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Group

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INFORMATION CATEGORY

CRD

Authorized Classifier — 18 May '64 — Date

WANL-TME-775

Liquid Hydrogen Flow Decay From Test Cell "A" Feedsystem to Reactor or Orifice Flow Impedance (U)

May 18, 1964

Classification cancelled (~~or changed to~~ ______)

by authority of ______

by H. A. C., TIC, date SEP 1 1 1973

SPECIAL REREVIEW FINAL DETERMINATION	Reviewers	Class.	Date
Class: U	KAW	U	05/08/82
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In this memo is presented a simple analytical solution for liquid hydrogen flow decay from the Test Cell "A" feedsystem to either the NRX-A reactor or a fixed orifice. The information was presented for use as an analytical aid in preliminary development of a proposed propellant-nozzle-inlet-pressure control loop which would be used for safeguarding the reactor in event of a loss-of liquid flow to the mixing chamber during NRX-A reactor power testing. The proposed pressure control loop would actuate PCV-41 in such a manner as to force fluid from the mixing chamber in event that liquid flow to the mixing chamber was interrupted. (See Figure 1)

The following differential equation was used to represent storage of liquid in the Test Cell "A" feedsystem piping between the inlet to the mixing chamber and the propellant inlet manifold of the reactor or to a load orifice in the case of facility testing:

$$\frac{dP}{dt} = \frac{B}{\rho V} (W_{in} - W_{out}) \qquad (1)$$

where

B = liquid bulk modulus (psia)

W_{in} flow rate in (lb/sec)

W_{out} = flow rate out (lb/sec)

ρ = density of liquid (lb/ft^3)

V = volume (ft^3)

P = system pressure (psia)

t = time (sec)

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The feedsystem plumbing was assumed to be rigid. For the loss-of-flow accident, analog simulation data was obtained that indicated that the reactor resistance to flow was represented by the ratio of design inlet pressure to design flow rate (950 psia/71.3 lbs/sec) during the flow-decay transient.[2] Therefore, the following equation was used to represent the reactor resistance to flow:

$$P = KW \qquad (2)$$

where K = 950 psia/71.3 lbs/sec or 13.4 psia/lbs/sec

Equation (2) was differentiated with respect to time and the result substituted in equation (1) after equating the inward flow, W_{in} in equation (1) to zero. In this manner, a simple differential equation was obtained which was used to represent flow-decay from the Test Cell "A" feedsystem. This equation was integrated from initial flow rate, W_o, to the time dependent flow rate, W, and the following expression for flow-decay was obtained:

$$W = W_o \exp(-Bt/K\rho V) \qquad (3)$$

where ($K\rho V/B$) was defined as the flow-decay time constant. Equation (3) was integrated from time zero to infinity and the total liquid available for decay-flow was found to be given by the product of the flow rate to the reactor prior to the loss-of-flow and the flow-decay time constant, or

$$M_{total} = W_o \, (K\rho V/B) \qquad (4)$$

In future facility tests, which were proposed to develop a pressure-control loop on PCV-41 that would maintain flow after a loss-of-flow upstream of mixing chamber check valve 872, an orifice will be used as a flow resistance for testing the pressure loop. An orifice resistance was represented as follows:

$$P = K_1 W^2 \qquad (5)$$

Performing the same mathematical operations on equation (5) as done on equation (2) and using equation (1) in a similar manner as before, the following equation was obtained for representing flow-decay through an orifice from Test Cell "A" plumbing:

$$W = W_o - Bt/2K_1\rho V \qquad (6)$$

for $0 < t < (2k_1\rho V/B)\ W_o$ and $K_1 = 950$ psia/(71.3 lbs/sec)^2. The quantity $2K_1\rho V/B$ is the time for all decay flow to be expelled through the orifice.

A total mass flow corresponding to equation (4) was derived as before:

$$M_{total} = W_o^{\,2}\,(K_1\rho V/B) \qquad (7)$$

Some information pertinent to simulating the liquid hydrogen bulk modulus as a variable was obtained from LASL and is presented as follows for completeness.

LASL suggested that a constant entropy of S = 2.46 (Btu/lbm °R) appeared to be a fair guess at liquid hydrogen operating conditions in the feedsystem. The isentropic expansion condition along this constant entropy line as fitted to $(\partial P/\partial \rho)_s$ was

$$(\partial P/\partial \rho)_s = (2.08 + 0.00134P)\ 10^3\ (\text{psia/lbm/ft}^3) \qquad (8)$$

The bulk modulus was obtained from the above equation by multiplying it by the liquid density at the corresponding system pressure and it varied from 9700 psia to 9200 psia over the operating range of the feedsystem. In view of this, a constant bulk modulus of 9700 psia was used here because it was more on the conservative side as less decay-flow than would probably be available was predicted using it.

In Figures 2 and 3 the flow and pressure profiles are plotted for decay-flow to the reactor and to an orifice for comparison.

A feedsystem volume of 53 ft^3, liquid density of 4.4 lb/ft^3, and bulk modulus of 9700 psia was used in the loss-of-flow analysis. For the flow resistance defined by equations (2) and (5), a flow-decay time constant of 0.324 seconds and a time for all flow to decay of .65 seconds were calculated for the respective reactor and orifice flow resistances. The total decay flow available in both cases as calculated from equations (4) and (7) was about 24 pounds assuming a 70 lb/sec flow prior to the flow loss. (The plumbing downstream of check valve 872 holds approximately 233 pounds of liquid hydrogen at reactor design conditions).

RECOMMENDATION

The information in this report was presented for possible future use as an analytical aid in preliminary development of a proposed propellant-nozzle-inlet-pressure control loop for safeguarding the reactor in event of a loss-of-liquid flow to the mixing chamber during reactor power tests.

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SCHEMATIC DIAGRAM OF NRX-A FLOW SYSTEM

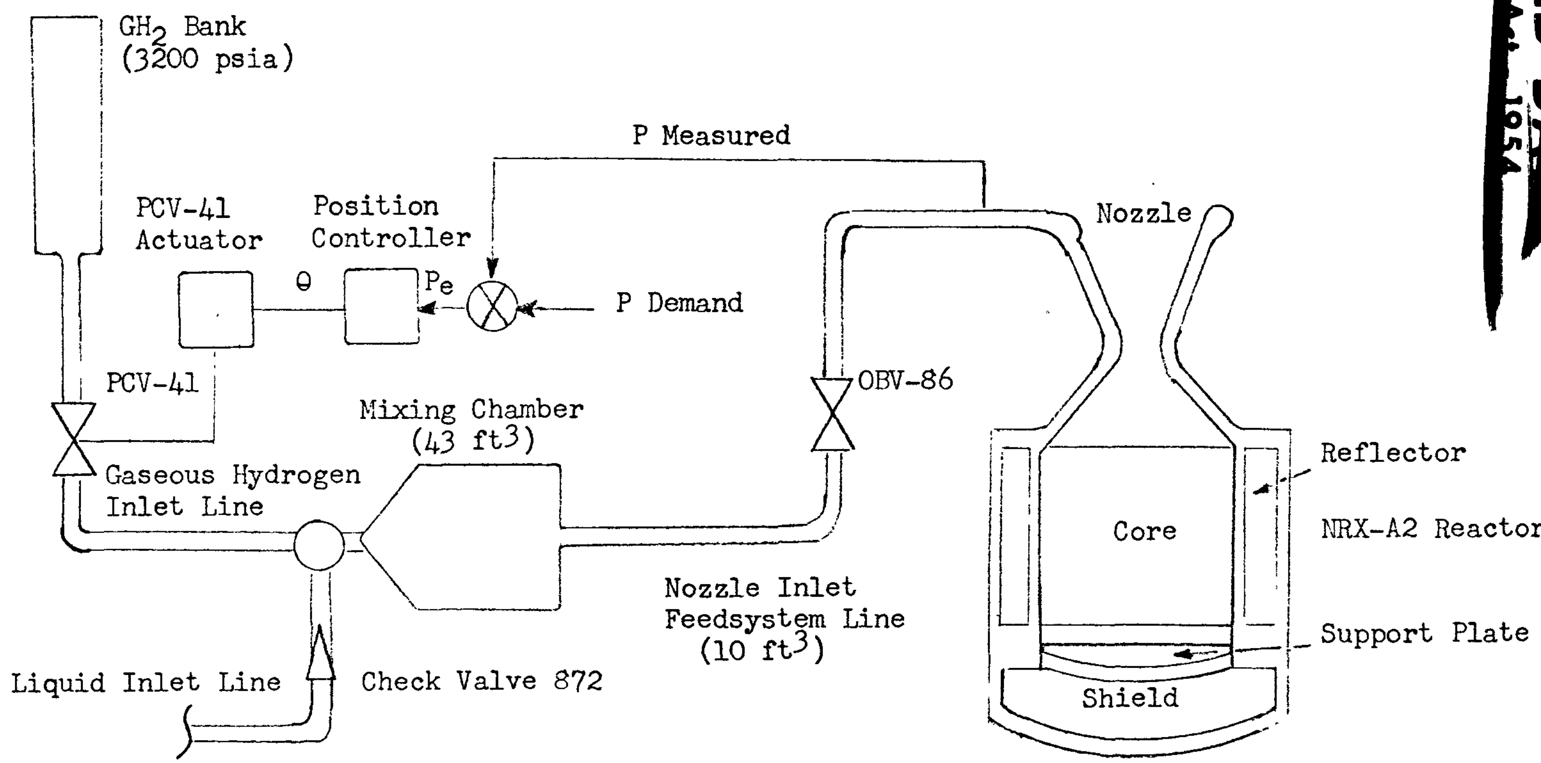

FIGURE 1

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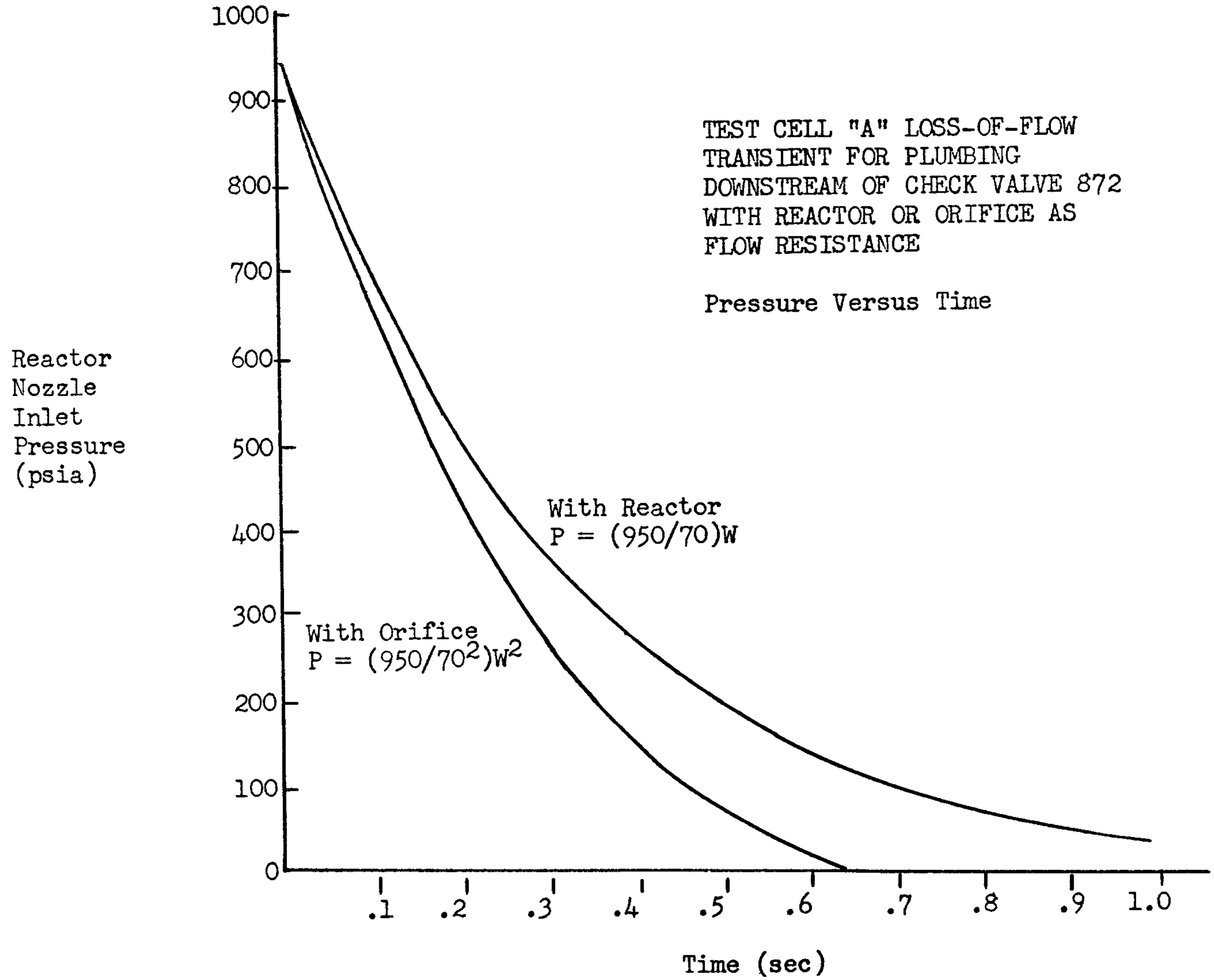

FIGURE 2

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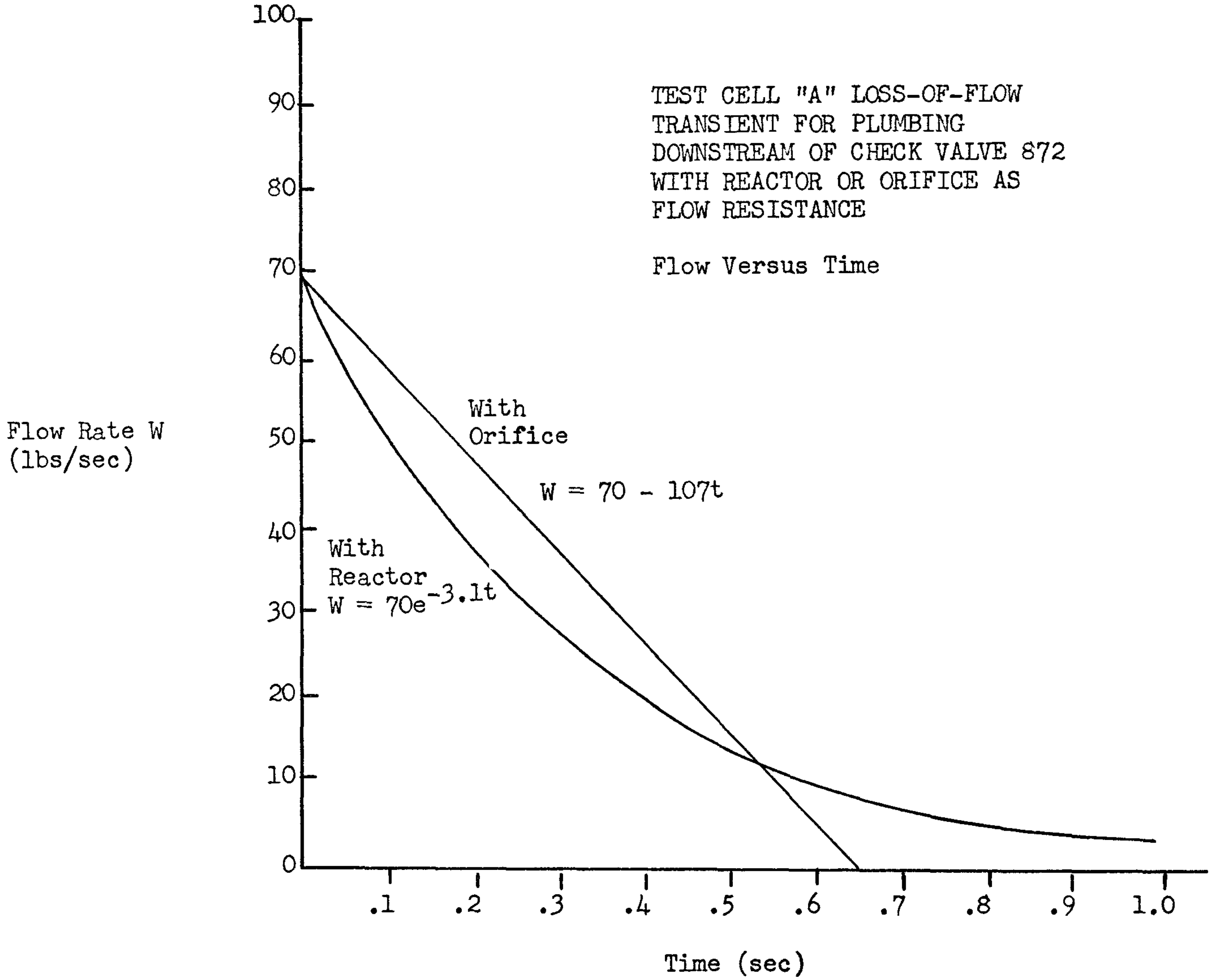

FIGURE 3

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REFERENCES

1. NRX-A2 Test Specification, Draft - WANL-TNR-153, Test Engineering, March, 1964

2. NRX-A2 Flow-Loss-Accident Analysis, WANL-TME-721, P. Gurski and J. Rovnak, (to be published).

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