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DOCUMENT NO.

HW-77070

SERIES AND COPY NO.

January 17, 1964

TITLE
PRODUCTION TEST IP-580-AL. IRRADIATION OF
"C" AND "J" FUEL ELEMENTS AND THERMOCOUPLE
SLUGS FOR CORROSION TESTS IN THE 1706-KE
SINGLE-PASS FACILITY.

AUTHOR

D. R. Dickinson

R. G. Geier

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CORROSION TESTS IN THE 1706-KE SINGLE-PASS FACILITY

By Authority of

CG-PR-2,

D. R. Dickinson

R. G. Geier

By

DS Kenna, 3-18-94
J. M. Alley, 3-31-94

Verified By

DK Hanson, 4-4-94

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RICHLAND, WASHINGTON

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PRODUCTION TEST IP-580-AL. IRRADIATION OF "C"
AND "J" FUEL ELEMENTS AND THERMOCOUPLE SLUGS FOR
CORROSION TESTS IN THE 1706-KE SINGLE-PASS FACILITY

OBJECTIVE

The objective of this production test is to authorize (1) the irradiation of aluminum-clad fuel elements with U²³⁵-Al cores for corrosion testing in the 1706-KE Facility, (2) the irradiation of thermocouple elements to measure the temperature of the aluminum cladding, (3) installation of modified rear nozzles on the tubes in which these tests will be conducted, and (4) the use of two regular KE tubes as controls.

SUMMARY

In order to measure corrosion at higher heat flux and surface temperature than are ordinarily available, corrosion measurements will be made using enriched aluminum-clad fuel elements with "C" and "J" (U²³⁵ in Al) cores. One fuel element per charge will be provided with thermocouples inserted in the cladding to measure its temperature. These tests will be conducted in the ribless zirconium single-pass tubes in KE Reactor which can be supplied with water from 1706-KE. These fuel elements will have special end supports to avoid disturbances with flow and heat transfer on the lateral surface. Modified rear nozzles, of the type designed for use with K zirconium tubes, will be installed to permit smooth discharge of elements with these supports.

BASIS AND JUSTIFICATION

It is necessary to conduct tests of the corrosion of fuel elements at conditions more severe than is normally encountered in present reactor operation. Not only is this necessary in order to pilot any increases of reactor power level or temperature during the next few years, but it is equally necessary for tests applicable to present power levels. Corrosion of fuel elements serious enough to constitute a problem or limitation on operation tends to occur at hot spots, where high local surface temperatures exist by virtue of high local power density, high coolant temperature and/or poor coolant flow distribution. Since these localized severe conditions are statistically infrequent, they may not be encountered at all in a test involving one or two tubes. Corrosion data obtained by measurements of weight loss apply to the average heat flux and surface temperature for the entire fuel element, which are significantly below the maximum or hot spot conditions which may exist on that element. Therefore, in order to conduct a small-scale test to obtain corrosion data representative of the most severe conditions in present reactor operations, it is necessary to run the test elements at average surface temperature and heat flux considerably above those found in a typical reactor tube, and thus to use enriched elements.

Testing at higher temperature and heat flux will also improve the ability to predict corrosion rates. Present corrosion correlations are based on data obtained several years ago, at a maximum heat flux of 150 w/cm² and mostly in the neighborhood of 100 w/cm². By comparison, it is expected that Hanford reactors will soon be operating with a heat flux in the hole of 350 w/cm². Since the mechanism by which heat flux affects corrosion is poorly understood,

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and since existing correlations predict widely different rates when extrapolated to higher heat fluxes, corrosion measurements at heat fluxes at least up to 350 w/cm^2 are badly needed. Testing under more severe conditions will also be of value in differentiating between cladding alloys, inhibitors, and pH which may show more pronounced differences at higher temperatures.

It is desirable that corrosion test elements be of solid geometry. When I and E elements are used for corrosion testing, one has the problem of having a single weight loss which reflects the corrosion of two different surfaces at two temperatures and heat fluxes. This makes analysis of the data difficult and uncertain.

The use of enriched metallic uranium for corrosion test elements was ruled out because the core temperature of solid elements operating at the desired surface heat flux would exceed the alpha-beta transformation temperature of uranium, and split failures could be expected. To avoid this problem a core of U^{235} alloyed in Al was chosen, since it has a high thermal conductivity. This Al- U^{235} core has the additional advantage of having a relatively low corrosion rate, so that the chance of a stuck rupture or damage to the tube is remote.

Self-supported fuel elements were selected in order to avoid hot spots due to cocking, which could be particularly serious at higher temperature and heat flux. It is desirable that these supports not be fastened to the lateral surface of the slug; with the high heat flux expected on the lateral surface, a high temperature may be produced under the support tab sufficient to cause failure by intergranular corrosion. To avoid this a support spider will be used, fastened only to the ends of the fuel element. It is expected that this type of support will have the added advantage of producing less local turbulence over the heat-transfer region, thus removing an extraneous variable from the corrosion measurement.

It has long been recognized that the temperature at the oxide-metal interface is probably very significant in determining the corrosion rate. However, measurements of the cladding temperature have not been made on aluminum-clad Hanford fuel elements. It is expected that a significant temperature drop exists across the crud and oxide film on the fuel-element surface, which is dependent to a greater or less extent on pH, temperature, heat flux, and exposure time. It is planned to measure the cladding temperature over a range of test conditions by the use of thermocouples inserted into the cladding of special thick-wall fuel elements.

It is advantageous to use the thermocouple slugs in the same charge as the corrosion tests of "J" elements, since the latter produce enough power to give a high bulk water temperature in a region of high flux.

TEST DETAILS

1. Fuel Elements

The following fuel elements are authorized:

- (a) Regular "C". These have a solid core, 1.336" diameter by 6.00" long containing 16.4 g U^{235} alloyed in Al. These have been canned by the ALSi

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process in regular X-8001 aluminum jackets. The canned dimensions are 1.445" diameter by 6.64" long. A support spider welded to each end is 1/4" thick and has three projections 3/16" wide machined to a circumscribed diameter of 1.660". The overall length is 7.1".

- (b) Regular "J". These have a solid core, 1.336" diameter by 8.325" long containing 38.5 g U^{235} alloyed in aluminum. These have been canned by the AlSi process in regular X-8001 aluminum jackets. The canned dimensions are 1.445" diameter by 8.85" long. A support spider 1/4" thick is welded to each end with four projections 3/16" wide machined to a circumscribed diameter of 1.660". The overall length is 9.3".
- (c) Thick-wall "C". These are the same as the regular "C", except that the core has been machined down to 1.173" diameter and canned in a X-8001 aluminum tubular, 1.440" OD and 0.125" wall thickness, 7.1" overall length.
- (d) Thick-wall "J". These are the same as the regular "J", except that the core has been machined down to 1.173" diameter and canned in an X-8001 aluminum tubular, 1.440" OD and 0.125" wall thickness, 8.5" overall length.
- (e) In order to heat the water to temperatures where significant corrosion measurements can be made, the following types of regular fuel elements may be charged upstream of the Al- U^{235} elements: K4NS, K4ES, K5NS, K5ES, C4NS, C4ES, C5NS, and C5ES, provided a perf separates the "C", "J", and "U" elements.

The "C" and "J" elements have been fabricated by AlSi Product Engineering, FPD, under the supervision of E. V. Padgett.

2. Thermocouple Train

The thermocouple slugs and the provisions for leading the thermocouple wires out through the rear face are similar to those used successfully to measure aluminum cladding temperatures in three tests in KER.

The thermocouple slug is a thick-walled "C" or "J" element as described above. Three holes for the thermocouples were drilled into the 0.125" clad from one end parallel to the axis of the element. These holes are spaced 120° apart, 0.067" diameter, and extend 1-1/2" beyond the core-end cap boundary. These holes have been drilled so as to leave 0.040" of aluminum between the inside surface of the jacket and the near side of the hole. This 0.040" clearance has been verified by radiographing. The aluminum is peened around the thermocouples to secure them in the holes.

The thermocouples consist of 30-gauge chromel-alumel thermocouple wires embedded in magnesium oxide insulation swaged into 316 stainless steel tubing with 1/16" OD. Three are inserted in the holes in the thermocouple slug to measure the temperature of the clad. A fourth thermocouple will measure the water temperature a short distance downstream of the thermocouple slug.

The thermocouple wires will be led to the rear of the tube through the center of a column of 8" ribbed aluminum perfs. The mating ends of these

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perfs are conically beveled to 45° to ensure alignment of the perfs and thereby avoid sticking of the train on charging. One end of each perf is provided with a cross bar with a hole to support the thermocouple wires. One of the perfs in the train is longitudinally slotted to permit its removal from the assembled train, thereby permitting the train to be bent during transport. The perf adjacent to the thermocouple slug is appropriately notched to allow space for the thermocouple wires coming out of the thermocouple slug. This last perf is pinned to the support spider of the thermocouple slug to ensure that it remains properly aligned with respect to the thermocouple slug.

The thermocouple wires will pass out of the process tube through four $3/32$ " holes in the nozzle plug and through a single 1" hole in the nozzle cap. (Details are shown in Drawing SK-1-22817.) Swagelok connectors are welded to the outer face of the cap plug, and will provide a tight seal around the wires. These Swagelok connectors have proved adequate to prevent leakage in several tests in KER at 800 -1600 psi, 200-290 C. The thermocouple wires will connect on the rear face to thermocouple leads running to a recording potentiometer. The junctions on the rear face will be Amphenol connectors potted in Scotchcast resin to form a waterproof junction.

The assembled thermocouple trains, consisting of the thermocouple slug, perfs, wires, and nozzle plug, will be charged by hand as a single unit from the rear face. On discharging, the four thermocouple wires should be cut just inside the nozzle plug. This will allow the spacers to fall free when the charge is pushed out.

Personnel from Coolant Systems Development Operation will be present to assist with the charging of these thermocouple trains.

3. Test Facility

Irradiation under this production test is authorized in Tubes 2952, 3050, 4557, and 4863-KE. These tubes can be supplied either with process water or with special water supply from 1706-KE. All four have ribless zirconium tubes of 1.681" I.D.

4. Change of Rear Nozzle

The special supports on the "C" and "J" elements will present a problem on discharge through the present K rear nozzles since the projections tend to hang up in the circular groove near the outlet port. Therefore, the tubes in which these tests are to be conducted will be modified by replacing the existing rear nozzles by those of the type designed for use with the new zirconium tubes in KE and KW. This new nozzle is shown in Drawing H-1-33448. It has a perforated plate over the outlet port so as to present a smooth inside surface. Dummy fuel elements with the proposed supports have been discharged with no trouble from a tube with this new nozzle. The fuel elements with the special supports can be charged through the existing front nozzle by splining them past the entrance port; replacement of the front nozzle is not required. The new nozzle is quite compatible with conventional types of self supports.

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The replacement of the rear nozzle on Tubes 2952, 3050, 4557, and 4863-KE is authorized. No fuel elements will be charged under this production test in any tube until the rear nozzle has been replaced.

To preserve the ability to take effluent water samples from these tubes, the new rear nozzles will be modified to provide a sample tap connection on the barrel, similar to that on the present rear nozzles. The sample line will be removed from the old nozzle and replaced on the new nozzle.

All charges under this production test, including all fuel elements, coupon holders, spacers, and thermocouple train, will be test charged and discharged in a full-scale ex-reactor mock-up with the new type nozzle before being charged in-reactor.

5. Pre-Irradiation Storage

Storage and shipping of the unirradiated "C" and "J" fuel elements to be used in this test is authorized under the following conditions. The "C" and "J" slugs shall be shipped and stored in sealed bird-cages so that separate containers cannot approach closer than 1.0 foot. No more than 45 "J" slugs or 60 "C" slugs shall be stored or shipped in a single container. These containers shall not be stacked more than three high, and no more than 20 containers shall be stored together. Each group of 20 or fewer containers of "C" or "J" slugs shall be kept at least 10 feet from any other enriched elements and at least 6 feet from natural or depleted uranium.

The "C" and "J" fuel elements will be stored in the storage vault at the east end of the 1706-KE building.

6. Discharge Limits

The following criticality limits shall apply to "C" and "J" slugs on discharge.

<u>Type</u>	<u>Number of Slugs Permitted</u> <u>On Floor of Discharge Chute</u>	
	<u>C or J Slugs</u>	<u>+ Natural U Slugs</u>
J	Less than 23	Unlimited
J	23 to 45	Total J & U 45
C	Less than 30	Unlimited
C	30 to 60	Total C & U 60

On normal discharge, each individual tube charge will be discharged in an empty chute and picked up before the next charge is pushed. However, a single tube will contain no more enriched material than 22 "J" slugs or more than 18 "C" slugs plus 19 KIVE. In the event of a rupture, a single tube may be discharged onto a chute full of natural uranium. In no case shall "C" or "J" slugs be discharged into a chute containing E metal. The fuel elements in the tubes opened on the rear plus the fuel elements on the basin floor shall not exceed the limits above for either "C" or "J" material. To prevent inappropriate discharge, each tube containing either C or J elements will have an outer rear cap, as shown in drawing H-1-34256, covering at least two of the bolt heads of the rear nozzle cap. Only KE Processing Operation supervisors are authorized to remove these outer caps.

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Post-Irradiation Storage of C and J Fuel Elements

A special row shall be designated for storage of "C" and "J" fuel. All storage buckets containing the elements shall be supported by yokes.

The elements shall be stored in a standard storage bucket with an insert and outrigger. The fuel elements shall be stacked in the bucket in a close-packed pattern with all axes parallel. Buckets containing natural or enriched fuel shall be kept separated by at least one foot of water from enriched fuel on the floor or other buckets of enriched fuel. The maximum number of pieces per bucket shall be:

	% U-235	No. Per Bucket
J	7	80
C	4.1	106

7. Exposure Limits

The exposure limit of "C" and "J" fuel elements will be based on cladding corrosion. Maximum allowable exposures will be those which will result in a maximum calculated cladding corrosion of 20 mils. Exposure of thermocouple-bearing fuel elements will be limited such that corrosion of the cladding through to the thermocouple well will not occur. Such calculation shall be done using such methods and correlations as are considered by Reactor Engineering, Irradiation Processing Department, to be applicable and appropriate.

8. Water Quality

The tubes shall be supplied with process or service water containing 0.5 to 2.0 ppm $\text{Na}_2\text{Cr}_2\text{O}_7 \cdot 2\text{H}_2\text{O}$ and adjusted to any pH in the range of 6.0 to 7.6 by the addition of sulfuric acid or sodium hydroxide. For each test exposure, the water quality for each tube involved shall be specified by letter from Coolant Systems Development Operation to Coolant Testing Unit.

9. Number of Charges

The number of charges under this production test will not exceed a total of 40 for the four test channels during two years. This test will be terminated two years after date of issue.

10. Control Tubes

Two regular KE Zircaloy tubes will be used as control tubes. This will provide comparison data for corrosion in normal process water and give an indication of any variation in corrosion due to changes of reactor power level or seasonal variation in water quality. The control tubes will be charged with regular charges of weighed and numbered elements. They will be charged and discharged at the same time as the tubes containing "C" and "J" elements, except that the established goal exposures for regular KE tubes shall not be exceeded.

11. Coupon Holders

In order to obtain comparison corrosion data on unheated samples, self-supported coupon holders of the type shown in drawing H-1-33319 or SK-1-23211 may be charged downstream of the fuel elements. The holder shown in H-1-33319 may be substituted for one of the spacers in the thermocouple train, with the thermocouple wires passing through the hole in its center. The sample coupons may include aluminum, zirconium, steel, and nickel alloys. The number and location of the coupon holders will be specified by Coolant Systems Development Operation with the concurrence of Coolant Testing Unit and KE Processing Operation. Coupon holders will be removed from the tubes at the time rear caps are being removed for fuel discharge. Personnel from

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Coolant Systems Development Operation will be present to assist in the removal of these holders.

12. Premature Discharge

Premature discharge is authorized either of regular charges in tubes in which this test is to be conducted or of the charges irradiated under this test.

13. Effluent Activity Samples

Effluent water samples will be taken from tubes 2952, 3050, 4557, and/or 4863-KE during some of these tests as a part of the program to study and reduce effluent activity. When such sampling is desired, specific instructions will be submitted by the test authors.

14. Data Desired

Routine operating data (temperatures and pressures), including Panellit bases, should be recorded for the ribless (1706) tubes. For the two regular KE tubes, a separate record should be kept with readings once per shift during reactor operation of outlet water temperature and of crossheader and venturi (Panellit) pressures; the inlet water temperature should be recorded once per day, and the Panellit bases whenever changed. If thermocouple slugs are charged, all thermocouple readings should be recorded twice per shift.

Visual observation, weaseling, and weight-loss measurements before and after cleaning will be required for the discharged pieces.

Special pickup of discharged pieces is required.

15. Charge Pushing Forces

In the event that reluctance is encountered in the discharge of any tube under this test, maximum pushing forces shall be determined by the forces specified by the appropriate Process Standard for the weakest piece in the tube's charge.

16. Costs

a. Cost Code: xxxx-5R23-xxx.71

b. Time Per Tube Loading

	Elevator Time, Hours		Man-Hours
	Front	Rear	
Charge-discharge without thermocouple train	1/2	1/2	3
Charge-discharge when thermocouple train charged	1 1/2	1 1/2	9
Rear nozzle replacement, per tube	-	2	4

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c. Reactivity Change

The fuel charges under this production test will have a reactivity approximately the same as, or greater than, a standard charge of normal fuel elements.

17. Charge Order and Operating Limits

The charge order is given in Appendix A, together with appropriate operating conditions and water shut-off limits.

If it is desired to vary the charge order, (e.g. to produce a different range of surface temperatures) a separate document will be issued and approved by the managers of the Process and Reactor Development Subsection and the Process Technology Subsection, Research and Engineering Section.

HAZARDS

1. Criticality Incidents

The use of any enrichment in fuel elements increases the necessity for careful control of pre-irradiation storage, discharge requirements, and post-irradiation storage.

2. Fuel Failures

While exposures of the test pieces will be limited to avoid excessive jacket corrosion, the probability of failure of the test pieces is considered higher than for regular pieces because operating conditions are purposely being made more severe. However, the probability of a stuck charge in case of a failure is considerably less with the test pieces. This is true because aluminum-uranium alloy cores do not swell after a failure. In the event that two ruptures of C or J elements occur, testing under this PT will be suspended until the cause of the ruptures is determined and the test program is reviewed with representatives of KE Processing Operation and Coolant Testing Unit.

3. Fuel Burn-Out

Fuel elements in this series of tests will operate at heat fluxes substantially higher than those normally obtained in K Reactor fuel elements. Analysis has been made of the charge specified in Appendix A to assure adequate burn-out protection.

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RESPONSIBILITIES

Irradiation Processing Department

Research and Engineering Section

Testing Subsection

Coolant Testing Unit will be responsible for:

1. Operation of the 1706-KE equipment.
2. Recording operating data on the specified single-pass tubes.
3. Assistance in charging.
4. Scheduling tube charges with the concurrence of KE Processing Operation.
5. Providing KE Processing Operation with detailed procedures prior to charging and operation.
6. Reactor safety and production continuity as affected by 1706-KE operation.
7. Storage of "C" and "J" fuel elements prior to irradiation.
8. Scheduling replacement of rear nozzles with concurrence of KE Processing Operation.
9. Supplying rear safety caps.

Le. Barkin

Component Testing Unit will be responsible for post-irradiation examination of components in the test charge.

K. Z. G. G. G.

Process and Reactor Development Subsection will be responsible for:

1. Technical aspects of fuel element irradiation.
2. Assuming all reasonable and foreseeable precautions that are required in order not to compromise operational safety and production continuity.
3. Termination of the production test and issuance of the final report.

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Manufacturing Section

KE-KW Reactor Operation

KE Processing Operation will be responsible for:

1. Operational safety of the reactor.
2. Production continuity.
3. Recording operating data on the control tubes mentioned in Section 10.
4. Replacement of rear nozzles.
5. Installation and removal of rear safety caps.

R. H. Clough

Hanford Laboratories

Reactor and Fuels Laboratory

Coolant Systems Development Operation will be responsible for:

1. Analyzing corrosion and film data, and issuing technical reports.

R. B. Richman

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APPENDIX A

CHARGE ORDER AND OPERATING LIMITS
DETAILED LOADING AND OPERATING CONDITIONS

CHARGE ORDER

In tests where it is necessary to supply water from the 1706-KE pumps, the charge order will be that shown in Table I. When it is intended to supply water from the regular reactor process water supply, the charge will be the same except that the two most upstream "J" elements will be omitted. Because of the higher pressure supplied by the 1706-KE pumps, this will result in very nearly the same maximum surface temperature in these two cases. If an acceptable thermocouple train is not available, the thermocouple train (twenty-five 7 7/8-inch spacers and an 8.5-inch thermocouple slug) will be replaced either by twenty-five 8-inch ribbed aluminum perforated dummies and one 9.3-inch regular J element or by twenty-six 8-inch ribbed aluminum perforated dummies.

TABLE I

Charge Order for "J" and "C" Elements and Thermocouple Train
(Sequence from Downstream End)

<u>Number</u>	<u>Unit Length</u>	<u>Description</u>
1	1 1/2"	Modified nozzle plug
25	7 7/8"	Modified ribbed aluminum perf
1	8.5"	"J" Thermocouple slug (thick clad) } Thermocouple Train
1	7.1"	"C" element (thick clad)
1	9.3"	"J" element (regular clad)
1	7.1"	"C" element (regular clad)
1	9.3"	"J" element (regular clad)
1	7.1"	"C" element (thick clad)
1	9.3"	"J" element (regular clad)
1	7.1"	"C" element (regular clad)
1	9.3"	"J" element (regular clad)
1	7.1"	"C" element (thick clad)
3*	9.3"	"J" element (regular clad)
1	8"	Perforated dummy
2	8.9"	KIVNS elements

* Only 1 if water not supplied by 1706-KE pumps.

EXPECTED CONDITIONS

The expected operating conditions for this charge are:

	<u>1706 Pumps</u>	<u>105 Supply</u>
Flow	74 gpm	68 gpm
Outlet temperature	73 C	70 C
Maximum surface temperature	124 C	124 C
Maximum heat flux	450 w/cm ²	450 w/cm ²
Maximum corrosion rate	12 mils/mo	12 mils/mo

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These conditions are based on an assumed adjacent tube power of 1700 KW and an inlet temperature of 13 C. As the U^{235} is consumed, the power level, temperature and corrosion will fall below the values shown above.

CRITICALITY LIMITS

On applying the criticality limits given in the body of this production test to this charge:

1. One charge may be stored together and brought into the elevator in a single container.
2. One charge may be discharged on top of an unlimited number of natural uranium fuel elements in the discharge chute.

WATER SHUT-OFF TIME

1. Maintenance

The volumetric heat capacity of the "J" cores is essentially that of aluminum ($0.59 \text{ cal/cm}^3 \text{ } ^\circ\text{C}$), and is somewhat higher than that of uranium ($0.53 \text{ cal/cm}^3 \text{ } ^\circ\text{C}$). The solid "J" elements also have a slightly larger volume than K-III-N elements. Therefore, the water shut-off limits for K-III-N elements may conservatively be applied to "J" elements operating at the same power per element.

Since a "J" element will operate at 1.733 times the power of an adjacent K-III-N element, the water shut-off time for the charge specified above will be those specified in Process Standard A-030 for a standard charge of 38 K-III-N elements operating at 1.733 times the power of the adjacent tubes. (Alternately, the shut-off time for a standard charge of K-III-N in an adjacent tube may be divided by 1.733.)

2. Infinite

Five days after reactor shut-down the water to the tube may be shut-off indefinitely without the fuel exceeding $450 \text{ C.}^{(1)}$

OPERATING LIMITS

1. General

In case of failure of the 1706-KER pumps, the safety of the tubes depends on the process water backup system. The system is simple and can be considered highly reliable. Process water is available to the system through interconnecting lines, but it is excluded from the system by check valves. The check valves are held shut by maintaining the pressure in the 1706-KE supply system higher than the process water pressure. When pump failure occurs, the pressure in the supply lines decays and the check valves open.

A second check valve is situated in the 1706-KE supply lines upstream from the point of process water intertie. This valve will prevent the flow of

⁽¹⁾ Personal communication: S. S. Jones, Process and Reactor Development, Irradiation Processing Department.

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water from the back-up system to the 1706-KE pumps. It also protects against the remote chance that a line rupture occurs between the 1706-KE pumps and the process water intertie.

In order to insure protection, it is necessary to lock and tag open all stop valves on the process water lines upstream from the check valves.

2. Instability Limits

In order to insure safe and stable operation of the tubes, the provisions of Process Standard A-050 will be met for both high and low trip limits. Minimum operating pressure will be calculated on the basis of a 0.419 inch diameter venturi.

The use of crossheader pressure to detect upstream plugging is advantageous in that it is in excess of venturi throat pressure and is more sensitive to flow changes. Therefore, low trip limits will be monitored by a pressure signal obtained from the special inlet crossheader and by a pressure signal from the venturi throat. Low trip limits shall be calculated according to Process Standard A-020 (HW-46000 K). The tube outlet temperature must not exceed 130 C.

The self-supported "C" and "J" elements will have an expected R value of 1.14. Thus, with the downstream spacer pattern as specified and the outlet fittings, annulus boiling will not occur.

3. BPA Outage Limits

In case of a BPA outage, the 1706-KE pumps trip out and the tubes are supplied with coolant from the process water system. In such an event, two critical periods exist. The first comes within a few seconds after the BPA outage. The flow to the tubes decays in two steps after the power decays. The supply pressure to the tubes drops immediately to that supplied by the process water system. Next, the pressure supplied by the process water system decays as the flywheel energy on the 190-KE pumps is used up.

In order to pass through the first critical period safely, it is necessary to insure that the total flow decay before the beginning of tube power decay is not excessive. Such protection is obtained by the limits shown in Figure 1 which are based on a flow reduction of not more than 20 per cent before tube power decay commences.

The second critical period occurs about 100 - 150 seconds after the outage. At this time, the coolant flow has decayed about 85 per cent and the tube power has decayed about 88 per cent. Both the flow and

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power will remain relatively constant at these values for a considerable period of time. It is desirable that the tube exit temperature not exceed the rear crossheader saturation temperature. A maximum outlet temperature of 130 C has been specified under instability limits. In as much as this is 9 C below rear cross-header saturation temperature, safe operation is assured.

D. R. Dickinson
Coolant Systems Development Operation
Reactor and Fuels Laboratory
HANFORD LABORATORIES

R. G. Geier
Process and Reactor Development Subsection
Research and Engineering Section
IRRADIATION PROCESSING DEPARTMENT

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BPA FAILURE LIMIT

Maximum 1706-KE Tube Supply Pressure As Measured In The 105-KE Valve Pit - PSIG

Backup Process Water Pressure As Measured In The 105-KE Valve Pit - PSIG

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APPROVALS

pr
T. W. Ambrose, Manager
Process and Reactor Development Subsection
Research and Engineering Section

R. W. Reid, Manager
Process Technology Subsection
Research and Engineering Section

*for
Sub*
C. G. Lewis, Manager
Testing Subsection
Research and Engineering Section

O. H. Greager, Manager
Research and Engineering Section

R. G. Clough, Manager
KE Processing Operation
Manufacturing Section

A. R. Maguire, Manager
KE-KW Reactors Operation
Manufacturing Section

10/12/64
W. W. McIntosh, Manager
Applied Reactor Engineering Subsection
Manufacturing Section

R. S. Bell, Manager
Manufacturing Section

**DATE
FILMED**

8/11/94

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