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REVIEW OF A PROJECTED 1/12 SEGMENT REFLECTOR TEST
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INTRODUCTION

Individual parts of the outer reflector have been flow tested to establish pressure drops and flow rates under steady-state design conditions. These tests, D 2 and D 4, are continuing. D 2 uses a 2° sector of the outer reflector in which representative coolant holes from top to bottom are simulated by tubes. D 4 deals with various components of the control drum. Project 8940, in addition, is currently investigating two-phase hydrogen flow in a single straight tube and in three parallel tubes for both steady state and for transients such as chilldown during reactor start-up. A 1/12 segment flow test, the subject of this review, would integrate these active efforts and would progress well beyond that which is able to be synthesized from the results of the individual simpler tests.

Certain questions can profitably be asked:

1. Does the increased information and understanding justify the level of manpower and dollar expense involved?

2. For what mode of reactor operation would this 1/12 segment test be most valuable?

3. How sophisticated in design would the test piece be?

4. What new test equipment would be required to adequately test a 1/12 segment of the outer reflector?

On the basis of investigations of steady state operation alone, the effort involved in a 1/12 segment component flow test would probably not be justified. When off-design transient analysis, such as two-phase flow during reactor start-up, is an added requirement, a test of this level of effort is considered a necessity.

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APPROACH TO PROBLEM

*Transients during reactor operation which involve two-phase flow in the outer re-*flector introduce uncertainties of flow, temperature and pressure in its multi-passage cooling system and uncertainties of temperature distribution in its beryllium structure. Analytical studies which have defined flows through the reflector during transient conditions such as reactor start-up have used heat transfer coefficients whose correlation for generalized application is subject to improvement. The concept of quality of the fluid when not in thermal equilibrium and the faulty use of vapor and liquid mass fractions together with temperature of the superheated vapor have inhibited accurate analysis. Heat transfer correlations from Project 8940 are an initial step to improve input to the computor program for analysis of flow and temperature distributions. A 1/12 segment reflector test would be a second step to the realistic determination of these flows and temperatures in the reflector and to a detailed understanding of the mechanics of heat transfer to boiling hydrogen. In this test fundamental data would be obtained for correlation and generalized application.

Under normal reactor operation on the test stand and in flight, liquid hydrogen is expected to enter the reflector from the nozzle only during start-up and during cooldown flows, both pulsed and steady, after shutdown. This liquid phase would appear first in the reflector as a mist and progress as a function of time to slug flow, bubbly flow involving nucleate boiling and then liquid flow, all as a result of the cooling down of the nozzle. When the flow is observed simultaneously at, say, the entrance of the reflector and at other stations progressing downstream, the sequence of two-phase flow is from bubbly flow to slug flow and then to mist flow as the temperature difference of wall and liquid increases. *Since film boiling can be accompanied by pressure oscillations and since flow from the* nozzle coolant passages to the reflector encounter abrupt changes in flow direction, initial distributions in the reflector entrance can not be expected to be uniform under off-design start-up conditions. This entrance maldistribution could be aggravated by increased flow of the liquid in those passages which have the greatest flow rate.

Under exaggerated time conditions, for instance, a prolonged start-up, liquid can conceivably enter the reactor core, resulting in a severe controls problem. Under more normal conditions of chilldown during start-up, temperature gradients could be set up by flow and heat transfer maldistributions which would not be compatible with the mechanical functions of the reflector and control drums. Pressure oscillations and possible flow surges could induce objectionable vibrations. In determining solutions to probelms such as these, the 1/12 segment reflector test would serve as a comprehensive overall check on theoretical analyses done by computor and, in addition, and perhaps more importantly, would serve as a prime means of discovering and solving problems not attempted analytically. This component test equipment could be used to explain difficulties occurring during reactor operation that had their origin in the outer reflector and control drums.

Transient conditions have thus far in this review been emphasized; as great a value of this component testing could be found in studying reactor steady-state operation. Whereas cold flow and hot tests of the reactor lack sufficient instrumentation for this purpose, a steady-state test with the 1/12 segment of the outer reflector, flowing gaseous hydrogen, would readily describe the interaction of the outer reflector components and subassemblies in terms of flow, temperature and pressure distributions. This component test equipment could be used over wide ranges of operation. Exaggerated effects could be accomplished in areas of operation that the reactor would not reach during normal operation. Steady-state operation could be obtained for design and off design conditions. Behavior observations and measurements would be made in the following areas:

1. Flow instabilities and their effect on the control drum.
2. Flow and temperature maldistributions as functions of inlet plenum chamber conditions and of configuration perturbations from reflector inlet to exit. Considerations in this area are of particular importance since, from one reactor circumferential location to another, flow and temperature difference leaving the reflector may persist as maldistributions entering the core.

TEST DESCRIPTION AND ANALYSIS

A simplified 1/12 segment of the NRX-A outer reflector, flow tested under realistic transient environmental conditions, is recommended. The test piece would maintain shapes and sizes of the flow passages in the reflector and drum including the inner and outer bounding annuli. For cooldown applications with little or no heat addition to the structure the reflector parts would be fabricated from beryllium or from aluminum depending on availability and ease of machining. For applications requiring large addition of heat, electric heaters would have to be immersed in the aluminum or beryllium test pieces. Nozzle cooling flow channels and the transition from these to the reflector segment would be simulated.

The ultimate aim of the tests would be definition of the hydrogen flow at the axial stations of each flow channel in such detail that heat transfer and pressure drop characteristics could be correlated with generalized data. The burden on instrumentation is recognized. High response thermocouples are available for frequencies up to 20 cps, reference TME-538. Presently available static pressure transducers have been demonstrated to be adequate in measuring pressure oscillations during boiling hydrogen flow. The use of piezoelectric pressure transducers for this purpose is being investigated.

Presuming that the test piece is adequately instrumented to measure instantaneous gas, wall and interior structure temperatures and static pressures, techniques for calculating mass flows, heat fluxes and subsequently mass qualities over the wide range of two-phase flow characteristics are shown to be not only feasible but quite promising. It is in this area, however, that early and accelerated development work is required. The proposed test program includes an initial acceleration in this area to make more readily available techniques and devices for determining quality of two-phase flow.

PROGRAM SCHEDULE

The program would be carried out in the following steps:

1. Design and specifications for test system.
2. Procure and fabricate components and associated hardware.
3. Assemble components and associated hardware.
4. Instrument test system and test sections.
5. Test planning.
6. Perform shakedown tests.
7. Modify and repair.

Concurrent with these activities, there would be a development program which would consist of:

1. Develop quality measuring devices and techniques.
2. Develop flow measuring devices and techniques.
3. Improve instruments for fast response temperature and pressure measurements.

To obtain the maximum utilization from this program, measurements of flow properties are required for both transient and steady state conditions. While no major problems exist in the measurement techniques and instrumentation for steady state single phase operation, careful calibrations and additional investigations would have to be performed in order to establish confidence in the available instrumentation during transient behavior with two-phase flow.

COST ESTIMATES, MANPOWER AND SCHEDULE

The estimated cost of special test equipment and materials, shown on Table 1, is $129,930. These cost estimates are based on the use of aluminum reflector segments. Additional cost would be incurred if beryllium sectors would be used. However, it might be possible to use a beryllium sector which did not pass the requirements for hot reactor tests in this cold flow sector test.

It is estimated that five (5) engineers and two (2) technicians would be required for the design of the test apparatus, and the calibration of the instrumentation. During installation and checkout of the test loop and the sector the technician requirement will increase to five (5). Once regular testing is established, two (2) engineers and three (3) technicians will be required. Based on the subsequent schedule, a total of 50 man months of engineering effort and 40 man months of technicians in addition to 6 man months of drafting.

The pacing item will be the vacuum chamber housing for the reflector. A vacuum chamber to serve as an adiabatic enclosure for the reflector is required during the transient period. This item would require the following estimated procurement schedule and permit a test schedule such as:

Design and Drafting	7 weeks	
Procurement, Bidding and Approvals	9 weeks	
Fabrication	14 weeks	
Installation	5 weeks	
	35 weeks	(8 months)
Initial Testing and Checkout	4 weeks	
Comprehensive Tests and Modifications	9 weeks	
	48 weeks	(11 months)

CONCLUSIONS

1. Technically the 1/12 sector test would provide analytic and experimental verification of the integrated results of tests D 2, D 3 and D 4.

2. The 1/12 segment test would provide a valuable tool for determining transient reactor operation such as start-up and shut-off.

3. Timewise, the test would succeed NRX-A1 and be contemporary with NRX-A2. Hence, information from this test could, at best, be used for tests of NRX-A3. Some of the information derived from this reflector segment test will be similar to that obtainable from NRX-A1 cold flow tests. In the event that no problems are indicated from liquid hydrogen flow ramps during NRX-A1 cold flow test, this segment test would have limited desirability, but if major problem areas are indicated, it would be a valuable tool for determining the cause and evaluating the required modification which could be incorporated in later reactors.

While there are many technically desirable reasons for a segmental reflector test, the timing of the availability of the information from this test is such that it could only influence the flow scheduling of NRX-A3 or possibly NRX-A2. Block II reactors could use the information in determining their test plans. Block III reactors would be the earliest test which could factor such test information into their design.

TABLE I

COST ESTIMATE

Test Sections	
1/12th segment of the reflector, cast aluminum (two)	$ 19,000
1/12th segment of the nozzle	2,000
Vacuum Chamber Housing for Reflector	12,000
High Pressure Dewar, 1000-gallon capacity, 750 psi working pressure	35,000
Vacuum Jacketed Transfer Lines	2,000
Vacuum Pump	1,000
Instrumentation	
300 fast response thermocouples	5,000
50 pressure transducers (strain gauge type)	15,000
10 pressure transducers (piezoelectric type)	8,000
Flow loop modifications	5,750
Flow control valves	3,280
Miscellaneous Hardware	12,000
Oscillograph Recording Paper	3,500
Helium	2,000
Gaseous Nitrogen	400
Liquid Nitrogen	4,000
Grand Total for Program	$129,930