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| SUBJECT: | Heating and Cooling Tests on the ORR HN-1 In-Pile Loop Mockup |
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## SUMMARY

Heating and cooling tests were made on the ORR HN-1 in-pile loop mockup 0-1-20 to test the operation of the loop when subjected to reactor scrams or setbacks. The loop was fitted with additional heaters to simulate reactor heat. Reactor transients were simulated by manually changing the power at a predetermined rate. It was found that the loop control system was adequate and that loop temperatures could be maintained within a total change of 5°C.

## DISCLAIMER

## Heating and Cooling Tests on the ORR HN-1 In-Pile Loop Mockup

A number of heating and cooling tests have been completed on the ORR HN-1 in-pile loop mockup, 0-1-20. To simulate reactor fission and gamma heating, the loop was fitted with four heater-cooler units in addition to the units used for loop temperature control. In other respects, the loop construction and operation was similar to the loop to be operated in the ORR.*

The test runs were made to determine the ability of the temperature control system to minimize temperature excursions of the loop during a reactor setback or scram. A reactor scram was simulated by the sudden shut-off of power to the four additional heaters. A reactor setback was simulated by manually lowering the power at a predetermined rate to the desired power level. The results of these tests are described below.

### A. On-Off Control of Loop Cooling

1. Test Conditions

The initial series of tests, exploratory in nature, was carried out with 14 kw of heat input to the four auxiliary heaters, with no core cooling in most cases, and with on-off control to the loop cooling. Air-water mixtures were used as the cooling medium. The cooling water was controlled by the core $\Delta$ t recorder. The primary loop heater power input was controlled with a Brown pneumatic controller employing automatic reset and derivative units.

* See Dwg. TD-F-4778 for description of loop layout. CF 57-6-66 presents a discussion of the heater-cooler units.

A significant setting in this control system involves the time it takes to shut off the loop cooling water following a scram. This is determined by the adjustment of a switch in the core $\Delta t$ recording instrument which is actuated when the temperature has dropped to a specific value below the normal operating temperature. The closest setting attempted was the equivalent of a 1°C drop in the core $\Delta t$. This was believed to be the closest setting which would avoid accidental shut-off of loop cooling by normal fluctuations in reactor power.

Another significant setting is that of the steady-state power input to the primary loop heaters (primary refers to those heater-coolers which are part of the permanent loop system). With a total available heating capacity of 8 kw, the steady-state power input to the heaters was set at ~3 kw to control loop temperature at 280°C.

Attempts were made to kill the additional heat capacity of the secondary heater-coolers with a rapid injection of water when simulating a reactor scram. During the series of tests, changes were made in the proportional band, reset and derivative settings of the loop heater controller to improve the control.

To simulate a reactor scram or setback, up to 14 kw was removed from the secondary heaters. It has been estimated that a 40 gram/liter solution of fully enriched uranium in the HN-1 loop, with the ORR operating at 20 MW, would develop about 20 kw fission and 4 kw gamma heat. Thus, using 4 kw core cooling in the mockup leaves a net "fission" heat of 10 kw at a total heat input of 14 kw. This condition represents about one half of the maximum fission power levels anticipated with a 40 g/l fuel solution. However, if a 10 gram/liter fully enriched uranium solution is used, as is most likely, the test conditions generally are about twice as severe as anticipated in the ORR.

The loop was operated at a mainstream temperature of 280°C and a pressurizer temperature of 295°C for all tests.

2. Test Results

Sixteen scrams, simulating an unexpected scram from the reactor, at different instrument control settings were made with this system. Two additional scrams were made which were instigated by the scram control on the panel board. These runs are listed in Table I. In the reactor scram tests the total negative and positive temperature excursions of the loop averaged about 10°C and after improved settings averaged about 8°C. Generally, the temperature of the loop would drop 6 to 7°C below the set point of 280°C, then rise to about 2-3°C above, and then level out with minor oscillation for about 10 minutes following the removal of 14 kw heat. In the two runs in this series which were made using the panel board scram switch, which results in simultaneous removal of loop heating and cooling and core cooling, the total excursion was 4 to 5°C, with the temperature first rising to 2-4°C and falling to 0 to 3°C below the set point.

It is concluded that the loop temperature excursions following a reactor scram would not be particularly severe with on-off control of the cooling, but could be improved by using proportional control instead of on-off control on the loop cooling water. The latter control, based on the core $\Delta t$, was tried in the following tests:

B. Proportional Control on Loop Cooling

The use of proportional control on the loop cooling permits a greater degree of flexibility in the temperature control system for the cases where it is necessary to correct for less severe types of reactor power transients--particularly those involving reactor setbacks to some intermediate power level. It was also found in the following series of tests that loop temperature excursions following simulated reactor scrams were reduced by the use of proportional control of the loop coolers. It was hoped that at least for reactor setbacks the use of proportional control would prevent excessive lowering of the loop temperature, thus maintaining the rate of recombination of stoichiometric gas.

Table II summarizes the tests made with proportional control on the loop cooling water, manual control on the core cooling water, and derivative plus reset plus proportional band control on the loop heaters. Various fast setback rates were explored (in addition to the standard rate of 10% reactor power in 30 seconds) to account in part for the extra heat capacity of the mockup loop compared to the actual in-pile loop.

Core cooling was equivalent to 4 kw and was manually controlled, loop heat input was generally 14 kw in addition to the primary heat input of ~3 kw to the loop temperature-control heaters.

1. Scrams

Scram tests with this system indicated that if core cooling was shut off manually at an appropriate time after scram, a total excursion, negative and positive, of about 5°C was experienced. If the operator forgot to shut off the core cooling following a scram, the excursion was larger, particularly if the cooling air flow to the loop coolers (manual control) also was maintained. The recovery time of the system was also longer. As much as a thirty-second delay in manipulation of the core cooling water was possible, however, and the total excursion of the mainstream temperature was maintained between ± 2.5°C with a fairly tight proportional band.

2. Setbacks

Setbacks to 10% power in 30 and in 20 seconds were attempted. Generally these showed that the control system was adequate, the temperature excursion being held in the ± 2.5°C range.

3. Setbacks to Fractional Powers

Tests were made using a wider proportional band (50 to 100%) on the control of the loop cooling to provide control for partial setbacks to, for instance, one-half reactor power. It was anticipated that this "looser" control would adversely affect response to scrams and fast setbacks; however, it was hoped that a compromise setting would be achieved that could handle the three situations.

Tests 30 to 36 were setbacks to one-half power in 10 seconds. These runs showed total excursions of 6 to 10°C as a result of malfunction of the cooling water control valve. Following repair of the valve, run 36 showed a transient of - 4 and + 1.5°C. These tests, which did not involve manual core-cooling control, were considered encouraging. Thus, if conditions of reactor operation are such that the loop is subjected to relatively frequent setbacks to fractional powers, the control system can be set up to emphasize this situation with satisfactory control; however, at the expense of scram control. This is shown in scram runs 37 to 38 where negative excursions of 8 and 6°C, respectively, were encountered.

Runs 39 through 45 show that, with the same settings as used with those above on reactor setbacks to fractional powers, but with the aid of manual control on the core cooling the total excursion can be held to a total of 5°C when starting at 14 kw, 9 kw and 7 kw total heat input for scrams and fast setbacks to zero power.

C. Conclusion

It was found that changes in loop temperature resulting from simulated reactor scrams or setbacks could be minimized to about a total of 5°C using a control system with derivative control on the loop heaters and proportional control on the loop cooling water. Although some manual control was necessary, particularly on the core cooling rate, to meet all the test situations adequately, such manipulation was not critical. Present plans require an operator standing by at all times, and a delay in corrective action of up to one minute would not be serious.

It is recommended that a manually controlled bypass be installed around the loop coolant control valve to take care of unexpected situations, and a suppressed zero be installed on the core $\Delta$ t recorder controller. It is expected that the latter instrument which originally was designed for operation from a boron thermopile will be used with a gamma heating thermocouple to provide a signal of reactor power level. Probably such a direct power signal will improve the response and control of the system over that provided by a core $\Delta$t signal. However, the latter is available as a second line of defense.

It should be noted finally that pressurizer temperature control was excellent under all test conditions.

No quantitative instrumental settings have been included in this summary since it is expected that in-pile conditions, particularly with respect to heat capacity and heat losses from the system, would differ from test conditions, and require individual adjustment of the control system.

The valuable advice and assistance of S. Ball of the Instrumentation and Controls Division during these tests is gratefully acknowledged.

Table I.

ORR In-Pile Loop Temperature Control Tests with On-Off Control of Loop Cooling

| Test No. | Power to Control Heater kw | Core Cooling kw | Power to Auxiliary Heaters kw | Type of Heat Load Change | Maximum Loop Temp. Dev. °C Above | Below | Remarks |
|---|---|---|---|---|---|---|---|
| 1 | 1 | 0 | 14 | *Scram 14 kw | 2 | 6 | Loop CW turned off manually 15 seconds after scram. |
| 2 | 3 | 0 | 14 | " " | 0 | 7 | Loop CW turned off automatically 45 seconds after scram by core Δt TC. |
| 3 | 3 | 0 | 14 | " " | 2 | 7 | Same as Test 2 except manual injection of cooling to secondary heaters. |
| 4 | 3.2 | 0 | 14 | " " | 1 | 7 | Same as Test 3 - Loop temperature controller adjustments. |
| 5 | 0.8 | 0 | 14 | " " | 2 | 7.5 | Test effect of low idling power on primary HC's gain of control instrument low. |
| 6 | 0.8 | 0 | 14 | " " | 2 | 8 | |
| 7 | 3.2 | 0 | 14 | " " | 2 | 8 | Test effect of short injection cooling to secondary HC's. |
| 8 | 3.2 | 0 | 14 | " " | 2.5 | 7 | Same as Test 7. Effect of cooling small. |
| 9 | 3.2 | 0 | 14 | " " | 1 | 5 | Core Δt set to trip CW sooner (15 seconds) with injection cooling. |
| 10 | 2.9 | 4 | 14 | " " | 7 | 0 | All heat and cool off at once - check on residual heat. |
| 11 | 3 | 0 | 14 | " " | 3 | 5 | Range changed on loop heater controller - 225°C to 325°C. |
| 12 | 3 | 0 | 14 | " " | 3 | 6 | Adjustments on control system. |
| 13 | 3 | 0 | 14 | " " | 2 | 4 | Repeat of run 9 with extended range on loop heater controller. |
| 14 | 3 | 0 | 14 | " " | 1 | 6 | Repeat of run 13 with extended range on loop heater controller. |
| 15 | 3 | 0 | 14 | " " | 1.5 | 6 | Repeat of run 14 varying injection cooling in runs 13,14,15. |
| 16 | 3 | 4 | 14 | Loss of coolant | 7 | 9 | Accidental loss of loop coolant. |
| 17 | 3 | 0 | 14 | Scram 14 kw | 0 | 4 | Manual control of loop heating following scram. |
| 18 | 3 | 0 | 14 | " " | 3 | 2 | Simultaneous scram and CW shut off. |
| 19 | 3 | 4 | 14 | " " | 4.5 | 5 | Effect of core cooling on excursion. |
| 20 | 3 | 4 | 14 | FSB, 10% pwr | 3.5 | 2.5 | Manual core cooling shut off. |

NOTE: Normal operating conditions: Mainstream, 280°C; Pressurizer, 295°C.

*Scram represents the sudden removal of heat from the auxiliary heaters.

Table II.

ORR In-Pile Loop Temperature Control Tests with Proportional Control of Loop Cooling

| Test No. | Type of Transient | Maximum Loop Temp. Dev. °C Above | Maximum Loop Temp. Dev. °C Below | Remarks |
|---|---|---|---|---|
| 22 | Scram 14 kw | 1.5 | 2.5 | Loop cooling water on proportional control, core cooling on manual control. |
| 23 | Scram 14 kw | 1.0 | 3.0 | Repeat of 22. |
| 24 | Scram 17.2 kw | 0.8 | >5 | Control poor, core cooling on >5 minutes. |
| 25 | FSB to ~1/2 pwr in 5 sec | 6.5 | 2 | 8 kw remained on secondary heaters. Manual loop cooling control required for this transient. |
| 27 | Scram 14 kw | 3 | 2.5 | Repeat of 22. |
| 28 | Scram 14 kw | 0 | 5 | Repeat of 24 at lower power, core cooling on entire test. Control poor, leveled out below set point. |
| 29 | Scram 14 kw | 0 | 5 | Repeat of 28, core cooling off in 3 minutes. Control poor. |
| 30 | FSB to 1/2 pwr in 10 sec | 4 | 4 | 7 kw remained on secondary heaters, core cooling on for entire test. Poor control. |
| 31 | FSB to 1/2 pwr in 10 sec | 4 | 6 | Increased proportional band on core Δ t to 150. Poor control. |
| 32 | FSB to 1/2 pwr in 10 sec | 3 | 4.5 | Proportional band to 45. Runs 31 and 32 appeared to suffer from instrument malfunction. |
| 33 | FSB to 1/2 pwr in 10 sec | 4 | 1.5 | Instrument adjusted. Loop cooling under fair control, stabilized in 7 minutes. |
| 34 | FSB to 1/2 pwr in 10 sec | 4 | 2 | Repeat of 33. Apparently loop control valve showing malfunction. |
| 35 | FSB to 1/2 pwr in 10 sec | 4 | 4 | Repeat of 33. Same comment. Control valve repaired and replaced. |
| 36 | FSB to 1/2 pwr in 10 sec | 1.5 | 4 | Improved control, repeat of 33. Loop leveled out in 5 minutes. |
| 37 | Scram 14 kw | 0 | 8 | Repeat of 28, with repaired instrument and valve. Control still poor. |
| 38 | Scram 14 kw | 0.5 | 6 | Repeat of 22, 23 with instrument settings as in 36 (for setbacks), scram control degraded. |
| 39 | Scram 14 kw | 3 | 2.5 | Repeat of 38 with compromise adjustments on instruments. Control good. |
| 40 | FSB to 0 power in 20 sec | 2.5 | 2.5 | Test of compromise settings on FSB. Core off manually in 40 seconds. |
| 41 | FSB to 0 power in 30 sec | 2.5 | 2.5 | Core cooling off in 60 seconds. Control good. |
| 42 | Scram 14 kw | 2.5 | 3.5 | Core cooling off in 40 seconds. Control good. |
| 43 | Scram 9 kw | 0 | 5 | 4 kw core cooling (depleted uranium run, full reactor power), fair control. Suppressed zero on core Δ t required. |
| 44 | Scram 7 kw | 0 | 3.5 | 2 kw core cooling (depleted uranium run, 1/2 reactor power), fair control. Suppressed zero on core Δ t required. |
| 45 | Scram 9 kw | 0 | 5 | Repeat of 43. |

Note 1. Normal operating conditions: Mainstream, 280°C; Pressurizer, 295°C.

Note 2. All tests except where noted involved ≈3 kw steady-state power on primary heater coolers, ≈14 kw on secondary heater coolers, and ≈4 kw core cooling prior to scram or setback.

Note 3. Missing test numbers in sequence are non-transient tests.

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