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AEC Research and
Development Report
UC-81, Reactors - Power
(Special Distribution)

**SUPPORTING ANALYSIS FOR
THERMAL SUITABILITY
OF FUEL ELEMENTS
FOR SM-1A CORE I LOADING**

ALCO PRODUCTS, INC.
NUCLEAR POWER ENGINEERING DEPARTMENT
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FOR SM-1A CORE I LOADING**

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ABSTRACT

A recommended SM-1A Core I loading chart is derived from available, metallurgically acceptable elements at the SM-1A and SM-1 sites. The derivation is based upon local thermal and hydraulic considerations of minimum element-to-element coolant channel clearances. These clearances are determined from field inspection measurements of outer fuel plate spacing, as modified by analytical calculations of plate ripple growth during exposure to reactor operating thermal stresses.

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1.0 SUMMARY

Dimensional variations of the outer fuel plates of elements available for SM-1A Core I loading are evaluated to determine their acceptability from local thermal considerations.

As-fabricated dimensional data is obtained from field measurements of outer plate spacing relative to the element side plate edges, as listed in the Appendices. Using the analytical procedures derived in APAE Memo-300,⁽¹⁾ the data is interpreted to obtain the initial plate ripple amplitudes and the maximum ripple growth during exposure to reactor operating thermal stresses. The effects of the final ripple amplitudes upon lattice (between elements) coolant channel clearances are then evaluated from local thermal and hydraulic considerations.

Of the 8 control rod and 39 stationary fuel elements measured at the SM-1A site, (a) all control rod elements are found satisfactory for unrestricted core placement, (b) 26 stationary elements are thermally satisfactory for unrestricted core placement, but 7 of them are temporarily rejected on metallurgical grounds pending further examination at ORNL, and (c) 13 stationary elements are thermally satisfactory at rated plant power provided specific core placement requirements are observed.

Of the 8 stationary fuel elements measured at the SM-1 site, all are satisfactory for unrestricted core placement. Of these, 6 have been assigned for SM-1A Core I use as reject replacements, and the remaining 2 are unassigned.

A recommended SM-1A Core I loading chart is presented which achieves acceptable minimum coolant passage clearances between all fuel elements while minimizing modifications to the previously published chart⁽⁵⁾ based upon the ZPE element arrangement.

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2.0 INTRODUCTION

The report evaluates whether previously manufactured stationary and control rod fuel elements for SM-1A Core I are thermally acceptable. The analysis and approach are based on APAE Memo-300, "Supporting Analysis and Derivation of Dimensional Tolerance Specifications for Core II of SM-1A and PM-2A,"⁽¹⁾ which presented a method for translating inspection measurements of fuel plate spacing to obtain minimum coolant channel clearances under reactor operating conditions.

An examination of the original SM-1A Core I elements was made by ORNL personnel at the plant site, and the results transmitted to Alco.⁽²⁾ Plate measurements are summarized in the Appendix 8.1, and their comments in connection with element rejection discussed in Section 5.4. A portion of the introduction of their report is quoted below because of its appropriateness at the point:

"Late in April, 1961, the Oak Ridge National Laboratory was notified that the Army Reactors (group), Division of Reactor Development, was very concerned regarding the condition of the first core loading of stationary fuel elements for the SM-1A reactor at Fort Greely, Alaska. The contract was administered and the procurement handled by the AEC New York Operations office. The (stationary) fuel elements were manufactured in accordance with the fabrication procedures described in ORNL-2649 with the exceptions contained in a letter dated Feb. 25, 1960.

"There was no inspection of the fuel elements other than the normal inspection rendered by the vendor's inspection department. When the elements arrived at Fort Greely on June 16, 1960, after a critical test by Alco Products, dents, scratches, and rippling of the top and bottom fuel plates were reported. Three damaged elements were returned to Alco Products and were judged unacceptable by Alco Products. One in particular contained badly rippled top and bottom plates. This rippling stimulated grave concern on the condition of the balance of the elements at Fort Greely. The chief worry was, that under conditions of higher heat flux in the SM-1A compared to SM-1, the amplitude of the ripples in the pre-irradiated plates would increase during irradiation in the SM-1A. It was conceivable that the magnitude of rippling under irradiation would be greater than in the SM-1, and if bad enough, might cause burnout. While Alco Products was studying this problem to estimate the magnitude of rippling which might be expected under the SM-1A conditions, ARM requested an experienced metallurgist from ORNL to go to Fort Greely and inspect as much of the element as possible so that an opinion could be formed on whether or not these elements could be used in the SM-1A reactor."

Subsequent to this inspection by ORNL⁽²⁾ and an evaluation of its findings by Alco, 7 of the 39 stationary elements were judged unsatisfactory or questionable on metallurgical considerations⁽³⁾, and sent to ORNL for further examination. The remaining elements, as shown in this report, are satisfactory on thermal considerations provided that the custom core placement presented in Section 5.5 is used.

Army measurements of 6 SM-1 Core II and 2 SM-1 Core I unused stationary elements were made at Fort Belvoir and submitted to Alco⁽⁴⁾ for consideration as replacements for the returned SM-1A Core I elements. These measurements are summarized in Appendix 8.2. All elements were found acceptable, as shown in Section 5.3, and the 6 SM-1 Core II elements were specified in the SM-1A Core I loading procedure. The disposition of the two SM-1 Core I elements has not been decided by the Army as of November 1961. One application under consideration is their use as replacements for the 2 high-burnup stationary SM-1 Core I elements presently installed in SM-1 Core II.

The work reported was undertaken as Item 1.10, Task 1, of the Fiscal Year 1961 Program of Contract AT(30-1)-2639.

3.0 GENERAL THEORETICAL CONSIDERATIONS

3.1 FIELD MEASUREMENTS MADE

As shown by APAE Memo-300⁽¹⁾, the internal coolant passages of stationary and control rod fuel elements do not present a thermal problem because of ripple growth considerations. Significant deviations from the specifications to which the elements under consideration were manufactured would still be thermally permissible. Re-measurement of elements was therefore confined to outer fuel plates.

The re-measurement of internal channels in stationary elements is restricted by the limited access to measurement devices provided by the end boxes. No practical method for examining outer channels is presently available unless the end boxes are first removed.

Outer fuel plate spacing (distance from the plane of the side plate edges to the surface of an outer fuel plate at its span center) was measured at 1-inch axial intervals.

The designations "top" and "bottom" fuel plates refer to the orientation of the element in the brazing oven. The two types of outer plates are distinguishable from each other by the physical appearance of the associated braze fillets. Since the braze metal is deposited on upper surfaces of fuel plates prior to brazing, the braze fillets after brazing are more generous on the upper surface side.

3.2 DEFINITION OF PLATE PROJECTION

As stated in APAE Memo-300⁽¹⁾, the dimensional specification for outer plates of SM-1A Core II elements provides maximum, minimum, and spread limitations on spacing measurements. In deriving the worst plate geometry, from a restricted channel viewpoint, that still satisfies the specification, it is assumed that the total spread tolerance can be associated with one local ripple.

It is further recognized that discrete 1-inch measurement intervals may not indicate the full extent of a ripple since peaks and valleys can occur between measurement stations. To conservatively compensate for this possibility, the peak-to-valley spacing change indicated by these measurements is defined as the actual ripple amplitude.

By combining these two thoughts, the worst ripple geometry under operating conditions for SM-1A Core II specification purposes is illustrated in Fig. 3.1.

Fig. 3.1 Worst Ripple Meeting SM-1A Core II Specs,
 Longitudinal View of Outer Fuel Plate Along
 Center Plate Span

The maximum ripple amplitude "a" of an "as manufactured" element is, therefore, equal to the spread specification. This amplitude is increased during reactor operation at rated power by the growth factor "R". The projection "p" of such a local operational ripple into the lattice spacing, using a nominal flat fuel plate as the reference, is given by the relationship:

$$p = Ra - (\text{Min.} + \text{Spread} - \text{Nom}) \quad (1)$$

In the case of Core I elements, conjecture on worst ripple profile is not necessary since measurements along outer plates are available. A typical longitudinal view of Core I elements compared to specification is shown on the following page in Fig. 3.2.

Although the highest ripple of Fig. 3.2 extends beyond the "Minimum" limit, the ripple magnitude "a" is usually less than amplitude "a" of Fig. 3.1 so that the projection into the lattice spacing is less for the Fig. 3.2 geometry. Thus, some Core I elements which do not satisfy Core II specifications are still found satisfactory for unrestricted core placement on the basis of such customer analysis.

Fig. 3.2 Typical Longitudinal View of SM-1A Core I
Outer Plate Using SM-1A Core II Specifications

The basis for computing the channel projection "p" of a local outward ripple, given the actual outer plate spacing measurements, is shown in Fig. 3.3. Note that Fig. 3.3 is only an elaboration of Fig. 3.2 to indicate greater detail.

d = Deviation of Ripple Peak
M = Plate Spacing Measurement at Peak
Nom = Nominal Spacing

Fig. 3.3 Method for Determination of Projection of a Ripple at
Operating Conditions Past Nominal Plate Dimension

Note also from Fig. 3.3 that if the peak-to-valley spacing change is larger on one side of the peak than the other, the larger value is used as the ripple amplitude "a" for additional conservatism.

As shown by Fig. 3.3, the plate projection "p" measures only that portion of the ripple after growth that projects outward beyond the nominal plate measurement. Using the algebraic interdependencies indicated by Fig. 3.3, the magnitude of "p" is determined by the relationship:

$$p = a (R-1) - d \quad (2a)$$

$$= a (R-1) - (m-Nom) \quad (2b)$$

In examining tabulated inspection data to determine the axial location of the greatest plate projection "p" into the coolant channel, it is not sufficient merely to note the location of the minimum spacing measurement, since the associated ripple magnitude may be relatively small. Both the spacing "m" and the associated ripple "a" must be considered together according to equation (2a), so that the determination may not be readily concluded by visual inspection alone but may require some arithmetic calculation in the final choice.

A typical example would best illustrate the various aspects of projection determination discussed. Consider a partial series of outer plate measurements as follows:

<u>Measurement Station</u>	<u>Top Plate Spacing</u>
14"	0.030
15"	0.020 *
16"	0.032
17"	0.023 *
18"	0.035
19"	0.029

Inspection of the table reveals two outward ripples, as indicated by the (*), at the 15" and 17" stations. Substituting applicable numerical values of "m" and "a" for each case into equation (2a) yields:

$$\begin{aligned} p_{15t} &= a_{15t} (R-1) - (M_{15t} - Nom_t) \\ &= (0.030 - 0.020) (3.5 - 1) - (0.020 - 0.033) \\ &= 0.025 + 0.013 = 0.038 \end{aligned}$$

$$\begin{aligned} p_{17t} &= (0.035 - 0.023) (3.5 - 1) - (0.023 - 0.033) \\ &= 0.030 + 0.010 = 0.040 \end{aligned}$$

Thus the top plate projection at the 17" station is the larger, although the plate spacing measurement at the 15" station is the smaller.

3.3 DEFINITION OF ELEMENT SHIFT

For all the stationary fuel elements considered in this report for possible placement in SM-1A Core I, final machining of the end boxes for centering purposes (after attachment to the fuel plate section) is based upon measurements across points marked "o" in Fig. 3.4.

Fig. 3.4 Reference Points on Fuel Plate Section of Element Used as Basis for End Box Centering

As shown by the section diagram of Fig. 3.4, a deviation of the top or bottom fuel plates at the 3" or 24" measurement stations would result in a shift of end box center relative to the fuel plate section. Upon installation in a reactor, this produces an element shift of equal magnitude but in the opposite direction, thus tending to increase one outer coolant passage while decreasing the other. The relationship for calculating this element shift "s" and the algebraic sign conventions that will be followed are shown in Fig. 3.5.

For illustrative purposes, let the typical example of the previous section be extended as follows. Further examination of the inspection measurement report yields the following data:

1. At 3" station, $d_t = +0.008''$
 $d_b = -0.002$
2. At 24" station, $d_t = +0.020$
 $d_b = +0.004$
3. Location of largest top plate projection at the 17" station

Fig. 3.5 Determination of Element Shift "s"

The symbolic representation of Fig. 3.6 is used to visualize this data, patterned after Fig. 3.5

Fig. 3.6 Symbolic Representation of Element Shift Data

From Fig. 3.6, it is seen that the shift at the 17" station, as obtained by linear interpolation, is 7 mils toward the top plate. This is expressed in either of two forms as:

$$s_{17t} = +0.007$$

$$s_{17b} = -0.007$$

3.4 DETERMINATION OF OUTER CHANNEL RESTRICTION

With ripple projection "p" and element shift "s" data available, the total restrictive effect of a ripple under reactor operating conditions can then be readily determined.

Consider further the illustrative example previously described. Section 3.2 found that the maximum local projection of the plate occurred at the 17" station and amounted to 40 mils; thus:

$$p_{17t} = 0.040''$$

Section 3.3 determined that the element shift corresponding to the 17" station was 7 mils toward the top plate; thus:

$$s_{17t} = +0.007''$$

The total restricting effect "r" of the top plate on the adjacent outer coolant channel, if the element in question replaces a hypothetical nominal element, is simply the sum of projection and corresponding shift values:

$$\begin{aligned} r_{17t} &= p_{17t} + s_{17t} \\ &= 0.040 + 0.007 = 0.047'' \end{aligned} \tag{4}$$

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4.0 INDIVIDUAL ELEMENT ANALYSES

Field measurements of all the fuel elements considered are presented in the Appendix. The following sections pertain to the projection, shift, and restriction analyses applied to the elements individually, in accordance with the procedures described in Sections 3.2, 3.3, and 3.4 respectively.

Note that there are 4 lots of elements considered, as identified by the form of the element serial number given by Table 4.1.

TABLE 4.1
ELEMENT SERIAL NUMBER SIGNIFICANCE

<u>Serial Type*</u>	<u>Original Element Lot</u>
XXS	SM-1A Core I Stationary (Syl Cor)
CRXXS	SM-1A Core I Control Rod (ORNL)
XC	SM-1A Core I Control Rod (Syl Cor)
XXV	SM-1 Core II Stationary (Syl Cor)
SXX	SM-1 Core I Stationary (ORNL)

* where X refers to Arabic numeral of series.

4.1 ELEMENT SHIFT

Calculations of stationary element shift are presented in a form similar to Fig. 3.6.

4.2 LOCAL RESTRICTION

Since support combs are attached to the ends of the fuel plates in a stationary element assembly extending inward toward the 2 inch and 25 inch inspections stations, ripple growth evaluations have considered only inspection measurements between the 3 inch and 24 inch stations.

Table 4.4 lists the maximum ripple projection of each stationary element outer plate, the corresponding element shift at the ripple, and the associated ripple restriction. Since shift is not involved with control rod fuel elements, only projection is shown in Table 4.4 for outer plates of such elements.

Fig. 4.1 Element Shift Diagrams, SM-1A Core II Stationary

Fig. 4.1 (Cont'd)

TABLE 4.2
ELEMENT SHIFT DIAGRAMS, SM-1 CORE II STATIONARY

TABLE 4.3
ELEMENT SHIFT DIAGRAMS, SM-1 CORE I STATIONARY

TABLE 4.4
MAXIMUM LOCAL RESTRICTION OF RIPPLES, OPERATING CONDITIONS

Element Serial	Meas. Station of Worst Ripple		Ripple Peak Meas.		Ripple Magnitude		Ripple Projection		Shift at Ripple		Ripple Restriction	
	Top	Bottom	m_t	m_b	a_t	a_b	P_t	P_b	S_t	S_b	r_t	r_b
1S	17"	12"	0.038"	0.023"	0.010"	0.003"	0.020"	0.013"	+.005"	-.005"	0.025"	0.008"
2S	16	12	.037	.024	.003	.006	.004	.019	+.005	-.005	.009	.014
3S	6	15	.018	.010	.026	.026	.080	.083	+.009	-.010	.089	.073
6S	24	13	.035	.025	.006	.008	.013	.023	0	-.001	.013	.022
8S	12	23	.041	.025	.004	.002	.002	.008	+.006	-.005	.008	.003
9S	6	3	.029	.027	.009	.004	.027	.011	+.004	-.004	.031	.007
10S	20	9	.042	.024	.004	.007	.001	.022	+.003	-.003	.004	.019
12S	10	3	.036	.028	.005	.004	.010	.010	+.002	-.002	.012	.008
13S	11	15	.034	.025	.003	.002	.007	.008	+.002	-.002	.009	.006
14S	19	21	.032	.026	.005	.010	.014	.027	+.003	-.003	.017	.024
15S	9	14	.026	.026	.017	.003	.050	.010	+.004	-.004	.054	.006
16S	15	9	.018	.022	.022	.008	.070	.026	-.001	+.002	.069	.028
17S	20	10	.015	.016	.036	.015	.108	.050	+.008	-.009	.116	.041
18S	14	3	.031	.027	.017	.003	.045	.009	+.002	-.003	.047	.006
21S	9	16	.027	.021	.021	.004	.059	.017	-.004	+.003	.055	.020
23S	19	4	.019	.022	.023	.006	.072	.021	+.003	-.001	.075	.020
24S	14	10	.026	.025	.015	.003	.045	.011	-.001	+.002	.044	.013
25S	23	6	.034	.031	.004	.006	.009	.012	-.001	-.001	.008	.011
26S	3	9	.025	.019	.008	.003	.028	.017	-.001	-.001	.027	.016
27S	24	12	.030	.024	.003	.003	.011	.012	0	-.003	.011	.009
28S	7	18	.036	.029	.010	.008	.022	.019	+.002	+.001	.024	.020
29S	24	8	.016	.023	.006	.003	.032	.013	-.009	+.003	.023	.016
30S	11	23	.037	.021	.008	.005	.016	.020	+.004	-.006	.020	.014
31S	22	19	.036	.025	.003	.005	.005	.016	+.003	-.003	.008	.013
32S	24	24	.029	.023	.004	.007	.014	.023	+.001	-.001	.015	.022
33S	7	21	.035	.025	.015	.020	.036	.053	0	+.036	.036	.055
34S	5	3	.040	.020	.003	.006	.001	.023	+.007	-.008	.008	.015
35S	16	7	.040	.022	.003	.006	.001	.021	+.003	-.002	.004	.019
36S	24	6	.019	.023	.006	.004	.029	.015	-.005	+.006	.024	.021
38S	17	15	.023	.020	.018	.015	.055	.046	+.006	-.006	.061	.040
39S	22	20	.032	.028	.007	.002	.019	.005	-.003	+.004	.016	.009
40S	23	23	.030	.023	.009	.003	.026	.013	+.004	-.004	.030	.009
43S	16	18	.028	.021	.023	.012	.063	.037	+.004	-.003	.067	.034
46S	7	5	.029	.023	.006	.004	.019	.015	+.001	-.001	.020	.014
47S	23	16	.042	.021	.005	.005	.004	.020	+.011	-.009	.015	.011
50S	3	24	.040	.036	.003	.024	.001	.052	-.002	-.001	-.001	.051

TABLE 4. 4 (CONT'D)

Element Serial	Meas. Station of Worst Ripple		Ripple Peak Meas.		Ripple Magnitude		Ripple Projection		Shift at Ripple		Ripple Restriction	
	Top	Bottom	m_t	m_b	a_t	a_b	P_t	P_b	S_t	S_b	r_t	r_b
51S	20"	14"	0.039"	0.025"	0.013"	0.012"	0.027"	0.033"	+.007"	-.004"	0.034"	0.029"
52S	22	20	.049	.028	.019	.008	.032	.020	+.014	-.014	.046	.006
137S	24	13	.040	.025	.004	.005	.003	.016	+.004	-.005	.007	.011
17V	21	18	.037	.025	.013	.009	.029	.026	+.005	-.005	.034	.021
18V	3	13, 15	.041	.026	.004	.010	.002	.027	+.007	-.007	.009	.020
22V	5	23	.044	.018	.004	.004	-.001	.020	+.009	-.008	.008	.012
24V	24	9	.051	.026	.006	.003	-.003	.010	+.009	-.007	.006	.003
39V	10	17	.044	.023	.005	.005	.002	.018	+.007	-.008	.009	.010
40V	17	4	.036	.030	.013	.003	.030	.006	+.006	-.005	.036	.001
S63	9	5	.033	.027	.005	.011	.013	.029	+.002	-.003	.015	.026
S83	19	24	.030	.032	.015	.012	.041	.026	-.003	+.003	.038	.029
CR-2-S	21	4	.079	.072	.002	.003	0	.005				
CR-3-S	6	14	.079	.075	.003	.003	.003	.002				
CR-4-S	9	15	.079	.073	.002	.007	0	.014				
CR-5-S	3	2	.079	.072	.004	.005	.005	.010				
CR-6-S	3	3	.076	.069	.004	.004	.008	.010				
CR-7-S	10	20	.078	.071	.003	.005	.004	.011				
CR-8-S	3	6	.077	.071	.003	.002	.005	.003				
8C	3	21	.074	.066	.003	.004	.008	.013				

4.3 RESTRICTION DETERMINATION ERROR

Individual spacing measurements (absolute) are believed accurate within $\pm 0.002''$. Spacing differences (relative) are believed accurate within $\pm 0.002''$. The implications of these error margins on the previous projection, shift, and restriction calculations are shown in Table 4.5.

TABLE 4.5
CONSERVATIVE ERROR MARGINS

Individual measurements (absolute)	± 0.002
Difference measurements (relative)	± 0.002
Plate projection "p", equation (2)	± 0.007
Element shift "s", equation (3)	± 0.002
Total restriction "r", equation (4)	± 0.009

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5.0 SM-1A CORE I APPLICATION

5.1 CONTROL ROD FUEL ELEMENTS

As shown by APAE Memo-300⁽¹⁾, the minimum coolant channel clearance is 0.018". The minimum clearances of an outer coolant channel for a control rod fuel element are produced when the element lies against the control rod tube wall. The minimum outer channel clearances "c" associated with the control rod fuel elements (described in the latter part of Table 4.4) are shown in Fig. 5.1.

$$\begin{aligned}c_t &= \text{Nom}_t - p_t - 0.010'' \\&= 0.074'' - 0.008'' - 0.010'' \\&= 0.056'' \text{ minimum}\end{aligned}$$

$$\begin{aligned}c_b &= \text{Nom}_b - p_b - 0.010'' \\&= 0.069'' - 0.014'' - 0.010'' \\&= 0.045'' \text{ minimum}\end{aligned}$$

Fig. 5.1 Minimum Outer Channel Clearances of Control Rod Fuel Elements Examined

The minimum channel clearances obtained are much greater than the minimum requirement, so that all control rod fuel elements examined are thermally acceptable for unrestricted core placement in the SM-1A plant.

5.2 TYPES OF ELEMENT CLEARANCES

In the SM-1A core, there are 4 basic types of lattice channels of interest involving stationary fuel elements. These channels occur between adjacent stationary elements, stationary element and control rod tube, and stationary element and core skirt. Figure 5.2 illustrates these channel types, and also indicates the minimum clearances based upon nominally dimensioned flat outer fuel plates. All other tolerances involving the core support structure, control rod tube, and core skirt have been considered at their worst possible combination.

Fig. 5.2 Types of Lattice Clearances Involving Stationary Elements, With Minimum Clearances Shown Using Nominal Dimension Flat Outer Fuel Plates

5.3 THERMAL CLASSIFICATION OF STATIONARY ELEMENTS

All four outer channel types of Fig. 5.2 must have a minimum clearance operationally of 0.018". Since the channel in part (a) is potentially restrictable by two fuel plates, the permissible plate restrictions of its associated outer fuel plates are the smallest, and therefore establish maximum restriction limits for unrestricted stationary element placement. The derivation of these limits is shown in Table 5.1.

TABLE 5.1
DERIVATION OF RESTRICTION LIMITS FOR UNRESTRICTED PLACEMENT

1. Channel clearance per flat plate, Fig. 5.2(a) = 0.059"
2. Minimum channel clearance per ripple plate = .009
3. Maximum error of restriction calculation, Table 4.5 = .009
4. Maximum restriction per Table 4.4 for unrestricted core placement =
Item (1) - Item (2) - Item (3) = .041

On the basis of Table 5.1, the stationary elements examined in Table 4.4 are classified as shown in Table 5.2.

TABLE 5.2
CLASSIFICATION OF STATIONARY ELEMENTS CONSIDERED
(Under Thermal Considerations Only)

<u>Unrestricted Core Placement</u>		<u>Specific Core Placement</u>	
1S	35S	3S	24S (A)
2S (R)	36S (R)	15S	33S
6S	39S	16S	38S
8S (R)	40S (R)	17S	43S
9S	46S	18S (A)	50S
10S	47S (R)	21S	52S (A)
12S	51S	23S	
13S	137S		
14S			
25S	17V		
26S	18V		
27S	22V	(A)	Acceptable for unrestricted use if no consideration given to measurement error.
28S	24V		
29S (R)	39V		
30S	40V		
31S		(R)	Temporarily rejected for metallurgical reasons pend- ing further examination.
32S	S63		
34S (R)	S63		

5.4 METALLURGICAL REJECTIONS

Although the scope of this report is limited to thermal considerations, recognition must be made of the rejection of some of the available elements on metallurgical grounds, so that a thermally acceptable core loading arrangement can be specified.

The ORNL report ⁽²⁾ on the field inspection of the SM-1A Core I elements contains the comments concerning element rejections shown in Table 5.3.

After study of the ORNL report by Alco metallurgists, and consultation with the author of the report, the recommendations of Alco concerning element rejection, as transmitted to the Army, ⁽³⁾ are summarized in Table 5.4.

The seven rejected stationary elements have been received by ORNL for further study. Their unavailability (at least for present purposes) for the SM-1A Core I loading is indicated in Table 5.2.

TABLE 5.3
SM-1A CORE I REJECTION COMMENTS BY ORNL

<u>Element No.</u>	<u>Rejection Comment</u>
3S	Element should be rejected for not meeting (dimensional) specifications and because of bad ripple.
8S	Recommend rejection of element for lack of braze metal.
13S	Slight braze splatter in cladding of fuel section can be cause for rejection.
40S	Fire splatter of braze metal on cladding above fuel section. Under existing specifications, this is cause for rejection of element. Pit apparently filled with braze metal. This pit is on the cladding over the fuel section, and under the specifications is cause for rejection of the element.

TABLE 5.4
SM-1A CORE I REJECTION RECOMMENDATIONS BY ALCO

<u>Element No.</u>	<u>Recommendation</u>
3S	Metallurgically acceptable. Usable if thermally acceptable with custom core placement permitted.
8S	Concur with ORNL, reject.
13S	Concur with ORNL, choose to permit use of element.
40S	Concur with ORNL, reject.
2S 34S 36S 47S	Believe ORNL estimate of 2 mil depth of scratches probably correct, but recommend more accurate depth measurement before use. Greater depth requires rejection.
29S	
	Projection of top plate beyond side plate edges, as shown by inspection data, requires further study before acceptance to insure that projecting fuel plate will not be gouged during core insertion.

5.5 SM-1A CORE I LOADING CHART

Since the number of stationary elements classified per Table 5.2 for unrestricted placement is not sufficient for a core loading, reliance must be placed on a selective loading arrangement that considers the resulting outer channel minimum clearance of various element combinations.

The placement process in deriving this loading arrangement would involve the following considerations:

- a. The overall loading arrangement should require a systematic orientation of top fuel plates if possible.
- b. For geometries similar to Fig. 5.2(a), matching of plates with large and small restriction values as listed in Table 4.4 can maintain adequate channel clearances.
- c. The matching process in item (b) would in the general case include considerations of axial location of the opposing restrictions. However, this is a rather tedious task, and can generally be reserved as a last resort. This report initially considers only the largest restriction of each outer plate, conservatively assuming that these restrictions are aligned for a Fig. 5.2(a) geometry. If the resulting clearance is acceptable, no greater detail is necessary.
- d. The matching process of item (b) would also in the general case include considerations of radial variation of the ripple growth factor, as shown in Table 5.5. However, this increases the complexity of the element arranging process with only a relatively small benefit, and is also reserved as a last resort. This report initially considers only the maximum growth factor, and if the resulting clearances are acceptable, no greater detail is necessary.
- e. Outer plates, with restrictions of such a large size that the matching process of item (b) is not sufficient, may be placeable in core positions whose geometries are described by Fig. 5.2(b), (c), (d), as these positions provide increasing capacity for restriction in this respective order.
- f. If items (a) through (e) are insufficient to achieve a core arrangement which is readily seen to be acceptable, a conservative sketch of initial rippling amplitudes may be made based upon inspection data in an attempt to reduce the greater conservatism of the method defined in Section 3.2.
- g. If items (a) through (f) are insufficient, the rated power level of the plant must be lowered until the correspondingly reduced ripple growth factor permits acceptable channel clearances in the limiting core locations. This was not found necessary in the subject study.

TABLE 5.5
RADIAL VARIATION IN RIPPLE GROWTH FACTOR

<u>Core Position</u>	<u>Growth Factor "R"</u>
44	3.5
34	3.45
35	3.4
14	3.4
15	3.4
16	3.2
25	3.2
26	3.15

Applying the considerations of items (a), (b), and (e) as a first approach, the SM-1A Core I loading arrangement of Fig. 5.3 was obtained. This is, of course, only one of many equally satisfactory variations possible, but has minimized the changes necessary from the original loading chart (5) in order to reduce the associated nuclear calculations necessary for the complete loading procedure (6). Note that in all but 1 case (core position 67), the stationary element outer channel clearances are greater than the 18 mil minimum operating value desired, so that the more complex considerations of items (c) (d) and (f) are not required. However, both clearances of core position 72 are sufficiently close to the minimum that further attention will also be given them. The three cases requiring the more complex considerations are:

<u>Element</u>	<u>Core Position</u>	<u>Plate</u>
3S	72	Top
3S	72	Bottom
17S	67	Top

Applying the reduced R value of position #16 in Table 5.5 to position #72 because of symmetry, the top and bottom plate clearances are acceptable by a greater margin as illustrated in Fig. 5.4.

Applying the reduced R value of position #16 to #67, the top plate clearance is still not acceptable, as illustrated in Fig. 5.5.

In order to realize an additional 14 mils on the lattice clearance, in order to reach the desired +18 mil magnitude, the approach previously outlined in Item (f) will be explored. Consider the plot of inspection points shown in Fig. 5.6.

Fig. 5.3 Recommended SM-1A Core I Loading Chart

Fig. 5.4 Element 3S Lattice Clearances, Recognizing Reduced Ripple Growth Factor for Position #72

Fig. 5.5 Element 17S Top Plate Lattice Clearance, Recognizing Reduced R for Position #67

Fig. 5.6 Plot of Element 17S Top Plate Measurements

By the conservative method established in Section 3.2 to facilitate examination of the tabular data, the ripple peak was found at point P and the associated ripple magnitude a_t is 0.036". A look at the sketch of the plate profile indicates the true peak at P' with a magnitude of only about 0.025". Using the latter peak and magnitude provides a lattice clearance of 0.029" (by substituting into equation (5), $p_t = 0.083''$ now, rather than the former value of 0.108", or a benefit of 0.025").

Element 17S, and all other elements indicated in Fig. 5.3, are thermally acceptable as located in the loading chart of Fig. 5.3 for rated plant power.

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6.0 CONCLUSIONS

All of the 8 control rod fuel elements presently at the SM-1A site are acceptable for unrestricted SM-1A Core I placement.

As shown by Table 5.2, 26 of the 39 original SM-1A Core I stationary elements are acceptable for unrestricted core placement on a thermal basis but 7 of these elements are temporarily rejected on metallurgical grounds.⁽³⁾ The remaining 13 elements are acceptable provided specific core placement recommendations are followed.

The 6 SM-1 Core II stationary elements and the 2 SM-1 Core I stationary elements considered as available replacements for the rejected elements are found acceptable for unrestricted SM-1A Core I placement.

From the available and acceptable fuel elements, the loading chart of Fig. 5.3 was derived. Of all the elements considered, as listed in Table 4-4, the only elements not used for the SM-1A Core I loading are:

- a. Rejected stationary elements 2S, 8S, 29S, 34S, 36S, 40S, and 47S.
- b. SM-1A Core I stationary elements S63 and S83.
- c. Control rod fuel element 8C.

The corresponding disposition of these elements at the time of this report is:

- a. Returned to ORNL for further examination by ORNL and Alco metallurgists.
- b. Remaining at the SM-1 site unassigned. May be used in SM-1 Core II as replacements for 2 SM-1 Core I high burnup elements.
- c. Remaining at SM-1A site as a spare.

No provision currently exists for SM-1A Core I stationary element spares. It is probable that one or several of the 7 temporarily rejected elements will be found metallurgically acceptable and can therefore be sent back to the SM-1A site as spares. In the event that none prove acceptable, and that elements S63 and S83 are assigned to the SM-1 Core II, other stationary elements must be procured. An additional order to the present SM-1A Core II procurement program nearing completion is suggested.

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7.0 REFERENCES

1. J. O. Brondel, "Supporting Analysis and Derivation of Dimensional Tolerance Specifications for Core II of SM-1A and PM-2A," APAE Memo 300, November 3, 1961.
2. R. J. Beaver, "Report of Examination of 39 Stationary Fuel Elements at Fort Greely, Alaska," Oak Ridge National Laboratory, August 23, 1961.
3. Letter, W.S. Brown of Alco Products to New York Operations Office of AEC, attention I. Adler, dated July 11, 1961, file: AE-90-Task 1.10, contract AT(30-1)-2639, subject: Evaluation of SM-1A Core I Fuel Elements Inspection Data.
4. Letter, I. M. Adler of New York Operations Office, AEC, to W.S. Brown of Alco Products, dated August 9, 1961, file: RA:IMA:2639/3.1.10, subject: Inspection of SM-1 Spare Elements.
5. R. A. Robinson et al, "SM-1 Research and Development; Task XV Zero Power Experiments for SM-1 Core II and SM-1A Core I," APAE 58 Revised, October 12, 1960.
6. Sontheimer, K. C. , "SM-1A Core I Loading Procedure," TP-46 Revised, August 11, 1961.

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8.0 APPENDICES

8.1 FIELD MEASUREMENTS AT FORT GREELY

The outer fuel plate measurements made by ORNL at the SM-1A site at Fort Greely, Alaska, as extracted from their report⁽²⁾, are presented for ready reference in Table 8.1.

8.2 FIELD MEASUREMENTS AT FORT BELVOIR

The outer fuel plate measurements made by the Army at the SM-1 site at Fort Belvoir, Virginia, as contained in their report⁽⁴⁾, are presented for ready reference in Table 8.2.

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TABLE 8.1
ORNL MEASUREMENTS AT SM-1A SITE

Serial Plate	1S		2S		3S		6S		8S		9S		10S		12S		13S		14S	
	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom
Station 1"	0.030	0.016	0.034	0.022	0.032	0.022	0.035	0.030	0.037	0.025	0.033	0.021	0.035	0.022	0.035	0.019	0.030	0.020	0.035	0.023
2"	0.036	0.022	0.038	0.026	0.037	0.025	0.038	0.032	0.039	0.027	0.036	0.026	0.039	0.032	0.036	0.026	0.033	0.026	0.035	0.037
3"	0.037	0.024	0.043	0.026	0.044	0.023	0.041	0.030	0.045	0.027	0.039	0.027	0.042	0.030	0.037	0.028	0.034	0.029	0.039	0.032
4"	0.039	0.027	0.045	0.027	0.059	0.020	0.042	0.030	0.052	0.032	0.043	0.031	0.045	0.026	0.036	0.032	0.036	0.030	0.043	0.035
5"	0.038	0.028	0.042	0.025	0.044	0.015	0.040	0.029	0.056	0.030	0.038	0.033	0.044	0.026	0.037	0.031	0.037	0.029	0.041	0.033
6"	0.039	0.028	0.043	0.025	0.018	0.030	0.040	0.030	0.056	0.027	0.029	0.036	0.042	0.027	0.039	0.028	0.034	0.030	0.039	0.030
7"	0.040	0.028	0.044	0.030	0.036	0.039	0.039	0.027	0.051	0.027	0.037	0.034	0.043	0.030	0.035	0.028	0.034	0.030	0.038	0.030
8"	0.039	0.028	0.042	0.029	0.060	0.013	0.039	0.026	0.046	0.026	0.043	0.031	0.044	0.031	0.032	0.029	0.037	0.029	0.036	0.030
9"	0.038	0.027	0.039	0.028	0.040	0.017	0.040	0.027	0.044	0.025	0.035	0.029	0.046	0.024	0.033	0.029	0.037	0.028	0.037	0.031
10"	-	-	0.040	0.026	0.021	0.038	0.040	0.030	0.045	0.025	0.033	0.032	0.043	0.023	0.036	0.030	0.035	0.028	0.039	0.028
11"	0.039	0.026	0.043	0.024	0.045	0.025	0.039	0.027	0.045	0.026	0.039	0.031	0.043	0.025	0.041	0.031	0.034	0.027	0.038	0.025
12"	0.038	0.023	0.043	0.024	0.054	0.009	0.038	0.023	0.041	0.027	0.039	0.030	0.045	0.027	0.040	0.029	0.037	0.026	0.040	0.028
13"	0.041	0.024	0.040	0.030	0.032	0.033	0.039	0.025	0.042	0.027	0.033	0.030	0.044	0.027	0.040	0.030	0.040	0.028	0.040	0.032
14"	0.043	0.026	0.041	0.029	0.037	0.036	0.039	0.033	0.045	0.028	0.038	0.027	0.044	0.025	0.044	0.029	0.040	0.027	0.042	0.031
15"	0.046	0.026	0.040	0.025	0.059	0.010	0.040	0.029	0.043	0.031	0.041	0.028	0.042	0.021	0.039	0.029	0.039	0.025	0.046	0.028
16"	0.048	0.025	0.037	0.025	0.032	0.009	0.042	0.024	0.041	0.032	0.037	0.031	0.040	0.023	0.036	0.029	0.037	0.025	0.039	0.031
17"	0.038	0.025	0.037	0.025	0.019	0.033	0.040	-	0.043	0.030	0.031	0.029	0.041	0.028	0.037	0.028	0.038	0.027	0.037	0.029
18"	0.038	0.026	0.039	0.025	0.041	0.028	0.038	0.028	0.045	0.027	0.034	0.028	0.044	0.027	0.039	0.028	0.037	0.027	0.037	0.026
19"	0.036	0.027	0.043	0.026	0.061	0.010	0.039	0.029	0.044	0.026	0.042	0.028	0.046	0.024	0.041	0.028	0.039	0.027	0.032	0.027
20"	0.039	0.026	0.042	0.025	0.047	0.024	0.034	0.028	0.041	0.025	0.041	0.029	0.042	0.024	0.040	0.028	0.041	0.026	0.035	0.024
21"	0.040	0.026	0.040	0.023	0.044	0.039	0.034	0.028	0.041	0.026	0.033	0.028	0.041	0.024	0.041	0.028	0.038	0.026	0.038	0.026
22"	0.040	0.027	0.040	0.024	0.036	0.013	0.038	0.028	0.041	0.026	0.038	0.029	0.040	0.025	0.040	0.030	0.039	0.026	0.040	0.036
23"	0.041	0.026	0.041	0.027	0.053	0.009	0.041	0.031	0.040	0.025	0.041	0.032	0.038	0.023	0.037	0.029	0.041	0.027	0.041	0.035
24"	0.040	0.023	0.038	0.025	0.045	0.017	0.035	0.030	0.042	0.027	0.039	0.031	0.037	0.027	0.036	0.028	0.040	0.027	0.039	0.026
25"	0.037	0.025	0.036	0.025	0.037	0.023	0.030	0.030	0.037	0.024	0.035	0.029	0.037	0.029	0.033	0.028	0.035	0.029	0.035	0.027
26"	0.032	0.025	0.036	0.013	0.034	0.016	0.031	0.028	0.032	0.019	0.034	0.025	0.033	0.023	0.030	0.025	0.036	0.025	0.034	0.028

TABLE 8.1 (CONT'D)

Serial Plate	15S		16S		17S		18S		21S		23S		24S		25S		26S		27S	
	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom
Station 1"	0.029	0.027	0.015	0.018	0.038	0.019	0.031	0.023	0.027	0.027	0.020	0.031	0.027	0.030	0.037	0.024	0.008	0.021	0.035	0.020
2"	0.030	0.028	0.025	0.025	0.040	0.023	0.037	0.026	0.034	0.030	0.027	0.031	0.030	0.033	0.039	0.027	0.017	0.026	0.040	0.032
3"	0.039	0.028	0.029	0.030	0.047	0.024	0.037	0.027	0.028	0.032	0.035	0.038	0.030	0.034	0.039	0.032	0.025	0.022	0.038	0.023
4"	0.050	0.027	0.034	0.029	0.061	0.025	0.031	0.030	0.039	0.030	0.028	0.032	0.033	0.031	0.036	0.033	0.033	0.023	0.038	0.022
5"	0.037	0.026	0.033	0.032	0.059	0.017	0.032	0.031	0.040	0.028	0.033	0.031	0.036	0.029	0.039	0.037	0.035	0.023	0.038	0.023
6"	0.029	0.026	0.032	0.030	0.029	0.015	0.036	0.030	0.027	0.026	0.040	0.023	0.036	0.026	0.040	0.031	0.038	0.023	0.039	0.023
7"	0.047	0.027	0.032	0.031	0.026	0.024	0.039	0.029	0.037	0.025	0.029	0.027	0.025	0.027	0.040	0.027	0.040	0.023	0.039	0.024
8"	0.043	0.025	0.033	0.030	0.053	0.026	0.035	0.029	0.048	0.022	0.029	0.026	0.036	0.027	0.037	0.028	0.043	0.022	0.040	0.023
9"	0.026	0.026	0.038	0.022	0.061	0.015	0.041	0.029	0.027	0.022	0.044	0.024	0.042	0.028	0.038	0.029	0.043	0.019	0.040	0.022
10"	0.036	0.026	0.039	0.020	0.060	0.016	0.037	0.029	0.030	0.026	0.037	0.024	0.030	0.025	0.037	0.029	0.044	0.018	0.041	0.024
11"	0.047	0.027	0.035	0.020	0.037	0.031	0.034	0.029	0.048	0.026	0.023	0.024	0.027	0.025	0.037	0.029	0.045	0.019	0.039	0.025
12"	0.035	0.028	0.039	0.022	0.015	0.026	0.039	0.029	0.040	0.026	0.034	0.021	0.042	0.028	0.039	0.029	0.043	0.021	0.038	0.024
13"	0.031	0.029	0.045	0.024	0.048	0.017	0.034	0.030	0.027	0.030	0.044	0.023	0.035	0.029	0.037	0.031	0.038	0.021	0.037	0.027
14"	0.047	0.026	0.038	0.025	0.063	0.017	0.031	0.029	0.040	0.030	0.027	0.025	0.026	0.030	0.036	0.031	0.034	0.020	0.038	0.027
15"	0.041	0.026	0.018	0.025	0.048	0.024	0.048	0.028	0.047	0.025	0.021	0.024	0.041	0.030	0.036	0.034	0.036	0.023	0.039	0.025
16"	0.025	0.026	0.040	0.024	0.017	0.032	0.060	0.028	0.029	0.021	0.040	0.023	0.043	0.029	0.034	0.031	0.041	0.023	0.039	0.024
17"	0.040	0.028	0.045	0.022	0.029	0.020	0.043	0.028	0.035	0.024	0.048	0.023	0.030	0.027	0.033	0.028	0.047	0.022	0.039	0.023
18"	0.049	0.026	0.036	0.024	0.056	0.018	0.036	0.027	0.049	0.026	0.028	0.024	0.035	0.029	0.034	0.029	0.046	0.026	0.039	0.023
19"	0.036	0.026	0.020	0.025	0.051	0.017	0.032	0.027	0.033	0.027	0.019	0.029	0.035	0.031	0.037	0.029	0.043	0.030	0.040	0.025
20"	0.030	0.029	0.042	0.026	0.015	0.015	0.034	0.027	0.026	0.026	0.042	0.029	0.026	0.029	0.037	0.029	0.044	0.031	0.039	0.025
21"	0.042	0.028	0.041	0.027	0.018	0.025	0.034	0.028	0.043	0.027	0.042	0.026	0.037	0.028	0.036	0.032	0.047	0.029	0.037	0.024
22"	0.045	0.027	0.037	0.026	0.048	0.035	0.028	0.029	0.046	0.032	0.023	0.025	0.037	0.026	0.034	0.034	0.048	0.028	0.036	0.023
23"	0.047	0.028	0.031	0.026	0.055	0.030	0.026	0.029	0.032	0.032	0.023	0.022	0.031	0.027	0.034	0.036	0.047	0.025	0.033	0.023
24"	0.044	0.029	0.031	0.025	0.045	0.025	0.034	0.029	0.032	0.030	0.031	0.021	0.037	0.028	0.038	0.034	0.044	0.023	0.030	0.025
25"	0.035	0.024	0.023	0.025	0.031	0.023	0.027	0.030	0.037	0.029	0.022	0.025	0.028	0.033	0.043	0.027	0.034	0.024	0.022	0.023
26"	0.034	0.021	0.029	0.021	0.035	0.027	0.030	0.032	0.033	0.026	0.018	0.025	0.023	0.033	0.048	0.030	*0.039	0.0??	0.017	0.016

* No measurement-element higher than side plates.

TABLE 8.1 (CONT'D)

Serial Plate	28S		29S		30S		31S		32S		33S		34S		35S		36S		38S	
	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom
Station 1"	0.012	0.032	0.007	0.018	0.023	0.022	0.015	0.027	0.030	0.026	0.024	0.018	0.036	0.023	0.014	0.032	0.031	0.027	0.037	0.026
2"	0.028	0.032	0.012	0.025	0.033	0.035	0.027	0.029	0.039	0.031	0.040	0.023	0.040	0.026	0.028	0.030	0.023	0.026	0.037	0.026
3"	0.043	0.032	0.030	0.026	0.042	0.031	0.040	0.024	0.039	0.025	0.036	0.030	0.041	0.020	0.038	0.030	0.019	0.026	0.041	0.023
4"	0.042	0.031	0.037	0.024	0.040	0.030	0.038	0.025	0.039	0.028	0.043	0.025	0.043	0.025	0.040	0.024	0.022	0.030	0.040	0.022
5"	0.049	0.029	0.041	0.026	0.041	0.025	0.041	0.026	0.043	0.031	0.050	0.026	0.040	0.023	0.041	0.021	0.024	0.027	0.027	0.020
6"	0.046	0.029	0.038	0.026	0.041	0.027	0.043	0.027	0.044	0.030	0.050	0.034	0.038	0.021	0.043	0.019	0.026	0.023	0.037	0.022
7"	0.036	0.030	0.038	0.026	0.041	0.028	0.046	0.027	0.044	0.026	0.035	0.021	0.039	0.023	0.042	0.022	0.030	0.022	0.042	0.029
8"	0.035	0.030	0.038	0.023	0.044	0.027	0.050	0.026	0.044	0.024	0.027	0.021	0.039	0.022	0.042	0.028	0.034	0.023	0.025	0.024
9"	0.038	0.028	0.039	0.025	0.049	0.023	0.054	0.027	0.046	0.024	0.036	0.028	0.041	0.022	0.042	0.031	0.033	0.025	0.034	0.019
10"	0.040	0.026	0.037	0.027	0.045	0.022	0.056	0.028	0.046	0.025	0.050	0.029	0.041	0.023	0.043	0.031	0.032	0.027	0.049	0.022
11"	0.040	0.021	0.037	0.031	0.037	0.023	0.057	0.026	0.046	0.027	0.052	0.031	0.041	0.024	0.044	0.031	0.031	0.027	0.043	0.021
12"	0.039	0.018	0.037	0.031	0.032	0.025	0.056	0.028	0.046	0.029	0.042	0.042	0.041	0.024	0.044	0.030	0.032	0.027	0.029	0.020
13"	0.038	0.019	0.037	0.031	0.030	0.025	0.051	0.031	0.049	0.032	0.033	0.035	0.041	0.025	0.046	0.028	0.033	0.027	0.019	0.023
14"	0.038	0.021	0.037	0.030	0.033	0.024	0.047	0.030	0.047	0.032	0.037	0.023	0.041	0.026	0.045	0.026	0.033	0.025	0.030	0.018
15"	0.038	0.025	0.036	0.030	0.039	0.027	0.045	0.028	0.044	0.030	0.047	0.034	0.042	0.023	0.043	0.028	0.033	0.025	0.049	0.020
16"	0.040	0.024	0.036	0.031	0.040	0.025	0.043	0.027	0.042	0.030	0.045	0.047	0.042	0.023	0.040	0.028	0.032	0.024	0.041	0.035
17"	0.038	0.025	0.036	0.029	0.041	0.025	0.043	0.024	0.040	0.029	0.033	0.041	0.041	0.024	0.039	0.028	0.031	0.025	0.023	0.028
18"	0.036	0.029	0.036	0.027	0.042	0.027	0.043	0.023	0.037	0.027	0.029	0.027	0.041	0.025	0.038	0.028	0.030	0.026	0.024	0.018
19"	0.033	0.037	0.036	0.024	0.042	0.031	0.043	0.025	0.034	0.026	0.040	0.020	0.041	0.025	0.037	0.028	0.025	0.026	0.040	0.016
20"	0.036	0.034	0.033	0.025	0.038	0.026	0.039	0.030	0.034	0.026	0.041	0.037	0.041	0.024	0.038	0.026	0.024	0.027	0.044	0.018
21"	0.040	0.028	0.031	0.027	0.038	0.024	0.039	0.030	0.034	0.026	0.032	0.025	0.041	0.025	0.038	0.025	0.026	0.027	0.029	0.030
22"	0.040	0.027	0.026	0.030	0.041	0.026	0.036	0.029	0.034	0.027	0.031	0.045	0.041	0.027	0.039	0.025	0.027	0.027	0.024	0.025
23"	0.039	0.031	0.022	0.029	0.041	0.021	0.037	0.028	0.033	0.024	0.035	0.034	0.040	0.029	0.040	0.026	0.025	0.026	0.031	0.016
24"	0.037	0.035	0.016	0.029	0.040	0.024	0.038	0.030	0.029	0.023	0.036	0.037	0.039	0.033	0.038	0.027	0.019	0.023	0.037	0.022
25"	0.019	0.030	0.008	0.030	0.019	0.022	0.033	0.031	0.028	0.030	0.029	0.035	0.038	0.035	0.038	0.027	0.016	0.025	0.035	0.024
26"	0.001	0.025	-	0.027	*0.0??	0.023	0.036	0.026	0.024	0.023	0.013	0.032	0.035	0.026	0.036	0.028	0.010	0.020	0.033	0.023

* No measurement-element higher than side plates.

TABLE 8.1 (CONT'D)

Serial Plate	39S		40S		43S		46S		47S		50S		51S		52S		137S	
	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom
Station 1"	0.026	0.021	0.038	0.017		0.025	0.029	0.027	0.037	0.028	0.035	0.020	0.029	0.023	0.028	0.022	0.032	0.024
2"	0.030	0.028	0.036	0.027	0.018	0.025	0.035	0.027	0.040	0.028	0.039	0.025	0.031	0.026	0.040	0.023	0.038	0.026
3"	0.031	0.029	0.037	0.027	0.037	0.023	0.037	0.030	0.044	0.026	0.040	0.039	0.031	0.027	0.065	0.027	0.042	0.025
4"	0.030	0.031	0.036	0.027	0.049	0.019	0.038	0.027	0.046	0.022	0.043	0.029	0.035	0.029	0.050	0.026	0.044	0.024
5"	0.031	0.031	0.032	0.027	0.054	0.023	0.037	0.023	0.045	0.020	0.044	0.026	0.040	0.027	0.041	0.023	0.041	0.026
6"	0.031	0.031	0.026	0.029	0.033	0.027	0.035	0.025	0.043	0.019	0.043	0.024	0.041	0.026	0.042	0.024	0.042	0.027
7"	0.032	0.033	0.027	0.029	0.037	0.020	0.029	0.027	0.041	0.020	0.042	0.025	0.040	0.027	0.043	0.027	0.044	0.028
8"	0.031	0.035	0.030	0.028	0.056	0.017	0.027	0.025	0.041	0.020	0.042	0.024	0.038	0.030	0.045	0.025	0.043	0.029
9"	0.034	0.032	0.029	0.026	0.036	0.026	0.030	0.025	0.043	0.020	0.042	0.021	0.036	0.028	0.044	0.025	0.042	0.034
10"	0.035	0.030	0.029	0.025	0.028	0.030	0.034	0.027	0.044	0.020	0.043	0.028	0.038	0.024	0.042	0.033	0.039	0.031
11"	0.037	0.029	0.030	0.026	0.048	0.021	0.035	0.028	0.043	0.020	0.042	0.030	0.044	0.031	0.041	0.030	0.038	0.029
12"	0.036	0.030	0.032	0.026	0.045	0.021	0.034	0.027	0.043	0.021	0.042	0.025	0.049	0.037	0.041	0.029	0.040	0.026
13"	0.032	0.031	0.033	0.025	0.027	0.031	0.031	0.027	0.043	0.024	0.042	0.030	0.048	0.037	0.041	0.030	0.039	0.025
14"	0.033	0.030	0.032	0.025	0.043	0.026	0.033	0.026	0.043	0.026	0.042	0.035	0.043	0.025	0.041	0.029	0.037	0.030
15"	0.035	0.029	0.032	0.024	0.051	0.018	0.034	0.023	0.040	0.026	0.044	0.034	0.037	0.021	0.041	0.028	0.038	0.027
16"	0.034	0.029	0.032	0.024	0.028	0.022	0.035	0.025	0.040	0.021	0.042	0.027	0.036	0.023	0.041	0.030	0.038	0.025
17"	0.033	0.029	0.033	0.024	0.036	0.018	0.037	0.029	0.040	0.020	0.042	0.027	0.041	0.021	0.041	0.032	0.037	0.026
18"	0.033	0.029	0.032	0.025	0.055	0.021	0.036		0.040	0.021	0.043	0.030	0.035	0.015	0.041	0.026	0.039	0.030
19"	0.034	0.028	0.032	0.026	0.035	0.033	0.030	0.028	0.039	0.022	0.042	0.026	0.031	0.013	0.038	0.023	0.039	0.029
20"	0.040	0.028	0.031	0.026	0.024	0.034	0.029	0.025	0.039	0.023	0.042	0.024	0.039	0.020	0.037	0.028	0.040	0.030
21"	0.039	0.030	0.030	0.025	0.045	0.027	0.035	0.028	0.039	0.021	0.042	0.024	0.052	0.018	0.039	0.036	0.041	0.032
22"	0.032	0.032	0.030	0.024	0.052	0.023	0.038	0.029	0.040	0.020	0.041	0.041	0.042	0.015	0.049	0.032	0.042	0.029
23"	0.029	0.032	0.030	0.023	0.041	0.024	0.039	0.031	0.042	0.021	0.041	0.060	0.036	0.013	0.068	0.026	0.044	0.030
24"	0.028	0.030	0.039	0.026	0.034	0.023		0.037	0.047	0.020	0.042	0.036	0.039	0.017	0.054	0.024	0.040	0.027
25"	0.027	0.030	0.016	0.029	0.022	0.027	0.038	0.027	0.038	0.020	0.042	0.016	0.039	0.025	0.037	0.023	0.039	0.025
26"	0.020	0.023	0.015	0.028	0.018	0.023	0.037	0.021	0.034	0.014	0.041	0.019	0.038	0.025	0.031	0.023	0.031	0.025

TABLE 8.1 (CONT'D)

Serial Plate	CR-2-S		CR-3-S		CR-4-S		CR-5-S		CR-6-S		CR-7-S		CR-8-S		8C	
	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom
Station 1"	0.073	0.076	0.076	0.075	0.080	0.073	0.083	0.077	0.083	0.074	0.081	0.073	0.077	0.072	0.076	0.063
2"	0.076	0.079	0.074	0.077	0.079	0.072	0.083	0.072	0.080	0.073	0.079	0.073	0.080	0.073	0.077	0.063
3"	0.079	0.075	0.080	0.076	0.080	0.072	0.079	0.071	0.076	0.069	0.078	0.077	0.077	0.075	0.074	0.064
4"	0.080	0.072	0.081	0.076	0.080	0.073	0.079	0.072	0.076	0.070	0.080	0.073	0.079	0.075	0.076	0.064
5"	0.081	0.072	0.080	0.077	0.080	0.072	0.081	0.073	0.080	0.071	0.081	0.072	0.078	0.073	0.075	0.065
6"	0.082	0.070	0.079	0.076	0.082	0.072	0.080	0.074	0.081	0.070	0.083	0.072	0.078	0.071	0.075	0.066
7"	0.083	0.070	0.082	0.078	0.081	0.072	0.080	0.073	0.081	0.069	0.080	0.072	0.079	0.072	0.074	0.066
8"	0.081	0.071	0.082	0.076	0.080	0.072	0.080	0.074	0.083	0.070	0.080	0.072	0.080	0.071	0.074	0.067
9"	0.080	0.072	0.081	0.075	0.079	0.072	0.080	0.073	0.083	0.071	0.079	0.071	0.079	0.071	0.074	0.067
10"	0.082	0.073	0.083	0.076	0.081	0.070	0.080	0.074	0.082	0.069	0.078	0.070	0.079	0.072	0.074	0.067
11"	0.084	0.073	0.084	0.077	0.081	0.072	0.080	0.075	0.082	0.070	0.081	0.070	0.079	0.072	0.075	0.066
12"	0.083	0.072	0.082	0.080	0.081	0.072	0.081	0.074	0.082	0.071	0.082	0.070	0.079	0.073	0.076	0.066
13"	0.084	0.073	0.081	0.078	0.082	0.076	0.080	0.073	0.082	0.071	0.080	0.069	0.079	0.073	0.078	0.066
14"	0.084	0.073	0.082	0.075	0.082	0.080	0.080	0.073	0.081	0.070	0.081	0.071	0.078	0.072	0.078	0.065
15"	0.085	0.073	0.082	0.075	0.083	0.073	0.081	0.073	0.080	0.069	0.081	0.072	0.078	0.071	0.079	0.065
16"	0.084	0.073	0.082	0.076	0.084	0.070	0.079	0.074	0.080	0.069	0.081	0.072	0.079	0.072	0.078	0.066
17"	0.083	0.073	0.081	0.076	0.084	0.072	0.082	0.075	0.079	0.070	0.081	0.072	0.081	0.073	0.079	0.065
18"	0.082	0.073	0.082	0.074	0.084	0.074	0.081	0.075	0.079	0.070	0.082	0.074	0.082	0.072	0.077	0.066
19"	0.082	0.073	0.083	0.076	0.084	0.074	0.080	0.073	0.079	0.070	0.082	0.070	0.081	0.074	0.078	0.066
20"	0.080	0.074	0.083	0.075	0.084	0.074	0.080	0.071	0.079	0.070	0.080	0.071	0.082	0.075	0.079	0.064
21"	0.079	0.075	0.082	0.073	0.084	0.073	0.081	0.072	0.081	0.071	0.080	0.076	0.085	0.073	0.076	0.066
22"	0.081	0.077	0.080	0.074	0.081	0.074	0.080	0.074	0.079	0.074	0.081	0.078	0.081	0.073	0.074	0.070

TABLE 8.2
ARMY MEASUREMENTS AT SM-1 SITE

Serial Plate	17V		18V		22V		24V		39V		40V		S63		S83	
	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom
Station 1"	0.0335	0.021	0.036	0.019	0.033	0.021	0.0405	0.030	0.035	0.027	0.0415	0.0245	0.024	0.016	0.030	0.0295
2"	0.038	0.024	0.041	0.0275	0.041	0.025	0.0465	0.0305	0.041	0.0285	0.0425	0.0265	0.032	0.016	0.021	0.025
3"	0.040	0.0135	0.041	0.026	0.0465	0.024	0.050	0.0335	0.0455	0.0265	0.047	0.033	0.032	0.020	0.032	0.0335
4"	0.042	0.018	0.0445	0.024	0.048	0.022	0.0525	0.033	0.046	0.0255	0.0465	0.030	0.032	0.023	0.043	0.042
5"	0.0415	0.020	0.044	0.023	0.0445	0.0225	0.054	0.0315	0.0445	0.0275	0.043	0.0285	0.031	0.0265	0.052	0.033
6"	0.041	0.0225	0.041	0.023	0.0445	0.0255	0.054	0.032	0.044	0.028	0.038	0.0265	0.034	0.038	0.054	0.026
7"	0.040	0.024	0.041	0.025	0.0445	0.026	0.055	0.031	0.0445	0.028	0.0395	0.0265	0.0375	0.037	0.044	0.0305
8"	0.040	0.0245	0.041	0.026	0.043	0.0255	0.057	0.029	0.045	0.027	0.0435	0.026	0.0345	0.031	0.035	0.030
9"	0.040	0.025	0.041	0.023	0.0415	0.0245	0.057	0.0265	0.044	0.0265	0.044	0.026	0.033	0.0235	0.026	0.0295
10"	0.040	0.0245	0.042	0.023	0.041	0.024	0.056	0.025	0.044	0.026	0.0475	0.026	0.038	0.0235	0.024	0.031
11"	0.042	0.025	0.044	0.023	0.041	0.0245	0.055	0.025	0.0485	0.026	0.0435	0.0265	0.0425	0.0245	0.025	0.036
12"	0.041	0.025	0.046	0.0235	0.042	0.025	0.055	0.0255	0.0455	0.0275	0.041	0.0285	0.0405	0.0255	0.027	0.041
13"	0.040	0.030	0.046	0.026	0.0425	0.026	0.055	0.0265	0.044	0.0295	0.0405	0.0295	0.038	0.0255	0.0275	0.0405
14"	0.0405	0.036	0.046	0.036	0.0445	0.026	0.055	0.0265	0.044	0.0285	0.0415	0.029	0.036	0.0275	0.0335	0.047
15"	0.046	0.0365	0.047	0.026	0.045	0.025	0.055	0.0265	0.046	0.027	0.0515	0.0275	0.036	0.0315	0.035	0.0495
16"	0.0465	0.036	0.046	0.026	0.045	0.023	0.055	0.0245	0.046	0.024	0.0465	0.026	0.039	0.034	0.0325	0.0415
17"	0.043	0.034	0.046	0.0245	0.046	0.020	0.055	0.0235	0.0445	0.023	0.036	0.027	0.037	0.026	0.0475	0.0465
18"	0.0405	0.025	0.048	0.025	0.046	0.0215	0.0545	0.0235	0.0435	0.0275	0.0465	0.028	0.0345	0.023	0.045	0.055
19"	0.0405	0.0225	0.048	0.027	0.0465	0.025	0.055	0.025	0.0455	0.033	0.055	0.0295	0.031	0.022	0.030	0.0535
20"	0.038	0.022	0.050	0.029	0.0465	0.027	0.055	0.0265	0.0465	0.031	0.045	0.0295	0.031	0.022	0.0315	0.054
21"	0.037	0.026	0.0495	0.029	0.046	0.0255	0.055	0.026	0.046	0.028	0.043	0.028	0.0325	0.019	0.043	0.055
22"	0.0405	0.033	0.0495	0.026	0.0445	0.022	0.057	0.026	0.050	0.0275	0.0415	0.0275	0.0335	0.023	0.035	0.0525
23"	0.0465	0.036	0.0525	0.023	0.046	0.018	0.057	0.0275	0.049	0.0275	0.0445	0.0275	0.0315	0.0285	0.0285	0.0435
24"	0.0415	0.0295	0.048	0.025	0.043	0.021	0.0515	0.0295	0.0475	0.0285	0.043	0.027	0.032	0.0305	0.031	0.0315
25"	0.0375	0.028	0.042	0.025	0.0385	0.026	0.0455	0.0275	0.0405	0.0275	0.040	0.0245	0.034	0.027	0.0335	0.0255
26"	0.0325	0.0215	0.0375	0.0225	0.032	0.0245	0.037	0.020	0.035	0.025	0.0375	0.0225	0.0375	0.0275	0.029	0.020