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PROPOSED IRRADIATION OF SUBSTANDARD
FUEL ELEMENTS - PHASE II

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PROPOSED IRRADIATION OF SUBSTANDARD

FUEL ELEMENTS - PHASE II

By

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April 22, 1963

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PROPOSED IRRADIATION OF SUBSTANDARD
FUEL ELEMENTS - PHASE II

Reference: W. A. Blanton, "Proposal for Irradiating Substandard Fuel Elements in the Upstream Positions," 4-9-63.

INTRODUCTION

The reference letter outlined an initial proposal for irradiating limited categories of substandard fuel elements in the upstream positions of the reactor process tubes. As Phase II of this program, a comprehensive study has been made of all current fuel reject categories with respect to use in the upstream low rupture potential positions. This report describes additional "reject" fuel categories, the estimated cost savings, rupture potential, and procedures for identifying and handling pieces to fulfill the combined requirements of Phase I and II of this program. Future methods for grading fuel elements to reduce rupture potential in the downstream reactor positions are also outlined in this report.

SUMMARY

The combined fuel element reject categories proposed for charging in the upstream reactor positions are as shown in Table I. Use of these rejects, which account for about 7 percent of the fuels production throughput, will result in an annual estimated ALSi Shop savings of approximately \$366,000 less an estimated \$30,000 for increased handling costs. In addition, the use of bare core grain size rejects, amounting to about 3.3 percent of the cores received, will save the AEC complex in the order of \$247,000 per year.

Since the relative rupture potential (see Figures 1, 2, 3, and 4) is negligible, and ample capacity is provided in the first five upstream positions of the process tubes, it is recommended that all of the reject categories be irradiated in these positions. Irradiation severity (power and temperature) across the first five upstream positions for all fuel models under maximum service conditions is so low that neither fuel cladding corrosion nor dimensional stability would be significant factors. Therefore, all fuel elements included in the reject categories proposed for reactor charging would be expected to withstand variable goal exposures without incurring ruptures, providing the closures and cladding are free of defects that might permit coolant entry. Freedom from defects of this type can only be assured by the critical visual inspections applied to all fuel production.

Two types of marking are proposed to identify substandard fuel elements for charging in the upstream positions. One consists of a permanent "code" stamped on the base end of each fuel element to indicate reject category (Table II).

The other involves coloring both ends of the fuel elements green to distinctly identify pieces for handling and charging position. In addition, signs reading "UPSTREAM FUEL" will be attached to each side of the shipping pallets.

It is emphasized that the proposed use of substandard fuel in the upstream positions will not influence fuel quality. No relaxation in process specifications or quality control standards will be made as a result of this program. In fact, longer range plans include fuel grading on an attributes basis (Phase III) to permit charging premium grade fuel elements in the high rupture potential positions. The ultimate goal (Phase IV) in fuel grading is to match the reactor position rupture potential with fuel element quality as determined by variables measurements.

DISCUSSION

I. Phase II - Irradiation of Reject Fuel Elements in the Upstream Reactor Positions.

A. Description of Fuel Elements Proposed for Upstream Loading

Utilization of fuel element rejects in the upstream positions as shown in Table I will result in an estimated AlSi Shop saving of \$366,000, less about \$30,000 for increased fuel handling costs. This estimate includes the proposed savings outlined in the reference letter for using stains, inclusions, and marred surface rejects. An additional annual saving of \$247,000 in feed material costs will be realized from the use of bare core grain size rejects. A brief description of each reject category proposed for use in upstream reactor positions is as follows:

1. Rejects Occurring During the Canning Operation

The only rejects occurring during the canning operation that would be suitable for upstream reactor positions are AlSi slop-over and stuck sleeve rejects. AlSi slop-over rejects occur when the fit between the steel sleeve (used to protect the outside can surfaces from the molten AlSi) and the aluminum can is inadequate, allowing molten AlSi to be drawn down between the can O.D. and the sleeve I.D. by surface tension (capillary action). The resulting 0.002" to 0.003" thick layer of AlSi on the O.D. of the can wall can be removed by etching the reject in Aluminux (an inhibited caustic solution). This etching will also remove about 0.003" of the aluminum can wall, but with the average minimum can wall thickness in the range of 0.030" to 0.032", and by penetration testing the reclaimed pieces there is very little danger of accepting too thin a can wall. Elements with AlSi slop-overs extending the full length of the can wall will not be reclaimed for reactor charging, since this condition is usually indicative of having used the wrong size sleeve.

Stuck sleeve rejects occur when there is a restriction between the can O.D. and the sleeve I.D. that does not allow the canned fuel element to be removed without marring the can surface. This is usually due to a foreign material adhering to the sleeve I.D. or a burr at the mouth of the sleeve. Only those stuck sleeve rejects with marred surface defects less than 0.010" are proposed for upstream reactor charging.

By using stuck sleeve and AlSi slop-over rejects, it is estimated that 0.9% of the production normally sent to core recovery could be utilized.

2. Facing Rejects

Excess metal is faced from the cap and base end of all canned fuel assemblies to provide fuel elements of the proper length and with the correct end contour. Minimum cap and base thickness is specified to ensure adequate braze length protection from water leaks. Maximum cap and base thickness is controlled to avoid unwarranted reactivity losses. Long fuel elements usually result from not seating the cap properly on the core, resulting in a wider than normal AlSi braze between the cap wafer and core. Short fuel elements and contour dimension rejects usually occur due to tool holder slippage, tool breakage, or a loose fuel element collet. The types of defects found at the facing lathes that should be suitable for upstream reactor charging are:

- a. Length rejects that are up to 0.100" above the present limit and up to 0.050" below the present limit. This will still ensure a minimum braze length of 0.150" on the self-support models and 0.200" on the standard true-line models.
- b. Female contour rejects that are up to 0.100" over the present maximum diameter (1.010") and up to 0.050" below the present minimum diameter (1.000"). Included in this category are chamfer rejects up to a maximum depth of 0.100" at the mouth of the tube.
- c. Male contour rejects that are: 1) up to 0.050" over the present maximum diameter (1.000"), 2) up to 0.100" below the present minimum diameter (0.990"), and 3) a male projection that is 0.040" below the present minimum height (0.090").
- d. Marred surface caused by lathe curls should be acceptable, if not greater than 0.010" in depth.

Use of the above reject types found at the facing lathes will result in an estimated 0.2% of the production that would normally be sent to core recovery.

3. UT-4 Test Rejects

The UT-4 test was designed to ultrasonically detect voids and nonwet areas in the braze layer between the aluminum can wall and cap wafer and between the aluminum can base and spire wall. These defects, if long enough, are potential water paths to the uranium core, provided that these defects coincide with a defective weld closure. The UT-4 testers were put into operation on all production fuel elements in May, 1962, using temporary standards to determine the capabilities and limitations of the test. Engineering specifications have not yet been established for this test due to poor tester reproducibility and accuracy. The testers appear capable of detecting nonbond areas that are about 0.020" wide and with the present limits they will reject a single nonbond area that is greater than three-fifths of the 0.200" axial braze length being tested. If more than one nonbond area occurs in the braze layer, the assurance of a sound axial braze length is reduced from 0.080" to 0.024". If the weld bead extends into the UT-4 test area, or if the cap or base wafer is on the thin side allowing the test area to extend over the uranium core, the testers may pass rejectable elements or reject acceptable elements.

Studies are currently underway to determine the capability of the UT-4 testers to distinguish between various types of end closure braze defects, to eliminate observed bias between testers, and to improve tester accuracy. It is not proposed to use any of the UT-4 tester rejects until it can be ascertained that none of the rejects accepted for charging in the upstream positions have full length braze defects, exclusive of the weld zone. Once this capability has been established, those rejects which do not have full length braze defects will be subjected to two visual weld inspections under 3X magnification prior to acceptance for reactor charging. Using these rejects would save about 1.44% of the production that would normally be sent to core recovery.

4. Bond Test Rejects

A metallic bond between the uranium core and aluminum cladding is required to offer secondary protection to the uranium from the reactor coolant in the event of a jacket failure, and to uniformly dissipate heat generated during irradiation. All fuel elements are tested ultrasonically for voids in the braze layer or unbonded areas between the core and the aluminum can and spire wall. The present external bond test limits are established to reject fuel elements with a single void greater than 0.78 inch in circumferential length or elements with a total nonbond area (one large nonbond or numerous small nonbonds) of approximately 0.2 square inch or 100 total counts. In like manner, the present internal bond test limits are; a single void greater than 0.29 inch in circumferential length or a total nonbond area of approximately 0.07 square inch or 100 total counts.

It is proposed that only those bond test rejects having between 100 and 200 total counts be used in the upstream reactor positions. For the external bond this is a total nonbond area of between 0.2 and 0.4 square inch and for the internal bond an area of between 0.07 and 0.14 square inch. Fuel elements that are rejected for both internal and external bond defects will not be used for upstream positions. The use of these rejects is estimated to save 0.36% of the production that would normally be sent to core recovery.

5. Penetration Test Rejects

Electromagnetic detection of AlSi braze penetration is used to reject those fuel elements which have less than 0.020" residual can wall thickness and 0.015" residual spire wall thickness. If the aluminum jacket is corroded away by the reactor coolant so that points of excessive AlSi penetration are exposed, a relatively rapid penetration of a porous AlSi bond layer may lead to a fuel element failure. Beside a true AlSi penetration, the internal penetration test is sensitive to slight wrinkles in the spire wall, voids in the braze layer, and some marred surface defects. The external penetration test is sensitive to some types of small marred surface defects on the can wall. These small surface defects are believed to be responsible for the vast majority of the penetration rejects. There have been no known AlSi penetrations detected by the testers that have had less than 0.010" residual can or spire wall as determined by destructive examination of penetration tester rejects. The average minimum residual can wall thickness is between 0.030" and 0.032".

It is proposed that all penetration tester rejects be used in the upstream reactor positions except for fuel elements rejected for both internal and external penetration rejects. This would save about 0.40% of the production that would normally be sent to core recovery.

6. Surface Stains and Inclusions

Fuel elements with imbedded foreign particles (inclusions) and stains that do not exhibit a normal oxide coating or are dark enough to mask an inclusion are grouped into reprocess lots and re-etched, re-autoclaved, and re-inspected. Most of these defects are reclaimed by this process, however, about 0.5 percent of the total production is still being rejected after this reclamation process. It was proposed in the reference letter that the stain and inclusion rejects from the reclaimed elements that do not show evidence of a "halo" or pitting typical of sacrificial corrosion be used for upstream reactor positions.

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7. Marred Surfaces

Surface scratches, dents, and mars in the aluminum can walls greater than 0.004", but less than 0.010" were also proposed in the reference letter for use in upstream reactor positions. Use of these marred surface defects will save about 2.0 percent of the production that is now sent to core recovery.

8. Radiograph Rejects

The cap end weld and braze layer between the cap wafer and can wall is radiographed to assure a sound braze layer to prevent reactor coolant water from reaching the uranium core. There are two classes of voids that are currently being rejected by the radiograph:

- a. Any void regardless of size which shows no visible weld cover on the radiograph film.
- b. Individual voids, grouped voids, or porosity masses greater than $\frac{1}{2}$ the braze length or greater than $\frac{3}{8}$ " in circumferential length.

Discontinuance of radiography is being considered since essentially all of the radiograph rejects are due to voids in the AlSi braze adjacent to the uranium core and are 0.200" to 0.250" below the weld zone. Further, there are no apparent problems associated with the base end closure which is not radiographed. The use of these rejects will save about 0.02% of the production that is now sent to core recovery.

9. Rail Weld Rejects

The only rail weld rejects that appear to be suitable for upstream reactor positions are:

- a. Self-support elements with rail heights that are up to 0.004" below the minimum specified rail height.
- b. Bumper and self-support elements with cracking of the rail along the sides of the weld zone, provided the rail contains a minimum of 0.100" of sound metal across the weld zone.

Use of these rejects is estimated to save about 4.0% of the projection fuel production that is presently sent to core recovery.

10. UT-2 Test Rejects

The UT-2 tester, an ultrasonic test, is used to check all bare uranium cores for completeness of beta heat treatment (transformation) and to control the maximum grain size. Uranium cores that have not been beta

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heat treated or transformed may undergo gross dimensional changes during irradiation resulting in fuel element failures. Large grained uranium cores may contribute to surface bumping or roughening during irradiation; however, no known failure has occurred due to bumping. Ability of the UT-2 testers to distinguish between untransformed and transformed cores is dependent upon the smaller grain size of the untransformed uranium. Alloying elements, impurity content, and severity of quench during the beta heat treatment influences the grain size of transformed cores. Currently, the majority of the rejected cores are due to a small transformed grain size, since the present UT-2 tester limits are incapable of detecting the difference in grain size between these small transformed grains and the smaller untransformed grains. The last incident of untransformed uranium cores being detected by HAPU UT-2 testers was in June, 1962. This incident was caused by a sludge build-up problem in the NLO salt bath, resulting in some partially untransformed cores. NLO currently uses UT-2 testers to test core samples from each ingot and should detect any untransformed cores due to beta heat treating equipment malfunctions.

It is proposed that the UT-2 grain size rejects be used in the upstream reactor positions provided the reject cores are retested at tester limits that will distinguish between the majority of the small transformed grains and the fine untransformed grains. It is estimated that 95 percent of the UT-2 tester rejects (3.43 percent of the incoming cores in 1962) could be salvaged for a savings of about \$247,000 per year in the AEC complex. This savings results from the cost of 46¢ a pound for remelting, rolling, heat treatment, machining, and shipping 267 tons of UT-2 reject cores that would be returned to NLO if they are not used for upstream charging.

B. Rupture Potential

The proposed canning rejects can be irradiated in the first five upstream positions of the reactor process tubes with negligible rupture potential. Relative rupture potential by fuel element position as calculated by C. M. Heeb for 32 piece and 38 piece natural uranium fuel charges and 34 piece and 46 piece enriched fuel charges are as shown in Figures 1, 2, 3, and 4. These calculations were based on the present rupture model, adjusting for differences in severity (power and temperature) of service with position, and normalizing to a value of 1.0 for position of maximum severity. It will be noted that the relative rupture potential for the first five upstream positions is extremely low, ranging from 10^{-8} to 10^{-10} for the fifth position. Natural uranium fuel ruptures experienced in the reactors have been largely confined to the last 18 downstream positions and enriched fuel ruptures to the last 22 downstream positions, except in minor instances when the flux was peaked forward. These positions are most severe in terms of flux density and temperature, ranging from 10^{-2} to 1.0 in relative rupture potential.

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Assuming an unpeaked chopped cosine flux distribution for maximum reactor service conditions, local coolant temperature is not expected to rise more than 10 C across the first five upstream positions for any fuel model. Maximum specific power for the #5 position is in the order of 33 KW/fuel element. Under these conditions fuel cladding corrosion is negligible, and would not be expected to exceed 2-3 mils during maximum fuel residence time in the reactors. Post-irradiation examination of all fuel types has confirmed no significant weight loss or visible corrosion occurs in the forward positions under current goal exposures. Therefore, it is concluded that the proposed fuel reject categories can be irradiated in the first five upstream positions with a high margin of safety with respect to rupture potential, provided the end closures and cladding are free of defects that might permit coolant entry. Freedom from these defects can only be assured through the same critical visual inspection applied to acceptable fuel elements, using magnification or other aids as required.

Dimensional stability of the rejects categories that might effect hydraulic resistance would not be expected to be a significant factor under the low severity of service. Thermal stresses resulting from charging bond test rejects with unbonded areas of the proposed sizes should not constitute a warp problem. Neither should uranium cores rejected for small grain size differ in stability from those normally accepted if the cores are retested to assure that the uranium has been completely transformed. This is particularly true since small grain uranium has proven to be slightly more stable than the larger grain uranium accepted, primarily because the latter shows some tendency toward surface bumping under the most severe irradiation conditions.

C. Fuel Identification For Selective Charging

Of major importance to the "fail safe" use of substandard fuel elements in the reactors is the identification and handling of this material under procedures that will assure the pieces are charged in the proper positions. For this purpose, it is proposed that each reject fuel element designated for charging in upstream reactor positions be identified and handled as follows:

1. Each reject category will be assigned a code, as shown in Table II, which will be stamped on the base end of each fuel element as a permanent marking for reference before and after irradiation. Fuel elements falling into more than one canned reject category will not be used for reactor charging. However, UT-2 grain size reject cores are not to be considered as a canned reject category.
2. Both ends of each fuel element will be colored green using an appropriate marking ink to distinctly identify each piece for upstream loading.
3. All categories of reject fuel elements designated for upstream loading will be segregated by fuel model and shipped to the reactors

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as "R" lots in pallets with special markings. A white sign (2 feet x 4 inches) with the words "UPSTREAM FUEL" in green, will be attached to each side of the pallet.

II. Phase III - Attributes Fuel Grading

There are two methods of attributes grading to improve the quality of the fuel elements in the high rupture potential positions in the reactors. Neither method should be applied, however, until the bias between the nondestructive testers and individual tester precision has been improved. A significant improvement in tester reliability is expected within six months.

1. The first method is to tighten the UT-4 braze closure integrity and UE-1 bond test limits, thereby providing upgraded fuel elements for the high rupture potential reactor positions. This would probably mean expanding the upstream charging of substandard fuel elements from the first five positions to about the first nine positions. As shown in Table III, if substandard fuel elements could be used in the upstream reactor positions having less than a 10^{-6} relative rupture potential as compared to the highest rupture potential position, the maximum capacity for irradiating substandard fuel elements would be between 21 and 26 percent or an increase of between 11 and 16 percent over the first five positions proposed in Phase II.
2. The second method is to separate the output of the UT-4 and UE-1 testers into three grades (premium, satisfactory, and defective). The defective grade would be further separated as outlined in Phase II into rejects and fuel elements satisfactory for charging into the upstream five positions.

The first method offers the advantage of only segregating fuel elements into two categories. This method can be handled in the AlSi Shop and reactor areas similar to Phase II, with only minor changes to the testers.

The second method, however, requires dual presets for both the UT-4 braze closure and UE-1 bond testers, and the tester output conveyors or tanks must be modified to handle three grades of fuel elements. Identification and handling problems would be increased in the AlSi Shop and also in the reactor areas unless charging machine magazine loading is performed in the AlSi Shop.

The first method of attributes grading could be started as soon as the UT-4 and UE-1 testers have been stabilized, which is estimated to be about six months. The second method of attributes grading could not be started for at least a year after tester stabilization or in about 18 months.

Cost of the first method of attributes grading to the AlSi Shop is minor since no major equipment modifications are necessary. With the second method, however, equipment modifications in the UT-4 and UE-1 tester areas to permit a separation of the process stream into three grades are estimated to cost between \$75,000 and \$125,000.

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The expected improvement in rupture potential by upgrading the fuel elements in the downstream positions cannot presently be estimated. However, this upgrading should improve fuel element performance if the amount of nonbonding in the braze layer is a function of rupture proneness. As soon as the UT-4 and UE-1 testers have been stabilized, production tests should be run to determine the effect of various sizes of nonbond areas between the core and jacket wall (UE-1 test) and between the can and spire (UT-4 test). This testing program will take considerable time and effort, but is essential before Phase IV, "Variables Fuel Grading", can be considered.

III. Phase IV - Variables Fuel Grading

The ultimate goal in grading fuel elements is to match the reactor position rupture potential with fuel element quality as determined by variables measurements. To achieve such a grading system 1) the effect of each variable measured on the rupture potential must be determined, 2) a mathematical grading system must be devised for integrating all of the various variables, 3) a system of identifying each individual core or fuel element with the variables data must be established, and 4) a system for assuring that fuel elements are charged in the proper position must be devised. It is estimated that about four years will be required to establish a variables grading system if economically justified.

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TABLE NO. I

PROPOSED FUEL REJECT CATEGORIES FOR
LOADING IN THE FIRST FIVE UPSTREAM POSITIONS

REJECT CATEGORY	FUEL MODEL	ALSI SHOP COST/FUEL ELEMENT				ESTIMATED SAVINGS		
		LABOR	MATERIAL	IME	TOTAL	PERCENT OF TOTAL FUEL PRODUCTION	NO. OF PIECES PER YEAR	ANNUAL SAVINGS
AlSi Slop-overs & Stuck Sleeves	All	\$0.24	\$1.08	\$0.60	\$1.92	0.9	19,440	\$ 37,300
Facing	All	0.25	1.08	0.63	1.96	0.2	4,320	8,500
UT-4 (Braze Closure)	All	0.31	1.09	0.78	2.18	1.44	31,100	67,800
Bond Test	All	0.31	1.09	0.78	2.18	0.36	7,780	17,000
Penetration Test	All	0.31	1.09	0.78	2.18	0.4	8,640	18,800
Stains & Inclusions	All	0.42	1.12	1.05	2.59	0.5	10,800	28,000
Marred Surfaces	All	0.42	1.12	1.05	2.59	2.0	43,200	111,900
Radiograph	All	0.42	1.12	1.05	2.59	0.02	430	1,100
Rail Weld	Self-support & Bumper	0.48	1.15	1.20	2.83	4.0	26,780	75,800
Total Savings - AlSi Shop								\$366,200*
UT-2 (Grain Size)	All					3.3	(267 tons)	247,000**
Total Savings - AEC Complex								\$613,200

*Based on a production throughput of 52% regular, 17% bumper, and 31% self-support I&E.

**Based on a cost of \$0.46 $\frac{1}{4}$ /lb. for uranium remelt, rolling, heat treating, machining, and shipping.

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TABLE NO. II

PROPOSED STAMPING CODE FOR REJECT
CATEGORIES FOR LOADING IN THE
UPSTREAM FIVE POSITIONS

<u>REJECT CATEGORY</u>	<u>STAMPING CODE</u>
AlSi Slop-over	ALS
Stuck Sleeve	SS
Facing	FR
UT-4	UT4
Bond	BLI
Penetration	TW
Stains	ST
Inclusions	INC
Radiograph	XR
Marred Surface	MS
Rail Weld	RWR
UT-2	All fuel elements stamped with a special "R" lot number.

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TABLE NO. III
NUMBER OF ALLOWABLE UPSTREAM REJECT ELEMENTS
VERSUS
RELATIVE RUPTURE POTENTIAL

TYPE OF CHARGE	PROPOSED PHASE I & II REJECT CHARGING		RELATIVE RUPTURE POTENTIAL*					
			10 ⁻⁷		10 ⁻⁶		10 ⁻⁵	
	NO. OF UPSTREAM ELEMENTS	PERCENT OF CHARGE	NO. OF UPSTREAM ELEMENTS	PERCENT OF CHARGE	NO. OF UPSTREAM ELEMENTS	PERCENT OF CHARGE	NO. OF UPSTREAM ELEMENTS	PERCENT OF CHARGE
32 pc. Normal	5	15.6	7	21.8	8	25.0	10	31.3
34 pc. Enriched	5	14.7	6	17.6	7	20.6	10	29.4
38 pc. Normal	5	13.2	8	21.1	10	26.3	12	31.6
46 pc. Enriched	5	10.9	10	21.7	12	26.1	15	32.6

*As compared to the highest rupture potential position in the charge.

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RUPTURE POTENTIAL
32' PIECE CHARGE

(Natural Uranium)

Rupture Potential = $A \cdot (\text{Residence Time})^2$
 $A = 20.3 \times 10^{-7}$

("A" values are normalized so that
value at position of maximum rupture
potential equals 1.0)

RUPTURE POTENTIAL ($\log_{10} A$)

-20

-15

-10

-5

0

32

30

25

20

15

10

5

1

Position No.

(Downstream)

BD-5300-081 (11-60)
AEC-66 RICHLAND, WASH.

FIGURE 1

DECLASSIFIED

RUPTURE POTENTIAL

38 PIECE CHART

(Natural Uranium)

FIGURE 2

FIGURE 3

RUPTURE POTENTIAL
 46 PIECE CHART
 (Enriched Uranium)

-19-

RM-77367

DECLASSIFIED

FIGURE 4

DATE

FILMED

6 / 22 / 94

END