEL CLOSURE - - - - -	13
5.1 Cover Stowage - - - - -	13
5.2 "D" Closure - - - - -	13
5.3 Bolting - - - - -	13
6.0 REFLECTOR DESIGN - - - - -	19
7.0 FUEL ELEMENTS - - - - -	20
7.1 Plate Spacing - - - - -	20
7.2 Discrete Poison - - - - -	20
7.3 Suppressor - - - - -	21
7.4 End Box - - - - -	21
7.5 Control Rod Fuel Element - - - - -	22
7.6 Fuel Location - - - - -	22
8.0 CONTROL ROD - - - - -	35
9.0 CORE SUPPORT STRUCTURE - - - - -	39
9.1 Control Rod Array - - - - -	39
9.2 Bottom Plate - - - - -	39
9.3 Flow Divider - - - - -	40
9.4 Top Plate - - - - -	40
9.5 Skirt - - - - -	40
9.6 Securing Core Support Structure - - - - -	41
9.7 Placement of Dashpots - - - - -	41

TABLE OF CONTENTS (CONT'D)

	<u>Page</u>
10.0 REFERENCES AND REFERENCE DRAWINGS -----	49
11.0 APPENDIXES -----	59
A. Calculations of Thermal Stresses in Bolts (Operating in Water) -----	61
B. Core Support Structure Tie Down -----	65
C. Stationary Fuel Element Flotation -----	67
D. Vessel Closure Test Procedure -----	69
E. Bolt Test Procedure -----	71

LIST OF DRAWINGS

<u>Drawing</u>	<u>Title</u>	<u>Page</u>
AEL-521	Reactor Vessel	9
AES-341	Reactor Cross Section	11
AEL-519	Closure Test Rig	17
AEL-393	Stationary Fuel Elements	23
C9-50-1120	End Fixture Ass'y	25
R9-13-1017	Fuel Element	27
AES-319	Fuel Element Spacing Study	29
AES-419	Fuel Element	31
AES-410	Fuel Location in SM-1, SM-1A, PM-2A, and SM-2	33
AEL-445	Control Rod Ass'y	37
AEL-547	Cover, Core Support	43
AEL-577	Core Structure (Cross Section)	45
AEL-567	Core Structure	47

1.0 SUMMARY

The report covers the mechanical design studies performed under SM-2 Task 3 - Reactor Mechanical Design, during the period October 1958 to March 1960.

A small diameter stainless steel vessel was selected and designed. Thru bolts were selected for the reactor vessel closure, to permit easy replacement. A steel reflector was designed to reduce the neutron damage to the vessel walls.

The core support structure remained basically the same as the SM-1 design except that the dashpots were moved lower in the vessel, and a flow divider was inserted to permit two-pass, up-up flow. The control rod design was greatly improved over previous designs in that the cap was light and open. As another design change from SM-1, the weight necessary for scram was transferred to the rack to reduce the column loading on the control rod.

The stationary fuel elements were shortened considerably over previous designs and the ends opened to permit better flow distribution.

Test programs for the closure and flow divider were presented and approved, but not completed at this writing.

Layouts were prepared of the reactor vessel, closure test rig, fuel elements, control rod assembly and core support structure.

Stress calculations for the selected reactor vessel were performed which indicated stresses were within ASME Code limits.

Final results of Task 3 effort are not given, as work is continuing.

2.0 DESIGN REQUIREMENTS

The contract requirements for SM-2 Task 3 - Reactor Mechanical Design, are given below:

Task 3.0 Reactor Vessel

A design will be prepared for the reactor vessel together with all internal components and structures, including mechanical design of the fuel elements. Layouts will be prepared in sufficient detail to insure practicability of basic design, establish major dimensions, specify materials of construction, and show that major stresses are within safe limits. The final results of this work will be contract plans and specifications of the reactor vessel and contents integrated as a whole. Improvements in structure, size and materials will be incorporated based upon design studies of core structure, steel reflector, flow pattern, vessel closure and other items which may arise as the work progresses.

1. The core is to be of APPR type.
2. Fuel elements, both control rod and stationary as well as absorbers, are to be interchangeable with SM-1, SM-1A, PM-2A. Interchangeable is defined as: The active sections of the stationary and control rod elements are to be capable of installation in SM-1, SM-1A, PM-2A and SM-2, with end boxes and handles installed.
3. The pressure vessel is to be designed on the basis of the latest edition of ASME Unfired Pressure Vessel Code.
4. Bottom drives of APPR-1 type are to be employed.
5. Proper attention will be given to reduction of manufacturing costs.
6. Material to be selected on the basis of corrosion resistance and radiation stability.
7. 7 x 7 array of elements.
8. 45 fuel elements, 38 stationary and 7 control rod, using APPR-1 (SM-1) dimensions.
9. Effective core diameter 22 inches.
10. Effective core height 22 inches.

3.0 BASIC DESIGN EVALUATION

Task 3 of the SM-2 Core and Vessel program covers the reactor mechanical design from nozzle to nozzle, including the reactor vessel, closure, core support structure, steel reflector, control rods, and stationary fuel elements, but not the control rod drives.

At the program's start, all SM-2 Tasks consisted of studies to determine the best designs, based on operation, flow characteristics, thermal characteristics, mechanical characteristics, servicing, maintenance, and cost. Task 3 mechanical studies incorporated design criteria from hydraulic, thermal, and nuclear studies.

The initial Task 3 mechanical studies evaluated the number and type of flow passes. The evaluation is summarized below for five types of vessels studied. As a result of the study, a two-pass core with up-up flow was selected for SM-2.

Jointly with other SM-2 Task engineers, decisions were made to use a reactor design pressure of 2200 psia, and a vessel of either carbon steel or stainless steel. With these decisions made, it was possible to study the components separately.

3.1 SINGLE PASS, UP FLOW

This vessel was similar to SM-1 and SM-1A. The diameter of the vessel was reduced at the control rod drive penetrations to reduce the weight and water volume. Both inlet and outlet nozzles were 16-in. diam and located on the same plane above the core. Local shield plates supported off the core support structure were necessary to protect the nozzles from gamma streaming. The core support structure, supported from the vessel flange, also served as a flow divider. The water flow was down the outside of the core and up thru the core to the outlet nozzle. This design provided excellent decay heat removal, light weight and small volume, but required a longer vessel and thus offered a skid construction problem. Large diameter nozzles and piping would require a large primary pump, and the nozzles would have to be shielded. The design was eliminated from further consideration, as being economically unsound.

3.2 SINGLE PASS, DOWN FLOW

This vessel was of uniform diameter with two 16-in. nozzles below the core, but at different levels. The core support structure was supported on a

plate between the nozzles and served as a flow divider. The coolant entered the lower nozzle to the plenum chamber, flowed up thru the core, and down the outside of the core to the outlet nozzle. This design presented a simple vessel with reduced overall length, but was heavy due to large water volume. A large pump would be required, and decay heat removal would be a potential problem. This design was also considered economically unsound and was discounted.

3.3 TWO-PASS, UP-DOWN FLOW

This vessel was of uniform diameter with two 12-in. nozzles at two levels below the core. Flow dividers within the core support structure and in the core structure support established the two flow passages. The flow was up the center of the core, down the outside row of fuel elements and to the outlet nozzle. This design was attractive because of the shorter vessel, simplified flow dividers, and minimum steady state flow requirements. It was unattractive and rejected because of the increased weight, greater volume, and poor decay heat removal characteristics.

3.4 TWO-PASS, DOWN-UP FLOW

This design had the lower portion of the vessel of reduced diameter to save weight and volume. Both 12-in. nozzles were on the same plane above the core. Flow dividers directed the water down thru the outside fuel elements and back up thru the center fuel elements to the outlet nozzle. This design was attractive because of the excellent reliability for emergency flow characteristics and decay heat removal. It was unattractive because of vessel height, complicated core support structure, fuel handling problems and distribution of fluid thru the thermal shield.

3.5 TWO-PASS, UP-UP FLOW

This design utilized a straight wall, small diameter vessel with the inlet nozzle below the core and the outlet nozzle above the core. The coolant entered the vessel and flowed up the outside row of fuel elements, turned and went down the outside of the core, and turned again to go up thru the center of the core to the outlet nozzle. This design was attractive because of smaller volume than the other designs, and good decay heat removal.

4.0 REACTOR VESSEL

Main considerations in design of the vessel were cost, weight reduction, and the ability to meet conditions imposed by flow requirements, a revised rod pattern and steel reflector.

The first vessel designs were very compact, but studies by other SM-2 Tasks indicated that the neutron damage to the vessel walls was unacceptable. Austenitic stainless steels are capable of resisting radiation damage at integrated neutron fluxes at energies of at least 1 to 2×10^{21} nvt greater than 1 Mev. ASTM A-212B has satisfactory properties at integrated neutron fluxes up to 5×10^{19} nvt. APAE No. 61⁽¹⁾ discusses this problem in detail. Other SM-2 Tasks using the above information indicated that a carbon steel vessel should be designed to 55 in. ID and a type 347 or 304 ss vessel should be approximately 41 in. ID.

Designs of two vessels were prepared, one carbon steel and the other stainless steel. In order to save cover weight and stowage space, the neck of the vessel was reduced to 32 in. This would still permit the core structure and the first reflector rings to be installed after vessel fabrication. There would also be sufficient room for the upper flow divider removal and fuel transfer. Drawings were sent to fabricators for comment and cost studies. After receipt of this information, an Alco engineering evaluation was made, and a Type 304 ss vessel was selected as reference. A design of the vessel is shown on Dwg. AEL-521 and AES-341.

The selected vessel was straight-walled, and necked down at the closure end to reduce cover size. The inlet nozzle was below the core and the outlet nozzle above the core. Stress calculations for the selected vessel, based on operating conditions and materials used, were performed. Stresses were within limits allowed by the 1959 edition of the ASME Code for Unfired Pressure Vessels. The code calculations are not shown in this report as they are considered standard industry - wide type calculations.

Sample calculations of the cover bolts stress study are shown in the Appendixes to acquaint the reader with the method used. Closure tests to be performed will determine the adequacy of the calculation method, and permit selection of bolts.

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REACTOR CROSS SECTION			
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5.0 REACTOR VESSEL CLOSURE

Investigation of different type openings was made to reduce the weight and/or handling problems. Problems associated with the high pressure imposed on the reactor vessel were studied. Reactor bolting materials were evaluated to minimize galling between the stud and nuts.

With a large diameter vessel, the size and weight of the vessel cover presented a handling problem and required a large shield tank to accommodate the storage during fuel transfer. Preliminary investigations of other vessel heads and methods of handling a heavy head were conducted, but a design better than the bolted design could not be found.

5.1 COVER STOWAGE

A cover stowage mechanism was studied which would hold the cover in a horizontal position and swing it out of the way for fuel transfer. Because of the possible underwater maintenance problems, space requirements, and use of heavy, expensive equipment, this plan was abandoned.

5.2 "D" CLOSURE

Investigations were made of a "D" type closure which Alco Products, Inc., makes for heat exchangers, but the remote handling of the heavy blocks was as difficult or worse than remote nut handling. Stowage problems were the same as remote nut handling. Some forms of the modified "D" closure were examined, but none were more reliable or economical than the bolted closure.

Experience gained with the SM-1 reactor indicated that quick replaceability of studs was desirable. An investigation showed thru bolts feasible for this application. The vessel flange was designed with bolt keepers to hold the bolts in place. Replacement of a bolt could then be accomplished by removing the keeper and lifting the bolt out.

5.3 BOLTING

Since it was desirable that head bolts have the same coefficient of expansion as the vessel and head, A286 (AMS 5735) bolting material was selected as back-up for the stainless steel reactor vessel. This was believed the only high strength commercial bolting material with a coefficient of expansion approximating Type 304 ss. Although its use had been limited to high temperature applications because of cost and physical properties, it was reported as the most popular high temperature bolting material available.

However, A286 is not an ASME code approved material. Since the ASME does not generally grant approval of a new material for a single application without exhaustive proof of suitability, it was believed more practical to obtain a waiver from the AEC to use Aeronautical Material Specifications as the standard, (A286 is covered by AMS 5735.)

As a second disadvantage, little was known about the properties of A286 in the temperature range of interest. Of specific concern were its corrosion resistance (oxygen stress corrosion in water) in the anticipated environment, its ductility properties and its notch sensitivity. Testing to determine these characteristics would have had to precede its use for the SM-2 reactor.

As bolting materials, Type 403 or 410 ss had the major disadvantage of a coefficient of expansion about 2/3 that of the vessel and head material, Type 304 ss, introducing severe stress problems. However, both of these materials had ASME Code approval. Extensive testing at AEC facilities indicated these materials would provide satisfactory service under the corrosion environment (oxygen stress corrosion in water), provided proper heat treatment was used.

There was a large cost differential between bolts employing the two materials. Although costs on full sets were not obtained, quotations on single full size bolts indicated a differential of approximately \$150. per bolt, in favor of the Type 403 material.

A table of strength properties of the two bolting materials at comparable yield strength levels is noted below:

	<u>Bolting Material</u>	
	<u>A286</u>	<u>403</u>
Tensile Strength - psi	140,000	110,000
.2% yield strength - psi	90,000	90,000
.02% yield strength - psi	80,000	80,000
Hardness - Brinell	300	220

From a metallurgical standpoint, A286 should have provided a satisfactory bolting material, but Type 403 ss had to be selected to stay within the code, and meet the contract obligations.

Since reliability of the closure was considered marginal on the basis of analysis alone, a test program was instituted to prove and develop the closure design. Closure test rigs were designed and one selected to be built, in which the galling characteristics of the selected materials and the bolts could be checked under pressure and temperature conditions. Also, the temperature differential across the flange and head could be checked.

The test rig design, shown in Dwg. AEL-519, presented a simple vessel with the flange, gasket, cover, bolts and nuts the same as the proposed reactor vessel. Heaters and an external means of pressurizing were provided to simulate reactor conditions. Penetrations were provided so that pressure and temperature readings could be taken both inside and outside the unit. A simulated shield tank was provided to approach actual reactor conditions.

The vessel closure test procedure and bolt test procedure are included as Appendixes D and E, respectively, in this report.

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6.0 REFLECTOR DESIGN

Studies by the Reactor Engineering Section were made to determine whether to use a water or steel-reflected core; drawings of both types were made. Since the smaller diameter allowed in a stainless steel vessel requires a steel reflector to reduce gamma heating, it was decided to use a steel reflector with any vessel design selected.

The main design problems were weight, method of support, tolerances, expansion, and cost of the reflector. The space between the core and vessel wall was to be filled with steel as shown on Dwg. AEL-567, allowing only for necessary tolerances. The inner edge of the first reflector ring was to be as close as possible to the core; the ring was to be 1/2-in. thick. The second and third rings were transition pieces to go from the odd shape of the core to cylinders. The first three rings were to be supported off the core support structure and the remaining two were to be supported off the vessel wall. Calculations made by the Reactor Engineering Section indicated that the ring closest to the core should be 1/2-in. thick, and rings could get progressively thicker towards the vessel wall.

The water gap between all rings was set at 1/4-in. on the radius because actual movement during heat-up cannot be predicted. Movement would vary from ring to ring and even two rings of the same size might not move in the same manner. A large gap was desirable to avoid making close tolerance machining necessary.

The first rings were made as long as possible to protect the nozzle areas of the vessel. This was later found unnecessary and the rings were shortened, saving considerable weight.

7.0 FUEL ELEMENTS

Initial approach to fuel element design followed closely the design of SM-1 fuel elements. For economy, it was highly desirable to shorten the fuel element, since this would result in savings in vessel height, storage space, and shipping and manufacturing costs.

In design of the fuel element it was desirable to extend the element as little as possible beyond the 22-in. active core. Some dead end on the fuel plates was necessary to contain the fuel, amounting to 1/2-in. nominal on each end, thus making the fuel plate 23-in. overall length. As provision for handling the element, side plates were extended 1-in. on each end, making the fuel element 25-in. long. The space between the core support structure bottom plate and the fuel plate was determined so the length of the fuel element could be more accurately defined.

7.1 PLATE SPACING

Studies of plate thickness and spacing were conducted. Fuel element outside dimensions were to be such that this fuel element would fit any of the other Alco-designed cores with a cell size of 2.9375-in. Therefore outside dimensions were fixed at 2.874-in. by 2.865-in. to correspond to SM-1. Studies using 0.030 and 0.040-in. thick fuel plates were conducted. Other SM-2 tests indicated that the 0.040-in. thick plate was the most desirable. Side plates of varying thickness were studied and a 0.040-in. thick side plate was selected. With eighteen 0.040-in. fuel plates, the spacing between the plates was determined as 0.123-in. To permit a better welding job, extra material was left on the width of the side plates, which would be machined off after assembly.

7.2 DISCRETE POISON

Due to a requirement for addition of a discrete poison to the fuel elements, to help in reactor control, design changes were investigated. Three methods of adding poison were possible: external mechanical joining, external weld joining, and internal mixing with the fuel. Only the mechanical joining is discussed here. The welded joint method and internal mixing with the fuel were investigated under other SM-2 Tasks.

Two studies of mechanical joining were made, both giving undesirable results. The addition of a plate on the outside of the side plates would require many small rivets to hold the plate in place and prevent warpage due to the heat. Many small holes in the side plates would seriously weaken the fuel element and the plate thickness would tend to block the lattice flow of coolant.

As a second means of mechanical joining, the addition of strips between the fuel plates would require machining of the strips, and require many small rivets to hold the strips to the side plates and prevent warpage.

7.3 SUPPRESSOR

It was necessary to add a suppressor to the lower end of the stationary fuel element to eliminate the power spike. This was done by shortening the active fuel by 1/2-in. and adding a 1/2-in. suppressor internally in the fuel plate. The overall fuel plate length did not change as a result.

7.4 END BOX

To complete the design it was necessary to determine the end configuration of the stationary fuel elements. Several end box configurations were designed, as shown on Dwg. AEL-393. Pressure drop studies would have satisfactory pressure drop characteristics, but for proper flow distribution it was desirable to have the end as open as possible. The "Sabre," which is a protruding bar perpendicular to the fuel plates and extending beyond the side plates, was selected as offering the best conditions from pressure drop, flow, and handling standpoints. It is shown on Dwg. C9-50-1120. Also, a comb was added to the inlet end of the fuel element to insure that hydraulic collapse of the flow passages would not occur.

The most direct method of adding the "Sabre" would have been to simply extend the two outer fuel plates and weld a "Sabre" between them, but metallurgical considerations opposed this approach. Designs were made of an end fixture which could be attached to the extended side plates, which had the "Sabre" set perpendicular to the fuel plates with arms that could be attached to the side plates. This end fixture could be fabricated or cast. A casting was economically more attractive because machining problems would be minimized, and both ends could be identical. Drawings were sent to foundries asking for comment and prices. The comb would not be cast in place, so it would be added as a simple stamping operation during assembly. A slot in the bottom of the "Sabre" was added to receive the comb and prevent its movement in all directions. Slight clearance in the teeth was allowed for expansion of the element due to heat.

A hole was drilled in the "Sabre" on the upper end of the fuel element to permit tool engagement. The same tool can be used in transferring absorbers and control rod fuel elements, eliminating one of the fuel handling tools.

This design of the stationary fuel element was 7-1/8-in. shorter than the SM-1 fuel element and offered possible savings in vessel size, shipping charges and storage space. The design shown on Dwg. R9-13-1017 satisfied all design requirements. Drawing AES-319 shows the spacing of the elements in the core.

The same absorber used in the PM-2A reactor was selected because it met all conditions of SM-2 design and no future work would be necessary.

7.5 CONTROL ROD FUEL ELEMENT

The control rod fuel element remained basically the same as the SM-1 element except for thickness of fuel and side plates. The two extended fuel plates at the lower end of the fuel element were changed to permit better flow conditions. A cutout was made in the plates to permit water to get up the outside passages, and still permit proper orientation of the fuel element in the control rod. This is shown in Dwg. AES-419.

At the top end of the element, the design was changed to eliminate the handle. By extending the two center fuel plates, putting holes in them, and adding spacers to prevent buckling, the design conditions were accomplished.

As the design progressed, it proved necessary to add a flux suppressor at the top of the element and a comb at the bottom. The suppressor was added internally to the fuel plate, just as in the stationary fuel plate. The comb was added after cutting off the lower end of all fuel plates at the same plane and extending the side plates. Two spacers were added to hold the comb in place, which would also locate the fuel element in the control rod.

The cross-sectional dimensions of both the control rod fuel element and the absorber remained the same as SM-1.

7.6 FUEL LOCATION

Contract requirements included interchangeability of the active fuel sections in the APPR-series reactors. As the design progressed a mutual contract interpretation was made between the customer and NPED which permitted the end box design to be changed. The SM-2 fuel plates, with an appropriate end box or adapter, must be capable of installation in any of the APPR-series reactors. A study was made of fuel location with results shown on Dwg. AES-410. The study showed that the SM-2 fuel plate could be safely installed in any of the previous APPR-type designs.

STYLE-1

STYLE-2

STYLE-3

STYLE-4

STYLE-5

STYLE-6

LAYOUT	
FOR APPROVAL AND	
SUBMITTAL TO THE	
STATIONARY FUEL ELEMENTS	
DATE	BY
1978-12	W. J. A. A.
REVISION	NO.
1	1
STATIONARY FUEL ELEMENTS	
DRAWING NO. AEL-393	

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WELDMENT

FINISHED ASSEMBLY

ENLARGED VIEW
SCALE: 60" = 1 FT

NOTE:
SURFACES 'B' & 'C' TO BE PARALLEL TO EACH OTHER
& 'E' AT 'D' WITHIN .002 T.I.R.

PC. No. 1

PC. No. 2

OBSELETE
SUPERSEDED BY 89-50-1150

QTY	PART NO.	MAT'L OR Dwg. No.	DESCRIPTION
3	89-50-1118		COMB
2	ST. STL. TYPE 304		STRAUT
1	2	ST. STL. TYPE 304	PAD

ALCO PRODUCTS, INC.
NUCLEAR POWER ENGINEERING DEPT.
SCHENECTADY, N. Y. U. S. A.

END FIXTURE ASSY (SINGLE ELEMENT FLOW TEST RIG)

C9-50-1120

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Technical drawing of a ship's hull structure, showing various views and sections. The drawing includes a plan view (top left), a side view (top right), a cross-section (bottom left), and a longitudinal section (bottom right). The plan view shows the hull's width and length, with dimensions in feet and inches. The side view shows the hull's profile, including the deck, hull, and keel. The cross-section shows the internal structure of the hull, including the keel, ribs, and deck. The longitudinal section shows the hull's structure along its length, including the keel, ribs, and deck. The drawing is labeled with various dimensions and section names, such as "SECTION A-A", "SECTION B-B", and "SECTION C-C".

RS-13 1017

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SM-1		MINIMUM	MAX
A	STATIONARY ACTIVE	21 21 1/2	22 1/2
B	—	—	—
C	CONTROLLED ACTIVE	21 1/2	22 22 1/2
D	—	—	—
E	ABSORBED ACTIVE	20 1/2	20 21 1/2
F	GAP (SCREEN) BOTTOM	- 1/2	1/2 1/2
G	GAP (FUNGUS) BOTTOM	- 1/2	1/2 1/2
H	GAP (SCREEN) TOP	- 1/2	1/2 1/2
J	GAP (SCREEN) TOP	- 1/2	1/2 1/2

	SM-1A	MIN	NOM	MAX
A' STATIONARY ACTIVE	21	21	22	
B' —————	—	—	—	
C CONT ROD ACTIVE <small>NEUTRON COUNT RATE</small>	21	22	22	
D FLUX <small>NEUTRON COUNT RATE</small>	21	22	1	
E ABSORBER ACTIVE	20	20	21	
F GAP (CURRENT) BOTTOM	21	21	21	
G GAP (PULL) BOTTOM	21	21	21	
H GAP (SCRAM) TOP	21	21	21	
J GAP (SCRAM) TOP	21	21	21	

SM-1 & SM-1A

PM-2A		MIN	MAX	MAX
A	STATIONARY ACTIVE	21	21 1/2	22 1/2
B	—	—	—	—
C	CONTROL ROD ACTIVE <small>ADJUSTING FLUX</small>	21 1/2	22	22 1/2
D	FLUX - <small>INSTRUMENT</small> (CONTROL ROD)	3/4	1 1/8	1
E	ABSORBER ACTIVE	20 1/2	20 3/4	21 1/8
F	GAP (SCRAM) BOTTOM	-3 1/2	1 1/2	4 1/2
G	GAP (PULL OUT) BOTTOM	-3 1/2	1 1/2	4 1/2
H	GAP (SCRAM) TOP	-3 1/2	1 1/2	4 1/2
J	GAP (SCRAM) TOP	-3 1/2	1 1/2	4 1/2

PM-2A

3M-2		MIN	NOM	MAX
A	STATIONARY ACTIVE ^{INCLUDING FLUX}	22	22	25
B	FLUX SUPPRESSOR (STAT)	$\frac{1}{16}$	$\frac{1}{2}$	$\frac{1}{16}$
C	CONT ROD ACTIVE ^{INCLUDING FLUX}	2 1/2	22	22 1/2
D	FLUX SUPPRESSOR ^(CONTROL ROD)	$\frac{1}{16}$	$\frac{1}{2}$	$\frac{1}{16}$
E	ABSORBER ACTIVE	20 1/2	20 1/2	21 1/2
F	GAP (SCRAM) BOTTOM	0	1/4	1/2
G	GAP (FULL OUT) BOTTOM	0	1/4	1/2
H	GAP (SCRAM) TOP	-1/8	1/16	1/8
J	GAP (SCRAM) TOP	-1/8	3/8	13/16

SM-2¹

LAYOUT
ALLIED PRODUCTS INC
222 E. 11th AVE. N. MINN. 55401
JULIUS & SEYMOUR
NAME: JOHN J. SMITH PHONE: 554-1234
ADDRESS: 1234 E. 11th AVE. N. MINN. 55401
CITY: MINN. 55401
STATE: MINN.
FUEL LOCATION IN SM: SM-1A, PM 3A & SM-1
UNIQUE NO: AES-410

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8.0 CONTROL ROD

The same basic control rod used in SM-1 was to be used in the SM-2 design, consisting of the fuel element and absorber contained in a tube and the tube mechanically connected to a rack meshing with the rod drive pinion. Drawing AEL-445 shows the SM-2 Control Rod Assembly.

With higher flow rates anticipated in the SM-2, it was desirable to have straight thru flow in the control rod to achieve minimum pressure drop. The first step was to completely redesign the cap. Four pieces of tubing were used to accomplish this with the center completely open. The inner tubes had lugs on them to lock the cap in place. As in previous designs, the cap would not lock in place unless the control rod was loaded in the proper manner. The same type of tool used in SM-1 would be used to lock and unlock the cap in place.

Next, the piston was moved from the top to the bottom of the rack, which would permit redesign of the yoke. The piston is exactly the same type as used in previous designs except for its position along the axis of the control rod.

The function of the yoke is to join the tube to the rack. As much excess material as possible was removed to get the inlet flow as straight as possible. Although nearly straight thru flow was accomplished, the expected pressure drop across the control rod was high, and it was necessary to add weight by increasing the rack diameter to 2-3/8-in. With a pressure drop of 23 ft of water, a 95-lb control rod would be just heavy enough to scram the reactor at cold conditions. As the SM-2 program progressed, it became more necessary to know the expected pressure drop across this rod. Since pressure drop calculations were still uncertain, it was decided to make the rack as large as possible. A 2-5/8-in. diam rack would be the largest possible while still keeping the rod drive penetrations to the vessel grouped. It was decided to proceed with the proposed Task 11 test program to determine the actual pressure drop across the rod, before the control rod design was finalized.

Studies were performed to investigate a hydraulically balanced control rod. To accomplish balancing, the section of the vessel below the core must be sealed off and connected to the upper chamber by transfer tubes. With pressures of these two chambers nearly equalized, the control rod would be nearly balanced and require less weight to affect a scram.

However, a seal between the lower core support structure and the vessel would be needed, the control rods passing thru the bottom plate would have to be sealed with a sliding seal, and transfer tubes would cut into the outer reflector ring. It was felt that a development program would be necessary to determine what seals were to be used, and how much balance could be obtained.

The test program was to be started only if the conventional control rod would not meet the specification.

Flow tests on the control rod resulted in recommendations that the upper end of the control rod have a taper or funnel chamber to help the outlet flow conditions. This was not possible because six of the seven control rods are immediately adjacent to the flow divider. Baffles or flow distributors were also recommended at the inlet end of the control rod. These could be and were designed into the yoke of the control rod. The orientation of the fuel element was turned 90° so that the fuel plates were parallel to the flats on the yoke. Then the flow distributors could be extended and also used as the fuel element orientation device.

The control rod design was not further advanced until the pressure drop tests were completed.

CONTROL ROD ASSY
REL-445

80% P30

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9.0 CORE SUPPORT STRUCTURE

Once the two-pass, up-up flow pattern was established, it was possible to begin design of the vessel internal components. The stationary fuel element, control rod, and core support structure designs proceeded simultaneously.

The general design of the core support structure followed the SM-1 core structure except for addition of the flow divider. The structure consisted of a top plate, bottom plate and carrier plate tied together with long bolts or tie rods. Early design work concentrated on the top and bottom plates, the most unsettled areas.

9.1 CONTROL ROD ARRAY

The array of control rods was an early problem area. Two patterns were presented: the open array, which has each control rod surrounded by stationary fuel elements, and the closed array, which has some of the control rods adjacent to each other. From a mechanical design point of view, the open array is more attractive because of more room below the core to space the pinion supports. The open array also permits use of well balanced core cover doors at the top plate. With SM-1, the lifting lug was off centerline of the hinge point and presented opening and closing problems, but with SM-2 the lifting lug could be on the centerline, thus eliminating this problem.

9.2 BOTTOM PLATE

As the program progressed, the open array of control rods was selected as reference so that further work on the bottom and top plates could proceed. Several possible designs of bottom plates were presented along with the fuel element designs. The grid type structure was attractive because it approached a wide-open flow area. Drawings were presented to fabricators, but cost estimates could not be made because fabrication problems were considered too severe. The grid could not be constructed within tolerances allowed.

A bottom plate design with accurately bored holes was presented which would require fuel element end boxes and an orifice plate. This design had been proven on SM-1, but cost for SM-2 would be high. Studies were made to fine an improved bottom plate design.

In conjunction with SM-2 Task 6, it was proposed to: (1) fix the length of the fuel element, and (2) vary the hole sizes at the top and bottom plate to get the best flow and pressure drop conditions without the aid of an orifice plate.

Several bottom plate hole spacings were drawn, made, and tested. A perforated bottom plate with 5/8-in. diam holes was selected as reference. It would be necessary to size and locate the hole at the center of each fuel element accurately to maintain the proper fuel element spacing, but the remainder of the holes could be sized and spaced with fractional tolerances. Slots milled across the plate would accept the fuel element "Sabre," thus the fuel element would be positioned in all directions.

9.3 FLOW DIVIDER

Because of the flow divider, all the flow problems were not solved. To use a flow divider, it was necessary to move the first pass fuel elements outward. The spacing between the outer fuel element plate and flow divider was to be the same as the plate spacing. During design, in jumping across the flow divider with holes, a problem of sealing the flow was presented. If the holes were spaced to only butt up against the flow divider, then the lattice and some parts of the fuel elements would be starved. It was decided to jump the flow divider and use different sized holes where necessary to get the proper distribution. The lower edge of the flow divider was to be scalloped and butted against the lower plenum flow divider. With a butt joint, the seal would not be perfect, but slight leakage would be permissible across the two passes.

9.4 TOP PLATE

The same approach was used on the top plate or doors. Doors were first used to keep the size of the upper shield tank as small as possible and eliminate a storage problem. The doors could be made in pairs and lifted on the hinge centerline, which would help in fabrication cost, handling, and eliminate need for available storage space of a plate. The doors were to have slots to accept the "Sabre" and holes as described for the bottom plate. The slots would have a tapered leading edge to line up a "leaning" fuel element when closing the doors. This was accepted as the reference design; results of flow testing would be presented before finalizing the design. It is shown on Dwg. AEL-547.

As work progressed it was found that the top plate and upper flow divider could be combined. This would not impose a much greater storage problem than the flow divider by itself and would eliminate an extra step in fuel handling procedures. This design is shown on Dwg. AEL-577.

9.5 SKIRT

The outer skirt, or first reflector ring, was calculated to be 1/2-in. thick; no movement due to pressure variation across this ring would be

expected. The flow divider would be much thinner; to minimize deflections it would be tied to the skirt with two vertical plates at each side or with eight tension bolts on each side.

Stress calculations were made of a box beam with the ends supported and the edges overhanging. The faces of the skirt and flow divider formed two of the legs of the box and the tie bolts or stiffening plates formed the other two legs. The upper and lower ends were supported by grooves in the top and bottom plates. The flow divider and stiffener thickness were calculated at 0.094 in. and the skirt at 1/2 in.

The calculation used to determine skirt thickness was basically the same used in previous reactors; no serious problem was expected. However, this calculation has never been proven by comparison with test data. It was therefore proposed that a test be conducted on this flow divider to determine actual deflections. Testing in a water flow rig where pressure drops across the flow divider could be obtained was proposed, and a test program approved. Strain gages could be applied to the divider at selected points and readings taken. Prior to testing, the design shown in AEL-577 was selected as reference.

9.6 SECURING CORE SUPPORT STRUCTURE

The method of securing the core support structure was investigated. At the beginning of the program, it was planned to use four standard bolts to secure the core support structure to the core support plate. This could be done by using a long handled wrench which could extend through the bottom plate and be held at a very slight angle, but as the design progressed, this approach was no longer considered feasible. The tie rods were removed and replaced with tubes. The upper end of the tube is threaded and after the core structure is assembled a collar is screwed in place to hold the core structure together. After installation of the core structure to the vessel is made, long tie rods are inserted through the tubes and screwed into the support plate. The upper ends of the tie rods are extended and have a necked down portion which accepts the swing lock to hold the doors and upper flow divider in place.

The four swing locks were to be bars with a pivot point on one end. By means of a long tool, these would be turned into place and would lock the doors and upper flow divider in place. Detents would prevent the lock from being vibrated out of place and also would prevent excessive movement in the open position.

9.7 PLACEMENT OF DASHPOTS

As stated in Section 8.0, Control Rods, we moved the pistons to the bottom of the racks. To obtain proper movement of the rods, a plate with

the dashpots inserted was hung off the bottom of the carrier plate and hung with tie rods. The leading edges of both piston and dashpot cylinder were tapered to lead the piston into the cylinder.

Design of the core structure is continuing and some test work is being done. Upon completion of testing, the design will be finalized. Drawing AEL-567 shows the work done to date.

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10	1	10/1/67	W. J. ...	...

NOTE
REFER TO DWS REL-567 FOR
ADDITIONAL CROSS SECTIONS & DETAILS

LAYOUT	
DATE	10/1/67
BY	W. J. ...
CHKD	...
FILE	CORE STRUCTURE
LAYOUT NO	REL-567

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10.0 REFERENCES

1. Kelleman, R. W., "A Survey of the Effects of Neutron Irradiation on the Impact and Other Mechanical Properties of Pressure Vessel Steels for the SM-2 Reactor," APAE No. 61, April 1, 1960.
2. Gallagher, J. G. (proj. eng.), "Program for the Design and Development of the APPR-1B Reactor Core and Pressure Vessel" APAE Memo No. 138, Part I, December 11, 1958.
3. Gallagher, J. G. (proj. eng.), "Program for the Design and Development of the APPR-1B Primary System, Vapor Container and Secondary System", APAE Memo No. 138, Part II, August 26, 1958.
4. Alco Products, Inc, "APPR-1B Core Development Planning Task IX" APAE Memo No. 141, September 15, 1958.
5. Gallagher, J. G. (proj. eng.), "APPR-1B Reactor Core and Vessel Progress Report, APAE Memo 160, October 26, 1958 to December 4, 1958, December 10, 1958.
6. Gallagher, J. G. (proj. eng.), "APPR-1B Reactor Core and Vessel Progress Report," APAE Memo 166, December 5, 1958 to December 31, 1958, January 9, 1959.
7. Gallagher, J. G. (proj. eng.), "APPR-1B Reactor Core and Vessel Progress Report," APAE Memo 170, January 1, 1959 to January 23, 1959, January 30, 1959.
8. Gallagher, J. G. (proj. eng.), "SM-2 (Formerly APPR-1B) Reactor Core and Vessel Review Report," APAE Memo 173, December 5, 1958 to February 13, 1959, February 20, 1959.
9. Gallagher, J. G. (proj. eng.), "SM-2 (Formerly APPR-1B) Reactor Core and Vessel Progress Report," APAE Memo 185, February 14, 1959 to March 24, 1959, April 7, 1959.
10. Gallagher, J. G. (proj. eng.), "SM-2 (Formerly APPR-1B) Reactor Core and Vessel Progress Report," APAE Memo 192, March 25, 1959 to April 24, 1959, May 6, 1959.
11. Gallagher, J. G. (proj. eng.), "SM-2 Reactor Core and Vessel Review Report," APAE Memo 197, February 14, 1959 to May 27, 1959, June 5, 1959.

12. Gallagher, J. G. (proj. eng.), "SM-2 Reactor Core and Vessel Monthly Report," APAE Memo 215, May 28, 1959 to July 9, 1959, July 17, 1959.
13. Gallagher, J. G. (proj. eng.), "SM-2 Reactor Core and Vessel Review Report," APAE Memo 223, May 28, 1959 to August 24, 1959, September 8, 1959.
14. Gallagher, J. G. (proj. eng.), "SM-2 Reactor Core and Vessel Review Report," APAE Memo 235, August 25, 1959 to December 14, 1959. December 24, 1959.
15. Gallagher, J. G. (proj. eng.), "SM-2 Reactor Core and Vessel Monthly Report", APAE Memo 243, February 19, 1960.
16. Hoover, H. L. (proj. eng.), "SM-2 Reactor Core and Vessel Review Report," APAE Memo 250, March 25, 1960.

REFERENCE DRAWING LIST

<u>Drawing</u>	<u>Title</u>	<u>Reference Report</u>
AEL-237	Reactor Installation ¹ (10 MW)	
AEL-272	Primary System	
AEL-291	Control Rod Drive Supports	
AEL-292	10 MW 9.2% Reactor (plan)	
AEL-294	Control Rod Ass'y.	
AEL-295	Reactor 10 MW 9.2%	
AEL-296	Reactor 10 MW 9.2%	
AEL-386	Reactor Vessel APPR-1b Up Flow	APAE Memo's. 160, 141
AEL-391	Reactor Vessel 1 Pas Up Flow	APAE Memo 138
AEL-393*	Stationary Fuel Element	APAE Memo 160, This Report
AEL-394	Reactor Vessel 1 Pass Core	APAE Memo 160
AEL-395	Reactor Vessel 1 Pass Core	APAE Memo 160
AEL-396	Reactor Vessel 2 Pass Core	APAE Memo 160
AEL-397	Core Structure	APAE Memo 160
AEL-399	Reactor Vessel 2 Pass Core	APAE Memo 160
AEL-400	Core	APAE Memo 160
AEL-404	Reactor Vessel 2 Pass Core	APAE Memo 166
AEL-405	Primary System	
AEL-412	Reactor Vessel 2 Pass Core	APAE Memo 170
AEL-415	Core Structure Cover and Flow Dividers	APAE Memo 170
AEL-416	Flow Divider - Core Structure	APAE Memo 173

<u>Drawing</u>	<u>Title</u>	<u>Reference Report</u>
AEL-417	Top and Bottom Grids - Core Structure	APAE Memo 173
AEL-419	Pinion Bearing	APAE Memo 185
AEL-428	Control Rod	APAE Memo 185
AEL-433	Thru Bolts - Reactor Vessel Cover	APAE Memo 192
AEL-437	Test Rig - Thru Bolts and Studs	APAE Memo 192
AEL-440	Pinion Bearing Support	APAE Memo 197
AEL-445*	Control Assembly	APAE Memo's 197, 243, This Report
AEL-449	Pinion Bearing Support	
AEL-450	Reactor 2 Pass Core	APAE Memo 197
AEL-451	Reactor 2 Pass Core	APAE Memo 197
AEL-460	Reactor Vessel - Stainless Steel	APAE Memos 215, 223
AEL-469	Thru Bolts	APAE Memo 215
AEL-516	Hydraulic Balance Arrangement	
AEL-517	Pinion Bearing Support Arrangement	
AEL-519	Pinion Bearing Support Arrangement	
AEL-519*	Closure Test Rig	APAE Memo 235, This Report
AEL-521*	Reactor Vessel	APAE Memo 235, This Report
AEL-523	Bottom Plate	APAE Memo 235
AEL-525	Closure Vessel Set Up	APAE Memo 235
AEL-526	Core Support Cover	APAE Memo 235

<u>Drawing</u>	<u>Title</u>	<u>Reference Report</u>
AEL-547*	Core Support Cover	APAE Memo 243, This Report
AEL-567*	Core Structure	APAE Memo 250, This Report
AEL-577*	Core Structure Cross Section	APAE Memo 250, This Report
AES-142	Reactor Core	
AES-143	Seal Leak-off	
AES-215	Reactor Core	
AES-262	2 Pass Flow Study #1	APAE Memo 160
AES-264	2 Pass Flow Study #2	
AES-271	Control Rod Cap	APAE Memo 160
AES-272	Control Rod Piston	APAE Memo 160
AES-275	Stationary Fuel Element (Cross Section)	APAE Memos. 160, 223
AES-276	Control Rod Fuel Element (Cross Section)	APAE Memos. 160, 223
AES-284	Stud Stretcher	APAE Memo 173
AES-286	Cover Handling Device	APAE Memo 170
AES-290	Stud	APAE Memo 192
AES-291	Stud	APAE Memo 192
AES-294	Discrete Poison	APAE Memo 173
AES-299	Fuel Element Section	
AES-300	Fuel Element Section	
AES-301	Fuel Element Section	

<u>Drawing</u>	<u>Title</u>	<u>Reference Report</u>
AES-302	Core Support Structure	
AES-303	Fuel Element	
AES-304	Control Rod Element	
AES-305	Flow Divider	
AES-308	Flow Divider	APAE Memo 185
AES-310	Flow Divider	APAE Memo 185
AES-316	Control Rod Hydraulic Balance	APAE Memo 197
AES-318	Fuel Element Spacing	APAE Memo 192
AES-319*	Fuel Element Spacing	APAE Memo 192
AES-320	Control Rod and Absorber	APAE Memo 197
AES-322	Stationary Fuel Element	
AES-324	Plate Spacing Gage Details	
AES-325	Bottom Plate	APAE Memo 197
AES-329	Reactor Nozzles	
AES-341*	Reactor Cross Section	APAE Memo 215
AES-410*	Fuel Element Location SM-1, SM-1A, PM-2A, SM-2	APAE Memo 243
AES-419*	Fuel Element Control Rod	APAE Memo 243
R9-13-1016	Welded Box Fuel Element (Stat.)	APAE Memo 170
R9-13-1017*	Fuel Element - Stationary	APAE Memos. 173, 235, 250
C9-13-1028	Fuel Element - Control Rod	APAE Memos. 223, 235
C9-13-2099	Fuel Plate	APAE Memos. 223, 173
C9-13-2100	End Box	

<u>Drawing</u>	<u>Title</u>	<u>Reference Report</u>
A9-13-2101	End Box	
B9-13-2102	Side Plate	
B9-13-2103	Side Plate	
B9-13-2104	Comb	
C9-13-2105	Fuel Plate	APAE Memos 223, 173
B9-13-2106	Comb	
A9-13-2107	Fuel Element	
A9-13-2108	Fuel Element	
D9-13-2111	Fuel Plate	
A9-13-2112	Fuel Plate	
B9-13-2113	Side Plate	
B9-13-2114	Comb	
A9-13-2115	Handle	
A9-13-2126	Spring	
A9-13-2127	Spring	
Parts List 30	Control Rod	
Parts List 31	Control Rod	
C9-13-2138	Rod	
C9-13-2137	Tube	
C9-13-2136	Yoke	
C9-13-2135	Rack	
2P78225-022	Woodruff Key 3/16 x 3/4	

<u>Drawing</u>	<u>Title</u>	<u>Reference Report</u>
1P80120-022	Slotted Nut 3/4-10	
2P79023-040	Cotter Pin 1/8 x 1-1/4	
C9-13-1029	Assy. Cap, Control Rod	
B9-13-2140	Sleeve, Lower	
A9-13-2143	Lug	
A9-13-2145	Tube	
A9-13-2127	Spring Compr.	
B9-13-2141	Body	
B9-13-2139	Sleeve, Upper	
A9-13-2144	Tube	
A9-13-2152	Block	
A9-13-2126	Spring, Compr.	
A9-13-2142	Lug, Upper	
A9-13-2146	Screw Special	
C9-13-2097	Pinion Rack	
B9-13-2147	Rack Roller	
B9-13-2148	Rack Roller Pin	
1P83004-016	Washer 3/8 Plain 302	
1P80120-016	Slotted Nut 3/8-16 302 or 303	
2P79022-024	Cotter Pin 3/32 x 3/4	
C9-13-1028	Fuel Element - Control Rod	
D9-13-2094	Absorber - Control (same as PM-2A)	

<u>Drawing</u>	<u>Title</u>	<u>Reference Report</u>
D9-13-2094	Plate	
A9-13-2093	Plate	
A9-13-2019	Pin	
B9-16-2001	Reactor Stud Nut	APAE Memo 192
C9-50-1120*	End Fixture Assembly	

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11.0 APPENDIXES

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APPENDIX A
CALCULATION OF THERMAL STRESSES IN COVER BOLTS
(Operating in Water)

Materials:

Vessel & Cover	304 Stainless Steel.
Bolt	403 Stainless Steel.
Nut	304 Stainless Steel.

Temperature Gradients (Estimated)

<u>Location</u>	<u>Operating in Water</u>	<u>Operating in Air</u>
At Bolt in Vessel	300°F.	450°F.
At Center of Bolt	300°F.	425°F.
At Cover Flange	300°F.	425°F.
At Center of Nut	200°F.	400°F.

Coefficient of Thermal Expansion, K, per °F.

Nut	$9.5 \times 10^{-6} - K_1$
Bolt	$6.0 \times 10^{-6} - K_2$
Cover	$9.5 \times 10^{-6} - K_3$
Vessel	$9.5 \times 10^{-6} - K_4$
Expansion Joint	$9.5 \times 10^{-6} - K_5$

Assumptions:

Assembly done @ 75°F.

Imperfect threads, therefore, the nut & bolt will not expand relative to each other.

Stress on bolt due to vessel & cover expansion

$$\begin{aligned}
 S &= E (K_4 - K_2) \Delta T \\
 &= 28 \times 10^6 (9.5 - 6.0) \times 10^{-6} (300 - 75) \\
 &= 22,000 \text{ psi}
 \end{aligned}$$

S - Stress (psi)
 E - Modulus of elasticity
 (lb/in²)
 K - Coefficient of ex-
 pansion (in./in/°F)

ΔT - Temp change (°F)

Stress on bolt in nut

$$\begin{aligned} S &= E (K_1 - K_2) \quad T \\ &= 28 \times 10^6 (9.5 - 6.0) 10^{-6} (200 - 75) \\ &= 12,250 \text{ psi} \end{aligned}$$

Bolt load to assure tight gasket

$$W_{m1} = H + H_p$$

$$\begin{aligned} &= \frac{\pi G^2}{4} P + 2b \pi G m P \\ &= \frac{\pi (35.5)^2}{4} 2200 + 2 (.094) \pi \\ &\quad 35.5 (6.5) (2200) \end{aligned}$$

$$\begin{aligned} W_{m1} &= 2,180,000 \quad 300000 \\ &= 2,480,000 \text{ lb.} \end{aligned}$$

$$\begin{aligned} \text{Load/bolt} &= \frac{2480000}{24} \\ &= 103,300 \text{ lb.} \end{aligned}$$

$$S = \frac{L}{A}$$

$$= \frac{103300}{6.234}$$

$$= 16,600 \text{ psi}$$

Total Stress on bolt @ nut

22000 due to cover expansion
12250 due to nut expansion
16600 due to pressure loading
50850 psi Total

W_{m1} - req'd bolt load (lb)
 H - hydrostatic end force (lb)
 H_p - joint compression load (lb)
 G - gasket dia
 P - design pressure
 b - gasket contact width
 m - gasket factor
 π - constant

S - stress (psi)
 L - load (lb)
 A - Area (in²)

231 249

Total Stress on Shank of bolt

22000 due to cover expansion

22000 due to vessel expansion

16600 due to pressure loading

60600 psi Total

Given Tensile Strength of 403 @ 300°F = 91,500 psi

$$F. S. = \frac{T. S.}{S}$$

F. S. - Factor of Safety

T. S. - Tensile Strength

S. - Stress

$$F. S._{nut} = \frac{91,500}{50,850}$$

$$= 1.8$$

$$F. S._{shank} = \frac{91,500}{60,600}$$

$$= 1.5$$

The assumptions made must be proven in the laboratory and no definite conclusions made until the data examined and the above calculations checked.

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APPENDIX B CORE SUPPORT STRUCTURE TIE DOWN

Pressure forces Up Flow forces Up = Weight Bolt load.

Bottom plate - 27.5 in. dia.

Bottom plate Area, $A_P = 594 \text{ in.}^2$

Assume 45 - 2" ϕ openings in bottom plate

$$A_H = 45 \left[\frac{\pi 2^2}{4} \right] = 128.5 \text{ in.}^2$$

$$\begin{aligned} A &= A_P - A_H \\ &= 594 - 128 \\ &= 466 \text{ in.}^2 \end{aligned}$$

Pressure Difference across Core, $p_c = p_1 - p_r + p_2$

$$\begin{aligned} p &= 15(.491) - 5(.491) + 24(.491) \\ &= .491 (34) \cong 17 \text{ psi} \end{aligned}$$

Pressure force Up $f_u = A p$

$$\begin{aligned} &= 466 (17) \\ &= 7,920 \text{ lb.} \end{aligned}$$

Flow forces

$$\begin{aligned} \sum F &= F_1 + (-F_2) + F_3 \\ &= \frac{p_1 \rho_w A_1}{144} - \frac{p_2 \rho_w A_2}{144} + \frac{p_3 \rho_w A_3}{144} \\ &= \frac{62.4}{144} [15(219) - 5(404) + 24(187)] \\ &= 2480 \text{ lb.} \end{aligned}$$

Pressure forces Up Flow forces Up = Weight (assumed) Bolt load.

$$7920 + 2480 = 1500 + 660 + B$$

$$\begin{aligned} B &= 10400 - 2160 \\ &= 8240 \text{ lb.} \end{aligned}$$

Assume bolts in direct tension

$$S = \frac{B}{A}$$

S = Stress Assume 12000 psi

$$A = \frac{B}{S}$$

$$= \frac{8240}{12000}$$

$$= .687 \text{ in.}^2$$

Use 4 bolts

$$A_1 = \frac{.687}{4} = .172 \text{ in.}^2$$

From SAE Hand book

Tensile Area of 1/2 - 13 = .1419 in.²

Tensile Area of 9/16 - 12 = .182

Tensile Area of 5/8 - 11 = .226

Use 5/8 - 11 as it is more common in the shops.

APPENDIX C STATIONARY FUEL ELEMENT FLOTATION

In order for the fuel element to stay against the bottom plate

Weight > Flow forces

Weight fuel element in Air, $W_a = 15-1/2$ lb (Actual weight)

$$\begin{aligned}\text{Weight fuel element in Water, } W_w &= W_a \left(1 - \frac{62.4}{490}\right) \\ &= 15.5 (1 - .127) \\ &= 13.5 \text{ lb.}\end{aligned}$$

Flow Forces

$$\begin{aligned}f &= \Delta p_1 A \\ &= 18 (.433) (2.9375)^2 \\ &= 67 \text{ lb.}\end{aligned}$$

f - flow force (lb)
 Δp_1 - pressure drop at full flow (psi)
 A - Area on which forces act (in²)

But Weight < flow forces

Δp_f at which flotation will occur

$$\begin{aligned}\Delta p_f &= \frac{W}{A} \\ &= \frac{13.5}{(2.9375)^2} \\ &= 1.57 \text{ psi}\end{aligned}$$

Δp_f - pressure drop at which flotation will occur (psi)
 W - Weight in water (lb)

% of flow to cause flotation

$$\left(\frac{Q_f}{Q_1}\right)^{1.83} = \left(\frac{\Delta p_f}{\Delta p_1}\right)$$

Q_1 - flow rate at rated flow (gpm) 316 gpm measured
 Q_f - flow rate at flotation point (gpm)

$$\begin{aligned}\Delta p_1 &= 9.7 \text{ ft H}_2\text{O} (433) \text{ (measured)} \\ &= 4.2 \text{ psi}\end{aligned}$$

$$\left(\frac{Q_f}{316}\right)^{1.83} = \frac{1.57}{4.2}$$

$$\begin{aligned} Q_f &= \sqrt[1.83]{.374} (316) \\ &= 584 (316) \\ &= 184 \end{aligned}$$

$$\% = \frac{184}{384} \times 100 = 48\%$$

the fuel element will just float @ 48% of flow but the flow will never be below 95% of full flow so the fuel element will ride against the top plate except start-up and shutdown.

APPENDIX D

VESSEL CLOSURE TEST PROCEDURE

The purpose of the test is: (1) to determine reliability of closures under reactor operating conditions; (2) to check on bolt, seal, vessel, corrosion and wear.

Procedure: Testing was conducted in the closure test rig shown on Dwg. AEL-519. The test was to be run at 2000 psi and 510°F, with demineralized water. There was to be no flow, and heating of the water was to be by fluid convection around the heaters. At present there are four heaters of 1.632 kw each. Future calculations may indicate the necessity for additional heating capacity or insulation. All internal readings of temperature and pressure were to be made by penetrations through the 4-in. blind flange.

When closing the cover, eight bolts evenly spaced (every third bolt) should be measured for length and neck diameter. General condition of the bolts should be observed. The gap between the flange and cover should be checked at four points 90° apart with the bolts and seal in place and the nuts tightened hand tight. The nuts should then be tightened as follows:

1. Two opposite nuts (180° separated) should be tightened alternately until the bolts are approximately 120% of rated load (based on bolt elongation).
2. The two bolts at 90° to the two tightened ones should have the nuts alternately tightened until they are at 110% of rated load.
3. The remaining nuts are to be tightened evenly until each bolt is at 102% of rated load. Theoretically, all bolts will then be in equal load of 100% of rated load.

The same four points where the gap between cover and flange was checked before tightening should be measured again and recorded. The length of the eight bolts previously measured should be checked for elongation.

At the end of each closure seal test, the gap between the flange and cover should be measured at the four reference points before temperature and pressure are reduced. The eight bolts under study should then be removed and checked for elongation, neck diameter and condition of the bolts and threads.

The following readings should be taken during the test, twice during the day shift and once during each of the other two shifts.

1. Temperature of 8 of the 24 bolts.
2. Surface temperature at OD of seal.

3. Surface temperature at ID of seal.
4. Surface temperature at OD of flange.
5. Surface temperature at ID of flange.
6. Surface temperature at outside of cover.
7. Surface temperature on inside of cover.
8. Temperature of water inside closure.
9. Temperature of shield water.
10. Internal pressure of autoclave.

The seal should be tested for one month. At the end of this time, the unit should be brought back to room temperature and atmospheric pressure. A second seal should then be inserted and the test repeated for one month. During tests, water samples should be taken once each week from both the autoclave and shield tank. Corrosion effects should be noted on the bolts, the seal and the inside of the vessel. During testing, the water temperature in the shield tank on top of the vessel should not exceed 125°F. This may require a constant flow of city water through the shield tank.

APPENDIX E

BOLT TEST PROCEDURE

The purpose of this test is to determine the amount of galling of the threads between the stud bolt and the nut, for simulated reactor bolting.

Procedure: Four combinations of studs and nuts should be tested, all on the Biach Bolt Tensioner.

Each bolt should be checked on an optical comparator for thread form and lead. Each bolt and nut assembly should then be measured, placed on the Biach Bolt Stretcher, and tightened hand tight. The load should be applied by building up hydraulic pressure in the bolt tensioner. Elongation should be measured, and stress on the bolt increased gradually until a value equal to 150% of rated load is obtained. Pressure on the bolt is then relieved, bolts are taken out of the tensioner and nuts are unscrewed. Threads should be examined for galling and deformation, and thread diameter and length checked. Bolts should be rechecked on the optical comparator to determine if thread distortion exists.

Each of the other three bolt and nut assemblies are inserted in turn, and threads checked after tensioning.

Corrosion testing should be included. Water inside the autoclave should have a purity sufficient to give a specific resistivity in the range of 0.4 to 0.7 megohm cm. Water should have an oxygen concentration of less than 0.5 ppm when testing is started. This level could be obtained by hailing before start-up or through use of deoxygenating resin on the intake line. The simulated shield tank water should be maintained in the range of 80,000 to 200,000 ohm cm specific resistance by mixing tap water with demineralized water. The shield tank should also be continuously aerated with a stream of water washed air (to remove entrained impurities) from a shower type sparger near the bottom of the shield tank, and should have a flow rate of 0.1 to 1 cfh.

Immediately upon removal of the bolts and nuts after each test, each should be visually examined and surface appearance noted. The surface should also be checked for cracking.

Corrosion tests on bolting materials should also be run independent of the above test to determine if corrosion cracking of Type 403 or A286 material occurs, and to determine conditions under which cracking will not occur.

Small bolts should be obtained of each bolting material being considered. Nuts should be obtained of Type 304 ss and A286. Two-inch sleeves and washers should be prepared of Type 304 ss and the bolts inserted in the sleeves

with a washer at each end of the sleeve. The nuts should be tightened to the specific stress as measured by elongation. Three bolts each should be tightened to each of three stress levels: at 85, 100 and 115% of the nominal SM-2 stud stress.

Specimens should be submerged in water continuously refluxing and with positive aeration. Water should have the highest purity level anticipated for the shield water in the SM-2. Tests shall run 500 hr or until bolts crack.

The test rig can also be used to develop and test the handling tools. The sequence of tightening the nuts should be determined. A Biach Bolt Tensioner is used to tighten bolts. Through hydraulic pressure, it stretches the bolt to the desired tension; the nut is turned in place under no load, and the hydraulic pressure is relaxed leaving the bolt as tight as required. Actual elongation of the bolt can be recorded before and after pressurizing and heating to determine additional loads imposed on the bolts.

The method of cover handling can also be developed with this test rig. Better means for hoisting and transferring the cover can be investigated after the initial bolt testing.

If further data and tests on studs are required, a double end flange can be added between the present cover and flange with bolts at the bottom (proven in the first test), and studs in the top.

Investigation of gaskets was also proposed for this test rig. It is desirable that a solid ring gasket be softer than surfaces of the gasket groove. With a Type 304 ss vessel and head, materials meeting this requirement and possessing necessary corrosion resistance are limited, since Type 304 ss is softer than most materials of gasket construction.

The most desirable material from a metallurgical standpoint, which gives resistance to corrosion, is Type 304 ss. No corrosion problems would be anticipated with use of a dead soft Type 304 ss gasket. However, gasket groove problems may be introduced with use of this material, since hardness of the gasket would be only slightly less than hardness of the gasket grooves. Service performance of Type 304 ss gasketing is available.

A gasket material appreciably softer than the gasket grooves and with moderately good corrosion resistance is nickel. In the dead soft annealed condition, a hardness differential of approximately 40 Brinell would be expected. However, some corrosion problems would be anticipated.

Pitting of the nickel gasket and some corrosion product buildup at the gasket-gasket groove junction would be probable. Pitting would not be expected to be severe enough to cause failure. However, examination of the gasket at head removal, and replacement when necessary should be made. Provision should be made to clean gasket grooves of corrosion product when the gasket is replaced.

The full scale closure test would provide the opportunity to test and evaluate the ability of nickel gasketing to provide satisfactory service under operating conditions. Without this test, Type 304 ss gasketing would be preferred metallurgically.

Further laboratory work on gasket material would be run to determine if Nickel A is subject to corrosion under SM-2 operating conditions. This material would be softer than Type 304 ss in the head and flange; thus, it would make an ideal gasket if there were no corrosion problems.

Crevice specimens of Nickel A would be bolted to Type 304 ss and inserted in aerated water with the purity of SM-2 and at operating temperature. The test would also be run in high purity degassed neutral water at operating temperature. Both tests would run for a minimum to 500 hr and should determine the extent of corrosion.