DECLASSIFIED

HANFORD TECHNICAL RECORD
GENERAL ELECTRIC

HANFORD ATOMIC PRODUCTS OPERATION - RICHLAND, WASHINGTON

DOCUMENT NO.

HW-48519

DATE

February 18, 1957

COPY NO. AND SERIES

56

FILE DESIGNATION
TECHNICAL INFORMATION FILES

TITLE

PRESSURE, FLOW, AND TEMPERATURE
RESPONSES TO A RAPID PLUGGING
OF A PROCESS TUBE

AUTHOR

G. M. Hesson
W. L. Thorne

THIS DOCUMENT IS UNCLASSIFIED. IT MUST BE STORED IN AN APPROVED GUARDED AREA, WHILE IT IS IN YOUR POSSESSION AND UNTIL YOU HAVE OBTAINED A RECEIPT FROM THE ISSUING OFFICE. IT IS TO BE KEPT AND ITS CONTENTS WITHIN THE LIMITS OF THIS PROJECT AND FROM ANY UNAUTHORIZED PERSON. ITS TRANSMISSION OR STORAGE AT YOUR PLACE OF RESIDENCE IS PROHIBITED. IF ADDITIONAL COPIES ARE REQUIRED, OBTAIN THEM FROM THE RELATED ISSUING FILE. ALL PERSONS RECEIVING THIS DOCUMENT ARE REQUESTED TO SIGN IN THE SPACE PROVIDED BELOW.

ROUTE TO:

PAYROLL NO.

LOCATION

SIGNATURE

DATE

RECORD
COPY

Indefinite Retention

Disposal Date

Authority

Authority

DECLASSIFIED

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, make any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

DECLASSIFIED

HW-48519

1. F. W. Albaugh	24. J. H. Gerety	47. L. H. McEwen
2. W. K. Alexander	25. S. M. Graves	48. J. H. M. Miller
3. J. M. Atwood	26. O. H. Greager	49. D. L. Moore
4. W. D. Bainard	27. C. N. Gross	50. J. F. Music
5. J. J. Baker	28. S. Goldsmith	51. S. L. Nelson
6. J. M. Batch	29. R. E. Hall	52. E. W. O'Rourke
7. R. S. Bell	30. R. B. Hamilton	53. E. T. O'Sullivan
8. R. R. Bloomstrand	31. A. K. Hardin	54. J. R. Pierce
9. R. V. Bowersock	32. H. W. Heacock	55. R. H. Purcell
10. J. H. Brown	33. K. W. Hess	56. R. W. Reid
11. R. O. Brugge	34. G. M. Hesson	57. G. J. Rogers
12. L. P. Bupp	35. E. T. Hubbard	58. E. R. Rudock
13. R. L. Call	36. M. E. Jackson	59. R. J. Shields
14. A. B. Carson	37. R. T. Jessen	60. H. G. Spencer
15. R. G. Clough	38. S. S. Jones	61. W. L. Thorne
16. D. L. Condotta	39. J. E. Kaveckis	62. K. G. Toyoda
17. H. G. DeVoss	40. H. R. Kosmata	63. W. E. Vetter
18. R. L. Dickeman	41. E. E. Leitz	64. A. P. Vintner
19. E. J. Filip	42. C. G. Lewis	65. R. K. Wahlen
20. J. M. Fouts	43. D. S. Lewis	66. P. C. Walkup
21. G. C. Fullmer	44. G. L. Locke	67. C. C. Wheeler
22. W. J. Gartin	45. D. B. Lovett	68. E. C. Wood
23. R. H. Gay	46. A. R. Maguire	69. Record Copy
		70. File Copy

February 18, 1957

This document classified by

L. H. McEwen
L. H. McEwen

This document consists of
27 pages, Copy 56 of
70 copies, Series .

PRESSURE, FLOW, AND TEMPERATURE
RESPONSES TO A RAPID PLUGGING
OF A PROCESS TUBE

by

DECLASSIFIED

GROUP 1

G. M. Hesson
and
W. L. Thorne

By Authority of

Ch-PR-2
Robert M. Sten 10/29/92
DD Krushew 12/2/92
J E Savely 12-11-92

MASTER

DECLASSIFIED

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

PURPOSE

This report presents the results of initial experiments concerning the protection afforded by the Panellit system against hazards associated with the inadvertent plugging of a process tube.

INTRODUCTION

Process tubes are subject to inadvertent plugging from a variety of causes. Such plugging may be slow or fast, and either upstream or downstream of the venturi throat. Protection against such occurrences is provided by several means. One such means is the Panellit system which monitors the venturi throat pressure and is connected to the scram circuit. Procedures, termed "instability limits" are in force which aim at lessening the hazard from plugging occurrences by stipulating particular permissible relationships between tube outlet temperatures and Panellit gage operating pressures and Panellit gage trip pressures.

Current "instability limits" come from calculations based on experiments which determined the pressure versus flow relationships for process tubes under abnormal situations, but always under steady state conditions. For plugging occurrences which are rapid, the dynamic response of the process tube system is only vaguely related to steady state conditions.

Consequently, experiments were performed in the 189-D Thermal Hydraulics Laboratory to simulate rapid plugging occurrences and thus to enable appropriate review of the protection afforded by the Panellit system. This report describes such experiments, all of which were performed under conditions generally typical of old (B, D, DR, F, and H) reactor operation prior to CG-558 modifications but at central zone tube powers near 1000 KW and normal initial tube outlet temperatures near 120°C.

SUMMARY

An experimental assembly was used which utilized direct current electrical heating of a metal rod to simulate nuclear heating of a 32 slug train of standard solid slugs in BDF tube geometry. Through proper choice of materials, the important thermal properties of the heater rod generally resembled those of uranium. To such a system operating under steady state conditions at 400 psig front header pressure and 20 psig rear header pressure, at 1000 KW tube power and 120°C outlet temperature, a sudden partial closing of a throttle valve was applied. In this manner step reduction of tube flow was effected. In the tests performed, the flow immediately following actuation of the throttle was about 25, 40, and 60 per cent of initial, each representing a substantial reduction in tube flow.

Following insertion of the throttle the tube flow experienced a self-induced further decrease owing to operation in the unstable flow regime. The flow, tube inlet pressure, heater rod temperature, and other variables were monitored by high speed recording devices. About seven seconds following actuation of the throttle, tube power was reduced in accord with a 250 inhour scram.

From the measurements of tube inlet pressure and flow rate, venturi throat pressures were calculated for venturis with initial throat pressures of 150, 200, and 250 psi. From these, Panellit pressures were calculated after taking into account gage dynamics. This permits estimation of the time of occurrence of Panellit scrams over a wide range of possible instrument settings. Examination of rod temperature traces and fusible buttons on the rod surface, and lack of indication of scorching the insulating

DECLASSIFIED

-3-

HW-48519

varnish on the inside of the experimental process tube, provided qualitative evidence bearing on whether or not gross damage to the reactor would have resulted from the flow interruptions simulated.

Test results from three of the runs are given in Figures 3 through 8 which report the measured process variables and calculated Panellit pressures. In no tests were rod temperatures recorded which would be indicative of gross damage to a reactor. The range of conditions studied were:

Process tube type - BDF
Tube power - 1000 KW
Front header - 400 psig
Rear header - 20 psig
Outlet water temperature before plugging - 120°C
Flow reduction due to plugging - 40, 60, 75%
Strength of scram - ~250 inhour

CONCLUSIONS

1. If it is granted that the laboratory tests constitute an effective and accurate simulation of a similar event occurring in a reactor process tube, some interesting conclusions may be drawn upon examination of the data. It should be noted, however, that the conclusions are applicable only over the range of conditions studied:
 - A. If the Panellit gage is not unduly sluggish, and if the initial Panellit pressure is anywhere between 150 and 250 psig, and if there is a 50 psi range between the high and low pressure trips, and if the initial Panellit pressure is not any closer than 5 psi to the high trip pressures - - -
 - I. A sudden plugging occurrence upstream of the venturi throat will trigger a low pressure Panellit trip within a second or two after the flow reduction. Shutdown will be free from serious damage to the reactor.
 - II. A sudden plugging occurrence downstream of the venturi throat will trigger a high pressure Panellit trip within a second or two after the flow reduction. Shutdown will be free from serious damage to the reactor.
 - B. If the Panellit gage is not unduly sluggish, and if the initial Panellit pressure is anywhere between 150 and 250 psig, and if there is any range up to 80 psi between high and low pressure trips, and if the initial Panellit pressure is anywhere between the high trip pressure and low trip pressure, and if there is deliberately introduced a short (1/4 to 1/2 second) delay between the Panellit scram signal and actual actuation of the scram circuit - - -
 - I. A sudden plugging occurrence upstream of the venturi throat will cause either a low pressure trip, or a high pressure trip, or both, within a few seconds after the flow reduction. Shutdown will be free from serious damage to the reactor.
 - II. A sudden plugging occurrence downstream of the venturi throat will cause a high pressure trip within a second or two after the flow reduction. Shutdown will be free from serious damage to the reactor.

DECLASSIFIED

2. From the above it appears that the Panellit system as it is now applied provides satisfactory protection against sudden plugging occurrences over the range of conditions studied experimentally. It also appears likely that adequate protection would exist even if the present Panellit system requirements were relaxed significantly.
3. In the case of the step reduction of flow to about 60 per cent of normal, the scram simulated in the experiments was so early in the flow reduction sequence that heater rod temperatures did not rise to a point close to any sort of damage threshold. Scrams of substantially greater time delay would probably be free from serious damage to the reactor.
4. Further tests of a similar sort, embracing other geometries, a wider range of flow reduction, and under process conditions more representative of future operating conditions should be performed.

DISCUSSION

Experimental Equipment

The tests were performed in the 189-D Thermal Hydraulics Laboratory. A diagram of the equipment is presented in Figure 1. The equipment consists of a mockup of a reactor process tube containing an electrically heated rod simulating a uranium slug column, a 1125 KW dc generator system to provide the electrical power for the heater rod, a water recirculation system to provide the coolant water flow, and instrumentation to measure the process variables.

The coolant water system consists of a valve to control the rear header pressure, a condenser to cool the heated water, a high pressure pump, a pre-heater to adjust the inlet water temperature, and a valve to control flow through the process tube. The test section is made up of a BDF process tube discharging to rear face piping components of standard design. The tube is divided into an active section containing the heater rod and an off-set section containing a standard dummy slug loading. The off-set is necessary to permit the electrical connections to be made to the heater rod. The active and dummy sections are connected with approximately 2 1/2 feet of 1 inch I.P.S. pipe which introduces only a small increment of additional pressure drop. The active test section is 23 1/2 feet long. The inside of the process tube is coated with a 0.005 inch layer of insulating varnish (Heresite) to provide electrical insulation. The heater rod diameter is 1.430 inches, 0.010 inches less than that of standard slugs in order to compensate for the Heresite lining in the tube.

The heater rod is made up of sections of brass and copper-nickel alloys welded together. Some of the sections are bored out internally to reduce their cross-sectional area. The variations in electrical resistance effected by the variation in materials and cross-sectional areas results in a stepwise variation in heat generation along the length of the rod approximating the chopped cosine heat generation in a reactor process tube. Rod materials are chosen to create an assembly with thermal diffusivity and thermal conductivity generally similar to that of uranium so the transient temperature responses of the electrically heated rod will generally resemble those of uranium slugs. The details of the construction of the rod and the form of its heat generation characteristics are shown in Figure 2. Since recourse was made to drilling central holes to regulate heat output, and since various rod materials were used, the thermal responses of the rod vary from point to point and are not in all respects the same as those expected from uranium. The thermal properties of the rod materials are as given below in Table I.

DECLASSIFIED

-5-

HW-48519

Table I

THERMAL PROPERTIES OF ROD MATERIALS

	<u>Uranium</u>	<u>Brass</u>	<u>Copper - Nickel</u>	
			<u>70-30</u>	<u>85-15</u>
Thermal Conductivity B/hr F ft	17	69	20	30
Density lb/cu ft	1154	529	558	558
Heat Capacity B/lb F	.028	0.09	.09	.09
Thermal Diffusivity sq ft/hr	.525	1.45	.4	.6

Six thermocouples were imbedded in the rod with their leads brought out through the center hole. The thermocouple installations are such that they measure the rod temperature slightly below the surface, and therefore indicate temperatures somewhat higher than but proportional to the true surface temperature. In addition six fusible plugs (zinc and silver solder) were imbedded in the surface of the rod to give additional indications of over-heating. These plugs were examined after the conclusion of the experiments. The locations of the plugs and thermocouples are indicated on Figure 2. Additional but indirect indication of heater rod surface temperatures arises from behavior of the Heresite coating on the inside of the process tube. Being an organic material, it will decompose rapidly at temperatures materially in excess of 400°C. On decomposition its electrical insulation properties are destroyed and this causes short circuits generally resulting in local melting of the process tube, loss of pressure, and termination of the experiment. Lack of short circuits during all tests reported herein is additional evidence that temperatures within the process tube did not reach levels which could properly be associated with gross damage to the reactor.

Experimental Method

Process tube flow stream plugging was simulated in the following manner: Initial conditions were established and the system allowed to reach steady state. The tube flow was then suddenly reduced by rapidly partially closing a valve upstream of the region of heat generation. The degree of closing was fixed by a pre-set stop on the valve. Flow, pressures and temperatures at various points in the system were then monitored by high speed recording instruments. Each of the runs was then continued at full power for a period up to 8 seconds, after which a scram was simulated. The power to the tube during the scram was controlled by a cam to simulate neutron flux decay arising from insertion of 250 inhours of poison.

Theory

A quantitative prediction of the tube behavior following a flow reduction cannot be made; but qualitatively the sequence of events appears to be as follows:

1. Immediately upon the insertion of the throttle the tube inlet pressure will drop to that corresponding to passage of liquid water at the reduced flow. The tube inlet pressure would remain nearly constant at this value for a time while the heater rod, water and process tube temperatures rise due to the excess heat generated above that removed by the reduced coolant flow.
2. When the water temperature reaches the saturation temperature some place in the downstream portion of the system, steam formation will start and cause an increase in back pressure. This causes an increase in tube inlet pressure.

DECLASSIFIED

3. With the increase in tube inlet pressure the flow further decreases and the pressures and temperatures increase toward new equilibrium values. Generally the new equilibrium values cannot be determined experimentally since these occur in cooling regimes characterized by burnout.

The time relations for this sequence of events would be about as follows:

- a. The time spent at the constant-pressure, below-boiling condition would be decreased by higher initial outlet water temperatures, higher tube powers and greater flow reductions. It could vary from infinity where the reduced flow is still a non-boiling flow to zero where the initial water temperature is above the saturation temperature at the pressures of the reduced flow.
- b. The rate at which the temperatures and pressures increase following the onset of boiling in the tube would be increased by a higher tube power and greater flow reductions. Since the rise of these temperatures and pressures represents an approach to an equilibrium condition on the tube boiling curve, the characteristics of the equilibrium boiling curve would affect the rate of rise. And, finally, the front header pressure would also affect the rates of rise depending upon the relationship between the front header pressure and the boiling curve.

Experimental Results

Sudden plugging runs were made at a tube power of approximately 1000 KW and initial outlet temperatures of 120°C. The experimental results of three of the runs are presented in Figures 3, 4, and 5 for cases of 40, 60, and 75 per cent flow reductions, respectively. Each figure is split into three parts, a part A showing tube flow rate and tube power, a part B showing the tube inlet and rear nozzle pressures, and a part C showing the tube outlet and one heater rod temperature. All are plotted against time from the start of the flow reduction. The heater rod temperature was measured 8' 10" from the downstream end of the active section. The tube outlet water temperature was measured approximately 2.5 feet downstream from the end of the active section.

The runs were continued at full power for from 6 to 8 seconds after flow reduction and then a scram was simulated. The time of initiation of power reduction is indicated by an arrow on the plots. In applying these results to reactor situations, some allowance (about 2 seconds) must be made for time delay between scram signal and actual initiation of reduction of neutron flux caused by rod insertion. The plots are continued for several seconds beyond the scram to indicate the subsequent response of the temperatures and pressures to the power reduction.

It may be noted that the flow reduction, while rapid, is not shown on the plots to be instantaneous. This arises from the finite time required to close the valve, the response time of the instruments, and inertia effects.

The facts of most importance to be deduced from these plots are : (1) the rod and outlet water temperature rises are not extremely rapid and (2) the initial tube inlet pressure drop and subsequent rise are large.

Reactor Applications

In interpreting these test results in terms of reactor application the question "Would a Panellit scram be effected in time to prevent excessively high slug surface temperatures?" is of prime interest. To seek such an answer venturi throat pressures were calculated from the measured tube inlet pressures and tube flow rates for all runs.

DECLASSIFIED

-7-

HW-48519

The venturi throat pressures were then transformed into indicated Panellit gage pressures, for gages with dynamic response constants of 0.22 and 0.5 seconds. These are typical of Panellit gages whose sensing lines are filled with water and those whose sensing lines contain a moderate amount of oil, respectively. These venturi throat pressures and indicated Panellit gage pressures are plotted against time from start of flow reduction in Figures 6, 7, and 8 for the cases of 40, 60, and 75 per cent flow reductions respectively. Each figure is divided into three parts, a part A, B, and C for the cases of venturis having initial throat pressures of 150, 200, and 250, respectively.

Such pressures assume the plug to have been inserted upstream of the venturi throat. No similar plots are presented for the case where the plug is considered to have been inserted downstream of the venturi throat. By simple calculation it is easy to show that for such cases the indicated Panellit gage and venturi throat pressures would rise nearly to the front header pressure a second or so following the flow reduction.

From these plots it may be concluded that for sudden plugging upstream of the venturi throat the Panellit reading will initially drop to a low value, but will nevertheless remain there long enough to effect a low pressure Panellit trip. Furthermore, the rates of rod surface temperature rise and Panellit reading rise following the onset of boiling are such that a subsequent high pressure Panellit trip could well occur before excessive rod temperatures would be reached. Use of venturis giving low initial Panellit pressures decreases the times the Panellit readings dwell below the trip point slightly, but not severely. However, use of these venturis significantly shortens the time for the Panellit gage to reach a subsequent high trip.

From the Panellit pressure plots given in Figures 6, 7, and 8, one can estimate the timing of the scram signal resulting from initial Panellit pressures and Panellit trip pressure settings spanning the general range of practical interest. From these it also appears that gages with dynamic response constants in the vicinity of 0.2 to 0.5 seconds are adequate for the process conditions.

From these results the tentative conclusions may be reached that under conditions up to as extreme as those of these tests the present type of Panellit system provides adequate protection against sudden upstream plugs. Further experimental work is planned to more closely define these tentative conclusions.

Galen M. Hesson

Wayne I. Thorne
Thermal Hydraulics Operation
HANFORD LABORATORIES OPERATION

DECLASSIFIED

DECLASSIFIED

FIGURE 1
Schematic Diagram of Full Scale Mock-Up
Official Use Only

HN-16519

DECLASSIFIED

DECLASSIFIED

Fig. 2

Figure 3 A

Power and Flow Behavior

DECLASSIFIED

DECLASSIFIED

-11-

HW-48519

Figure 3 B

Pressure Behavior

DECLASSIFIED

Figure 3 C

Temperature Behavior

Figure 4 A

Power and Flow Behavior

DECLASSIFIED

DECLASSIFIED

-14-

HW-48519

Figure 4.3
Pressure Behavior

DECLASSIFIED

DECLASSIFIED

Figure 4 C
 Temperature Behavior

DECLASSIFIED

DECLASSIFIED

-16-

HW-48519

Figure 5 A

Power and Flow Behavior

DECLASSIFIED

DECLASSIFIED

DECLASSIFIED

Figure 5 B
Pressure Behavior

DECLASSIFIED

Figure 5 C
Temperature Behavior

Figure 6 A

Panellit Gage Response with 150 psig
Initial Panellit Pressure

DECLASSIFIED

Figure 6 B

Panellit Gage Response with 200 psig
Initial Panellit Pressure

DECLASSIFIED

Figure 6 C

Panellit Gage Response with 250 psig
 Initial Panellit Pressure

DECLASSIFIED

DECLASSIFIED

-22-

HW-48519

Figure 7 A

DECLASSIFIED

Panellit Gage Response with 150 psig
Initial Panellit Pressure

Figure 7 B
Panellit Gage Response with 200 psig
Initial Panellit Pressure

DECLASSIFIED

Figure 7 C

Panellit Gage Response with 250 psig
Initial Panellit Pressure

DECLASSIFIED

DECLASSIFIED

Figure 8 A

Panellit Gage Response with 150 psig

Initial Panellit Pressure

DECLASSIFIED

DECLASSIFIED

Panellit Gage Response with 200 psig
Initial Panellit Pressure

DECLASSIFIED