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TITLE

TECHNICAL BASES AND CRITERIA
EXPANSION OF OVERBORE TEST FACILITIES
C-REACTOR

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AUTHOR

F. W. Van Wormer

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TECHNICAL BASES AND CRITERIA EXPANSION OF OVERBORE TEST FACILITIES C-REACTOR

by

F. W. Van Wormer
Reactor Engineering Unit
RESEARCH AND ENGINEERING

May 22, 1961

Classification Cancelled and Changed To
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TECHNICAL BASES AND CRITERIA
EXPANSION OF OVERBORE TEST FACILITIES
C-REACTOR

The Overbore Test Facilities of the C Reactor are to be expanded to permit pilot testing for the complete conversion of the reactor to enlarged fuel channels. This report sets forth the technical bases and appropriate criteria to accomplish this work.

I. PURPOSE

The purpose of the expansion of overbore tube facilities at C Reactor is to provide for the collection of fuel element data necessary to support the design of the full reactor conversion to larger fuel channels.

The fuel testing will provide:

- A. A "Quality Index" of the design and fabrication processes for the fuel, or will identify factors requiring improvement. These will be determined by post-irradiation testing, providing information regarding metal stresses and distortion, integrity of bonding and the service life of the cladding.
- B. Conversion ratio and product quality information applicable to the future modified reactor conditions.
- C. Engineering fuel design data, such as the removal of fuel generated heat by the respective coolant channels in relation to the flow balance provided.

To accomplish this purpose, an expansion of the Overbore Test Facilities at C Reactor by at least forty tubes must be accomplished by October 1, 1961. To provide the requisite conditions for the determination of conversion ratio, 32 of these tubes must be located in a 6 x 6 square less one tube at each corner.

II. GROUND RULES

The expansion is to be accomplished under the following ground rules:

- A. The test facility expansion will be constructed in a manner that is consistent with and, as nearly as possible, identical to the final conversion and will become a part of the final conversion.
- B. The process tubes to be installed for the expanded facility will be of Zircaloy-2 and of the same size as the Zr-2 smooth-bore process tubes currently installed, namely:

O. D.	= 2.250 inch, maximum
I. D.	= 2.147 ± 0.005 inch
Wall Thickness	= 0.040 inch, minimum
Length	= 43 feet, + 3 - 0 inches

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III. TECHNICAL BASES AND CRITERIA

To accomplish the stated purpose, under the ground rules, the following criteria are to be used in planning and carrying out the expansion of the Overbore Test:

A. Fuel Elements

The reactor design and the fuel design must be compatible, particularly with regard to the materials used in contact with the coolant. The choice of compatible materials is in turn restricted by the specific material characteristics required for fabricability of the fuel elements and for avoiding significant alterations in the element due to material interactions under service conditions. Operating limits, then, are primarily derived from material limitations, and design concepts or design variations are the means of making the material limitations as unrestrictive as possible.

1. Requirement

- a. The fuel elements must be adequately cooled at all times to prevent deterioration at rates exceeding those anticipated for service conditions of any of the materials in the fuel element complex.
- b. The service life of the fuel element should be sufficiently long to permit continued reactor operation without significant reduction in operating efficiency due to fuel element failure under operating conditions selected to maximize economic gains, i.e., fuel performance should not be limiting to exploitation of the reactor capabilities.
- c. The reactor physics characteristics of the fuel must be compatible with the reactivity requirements and with the capabilities of the nuclear control and safety systems.
- d. The hydraulic characteristics of the fuel element must be compatible with capabilities of the reactor coolant system.
- e. The fuel element geometry and dimensioning must be such that the products of characteristic fuel element failures peculiar to the selected fuel type can be accommodated to the extent that serious tube damage will not result from local physical disturbance or from insufficient flow under any conditions short of total inability of the reactor instrumentation to detect the failure.
- f. There must be mutual compatibility between the fuel materials and the reactor materials at all points of contact or common ambient environment.

2. Criteria

- a. The maximum temperature of the uranium in any fuel element shall not exceed the alpha-beta transformation temperature (662°C) at any time. In practice, to limit metal stresses to reasonable values, this temperature is held to about half of the maximum quoted.

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- b. The design of the fuel element shall permit meeting the criteria for coolant boiling and heat transfer burnout under the limitations of the established reactor coolant system parameters. (III-C, below)
- c. The average exposure of aluminum-clad elements in any tube shall not exceed 1500 MWD/T.
- d. Jacket corrosion shall be limited to a maximum corrosion rate of 10 mils per month or a total aluminum loss of 20 mils, whichever is smaller.
- e. The post-installation acceptance test for all zirconium tubes will be to pass a $2.137 \pm .002 \times 9$ inch plug gage throughout the tube length.

B. Process Channel Cooling - Hydraulic Characteristics of Process Tube Connector Systems

1. Requirement

The fuel element design of the overbored reactor is based on certain maximum pressure drop characteristics of the front and rear connector systems. Increased pressure drop results in a lower flow rate or lower uranium inventory which reduces plant return. In addition to absorbing a minimum of the available pressure drop, the front connector system must be highly resistant to failure. Rupture of a front connector can result in fuel element melting despite an instantaneous scram because the rear manifold pressure is insufficient to drive steam from the tube and restore adequate cooling. It is therefore a requirement that cavitation in the front connector system be avoided during normal operation.

The outlet water temperature limits are determined to a large extent by the hydraulic characteristics of the rear fittings. The flow characteristics of the present fittings are such that any flow change or power surge which leads to flow instability would cause a high Panellit trip in time to prevent fuel jacket melting. An enlargement of these fittings would reduce this Panellit sensitivity and may also reduce allowable outlet water temperature limits. The rear fittings also cause some degree of pressurization in the flow stream upstream of the rear manifold. This suppresses boiling in the tube and also results in a single liquid phase of the coolant at the point of temperature measurement. The pressure drop in the rear connector system must therefore be sufficient to suppress active section boiling, to assure adequate transient pressure response under abnormal conditions, and to provide for adequate temperature monitoring.

2. Criteria

- a. The pressure drop in the front connector system shall not exceed the value obtained from the following equation (coolant temperature of 20°C):

$$\Delta p (\text{front header} - \text{tube inlet}) = 0.0238 F^2, \text{ where } F \text{ is the tube flow rate in gallons per minute.}$$

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- b. There will be no cavitation in the front connector system during normal operation.
- c. The pressure drop in the rear connector system shall not be less than the value obtained from the following equation (coolant temperature 20°C):

$$\Delta p \text{ (rear nozzle - rear header)} = .006 F^2, \text{ where } F \text{ is defined as above.}$$

C. Coolant Boiling and Heat Transfer Burnout

1. Requirement

In order to ensure system flow stability, adequate cooling of the fuel elements, the accurate measurement of tube exit water temperature and to prevent adverse reactivity effects, the coolant supplied to the individual process tubes should be maintained in a single liquid phase. Therefore, coolant boiling within the individual process tubes should be avoided when operating at normal maximum design conditions of coolant temperature (95°C bulk water temperatures) and surface heat flux.

Partial or complete loss of normal coolant flow or a power level surge may result in overheating and melting of the fuel elements. It is therefore a requirement that continuous and adequate cooling be maintained at all times, and each process tube be protected against fuel element burnout by appropriate instrumentation.

2. Criteria

- a. There shall be no bulk boiling (net steam quality) in any part of the process tube system during normal maximum operating conditions. Normal maximum operating conditions are those achieved during operation at 95°C bulk outlet water temperature. This criterion may be met by maintaining process tube exit water temperature below its saturation temperature by an amount necessary to accommodate the variation in operating conditions. The boiling limit may be determined by the following equation:

$$T_o = \frac{T_s - T_i}{R} + T_i - \Delta t_t - \Delta t_p$$

Where: T_o = Boiling limit, °C

T_s = Saturation temperature at downstream end of active charge, °C

T_i = Inlet temperature, °C

Δt_t = Error limit of temperature measurement

Δt_p = Equivalent temperature error limit of tube outlet pressure measurement

R = Factor to account for non-concentric placement of fuel elements in tube. $R = 1.15$ for self-supported geometries.

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- b. There shall be no surface boiling (with no net steam generation) during operation at normal maximum design conditions. Surface boiling in present reactors occurs under conditions where the fuel elements are misaligned in the process tubes. Therefore, meeting this criterion is largely a matter of fuel design.
- c. Conditions of inadequate cooling will be detected by individual tube pressure instrumentation, and a reactor scram initiated immediately. At the reduced tube power immediately following the reactor scram, adequate cooling flow will be available to prevent melting and gross damage even through a partially plugged process tube flow channel. These criteria may be met in the overbored reactor with the present Panellit system in conjunction with presently specified instability limits.

D. Coolant System Monitoring

1. Requirement

The present requirements for monitoring reactor and tube power levels apply to the overbored reactor. Individual process tube instrumentation will be capable of measuring accurately the coolant temperatures and flow rates. The flow monitoring devices will provide for an automatic reactor shutdown in the event of high or low flow signals. These are intended to protect against single tube accidents which could cause reactor damage or contamination of the reactor environs. Examples of these events are undetected fuel element swelling, flow reduction from plugging of the process tube system by foreign materials, rupture of a process tube or fittings, and unstable boiling of the coolant.

There will be no bulk boiling (net steam generation) in the process tube during normal operation. Operation with a single-phase coolant in the process tube will be monitored by appropriate outlet water temperature measuring devices.

During all periods of reactor operation, it will be necessary to monitor continuously the exit tube temperature of various zones of the reactor as an aid in adjusting the reactor flux distribution.

2. Criteria

a. Process Tube Temperature Monitoring

- 1) Each process tube will be provided with an exit coolant temperature measuring device located in such a manner as to assure the temperature will be monitored at a point where excess pressure exists above saturation conditions.
- 2) It will not be mandatory that these temperature monitoring devices be in the Safety Circuit; therefore, the response time is of secondary

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concern. In order to provide for possible future utilization in the Safety Circuit, it is recommended that the devices respond to 63 percent of a step change in temperature within two seconds.

b. Process Tube Flow Monitoring

- 1) Each process tube shall be provided with a pressure sensing gauge (Panellit gauge) attached to the low pressure tap of a flow metering device (such as an orifice or venturi). The flow metering device will be sized to provide a pressure of 250 psig at 50 gpm and 400 psig front crossheader pressure.
- 2) Each Panellit gauge shall have a low and high pressure trip point connected electrically into the No. 1 Safety Circuit.
- 3) The reproducibility, accuracy, and response criteria shall correspond to that currently in use (HW-41000, Process Equipment Standard, Process Standard A-020).

E. Critical Equipment

1. Requirement

A failure of the process tube inlet nozzle or connector could, by permitting fission products to be released into the reactor work area, result in an estimated two million dollar direct cost plus four to six months of reactor downtime. Further, the Panellit system cannot assure protection against these failures, and either partial or complete failure may be significant. Thus, the integrity of the nozzle assembly is the prime protection against heat transfer burnout, release of fission products to the reactor work areas and the attendant clean-up cost that could result from such a failure.

2. Criteria

The minimum requirements that the nozzle assembly is expected to meet shall be based upon maximum credible service loads, and upon fatigue testing to three times the number of cycles (of repetitions of the load) that could reasonably be expected to occur during the service life of the nozzle. It is the intent of this criterion that the minimum requirements shall be sufficiently restrictive that failure to meet these minimum requirements will not necessarily imply that the component will fail in service.

To meet the requirement for maximum credible service loads, the inlet nozzle, nozzle closure, and tube-to-nozzle joint shall withstand without perceptible damage an internal pressure equal to five times the reactor maximum front crossheader pressure for a period of at least one minute. The inlet tube-to-nozzle joint shall withstand the tensile force that results from an internal pressure equal to five times the maximum front crossheader pressure.

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The maximum credible tensile load shall be the maximum tensile load which the charging machine is able to exert. The nozzle shall withstand, without perceptible damage, the maximum charging machine force applied for a number of cycles equal to three times the number of cycles which could reasonably be expected to occur during the service life of the nozzle.

The nozzle shall withstand, without perceptible damage, application of the maximum credible torque (from tightening and loosening end caps) for a number of cycles equal to three times the number of cycles which could reasonably be expected to occur during the service life of the nozzle.

Impact loading of nozzles may occur as a result of falling objects such as fuel elements and tools commonly found on the charge elevator. The nozzle shall withstand without failure or evidence of damage the maximum credible impact (fuel element falling a distance equivalent to the height of the reactor) a number of times equal to three times the number of impacts a single nozzle could reasonably be expected to suffer during its service life (16 drops for 20-year life, 4 drops for 5-year life).

F. Moderator Considerations - Graphite Temperature

1. Requirement

The temperature of the graphite at all parts of the moderator stack shall be within practicable limits so that dimensional changes in the graphite bars due to factors which are temperature sensitive shall contribute minimally to excessive distortion of the stack.

2. Criteria

a. Upper Limit

Although test information indicates that no substantial dimensional changes occur at temperatures up to 1000°C, under regular operating conditions, the temperature of the graphite at any point in the moderator stack shall not exceed 800°C.

b. Lower Limit

Under regular operating conditions, the average temperature of the cross-section in any direction of any filler block within the fueled zone of the moderator stack shall not be less than 200°C.

c. Temperature Calculation

Graphite temperatures shall be calculated using either 1) the computer code recently employed by Mollerus* using values for thermal conductivity of the graphite (or the equivalent parameter) determined by this code for recent actual operating conditions and measurements at C

* To be documented.

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Reactor, or 2) any other more accurate method of calculation. These calculations have been completed, using the first method noted above.*

NOTE: Since the quality of the reactor product is also dependent, to some degree, upon the moderator temperature, it may not be possible to operate the fully converted reactor under the conditions of maximum temperature quoted above.

G. Moderator Considerations - Dimensions and Condition of Overbored Tube Channels

1. Requirement

The overbored and cored process tube channels shall be of such dimensions and shape that the new larger zirconium process tubes can be inserted without undue difficulty and without damage to the tubes or the moderator stack. The extent of overboring and coring of the channels shall be such that under intended regular reactor operating conditions, the requirements for graphite temperature will be met. The longitudinal shape of each overbored channel shall not cause bends in the newly inserted process tube any more severe (i.e., no shorter radius of curvature) than the bends existing in the process tube in that channel immediately prior to the overboring operation. No process tube channel shall be overbored or cored outside of the tube and trunnion blocks of the original channel. The overboring and coring shall not produce stress risers in the internal surface of the tube blocks or trunnion blocks which could be expected to make the blocks more susceptible to fracture either transversely or longitudinally.

2. Criteria

As a minimum, for the first two channels and, irrespective of the sequence of operations, for the first two channels in the top ten rows to be overbored in the manner intended for the balance of the channels,

- a. horizontal and vertical displacement traverses shall be made through the original process tube,
- b. borescopic inspections of the channels shall be made before the overboring,
- c. borescopic inspections of the channels shall be made after the overboring,
- d. the diameter and length of the cored sections shall be measured, and
- e. horizontal and vertical displacement traverses shall be made through the new process tube.

* Agar, J. D., Graphite Temperature Parameters - C Reactor Overbore, HW-69754, 6/12/61, [REDACTED].

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Comparison of the traverse data before and after overboring shall indicate no more bend in the new process tube than in the original process tube in the regions of the inlet hump, the center depression, or the outlet hump.

Comparison of the borescopic inspection after overboring to that before overboring shall indicate no substantial increases in: 1) transverse or longitudinal breaks in the blocks, 2) size of gaps between blocks, or 3) voids due to break-out of massive pieces of the blocks in locations not observed to be cracked in the inspection before overboring.

The borescopic inspection after overboring shall reveal: 1) no locations where cutting of the enlarged channel has gone outside of the tube or trunnion blocks, and 2) no tool marks which might be deemed to be potential stress risers.

F. W. Van Wormer

F. W. Van Wormer, Supervisor
Reactor Engineering Unit
RESEARCH AND ENGINEERING

APPROVED BY:

J. H. Brown

J. H. Brown, Manager
Process and Reactor Development
RESEARCH AND ENGINEERING

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