Probability of a Check Valve Closure-Induced Water Hammer Transient at the ORNL High Flux Isotope Reactor

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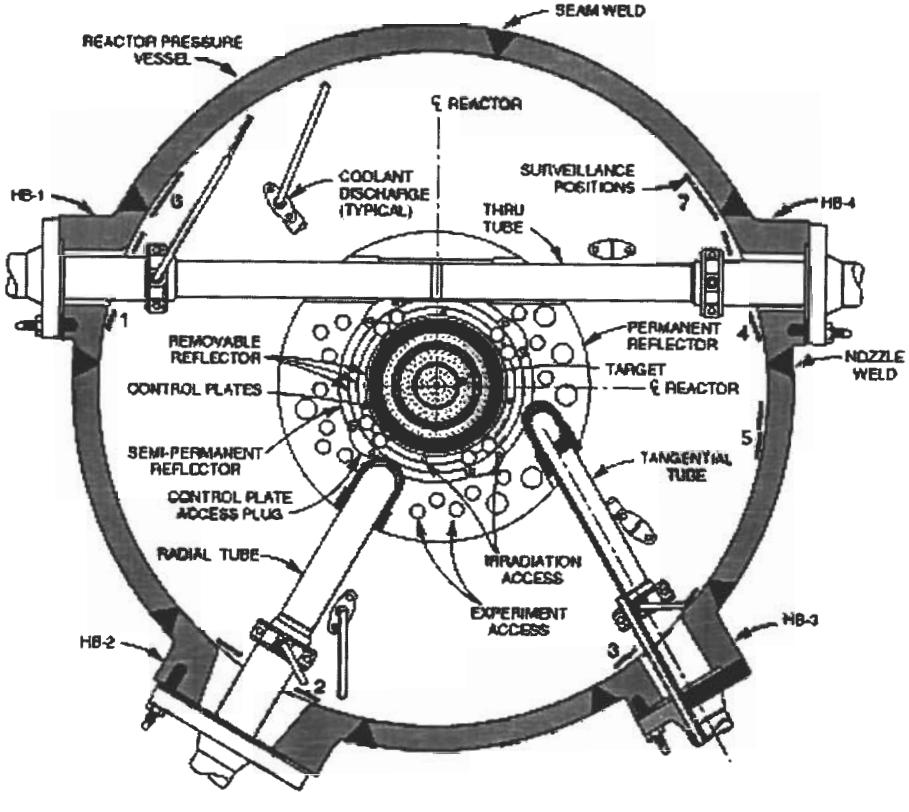
Overview of the High Flux Isotope Reactor

- History of design
- Purpose: Neutron scattering, isotopes, materials research
- Operating parameters
  T=110F, P=468psi, 16000 gpm
- Fuel - U_3O_8- Al Cermet
- PRA results & top contributors
  Internal: 5.7E-5/y
  External: 1.4E-4/y
  Wind, Seismic, Flow blockage



Sectional plan view of reactor core

HFIR Water Hammer Transient Scenario

Background of Event

- Source of concern – PISA due to discovery of 1965 memo when addressing another water hammer scenario related to swapping pumps
- Not a transient analyzed in USAR; pressure wave could impact primary pressure boundary and embrittled reactor vessel
- Dr. C. Samuel Martin (Ga. Tech) performing PNET modeling calculations on HFIR PCS

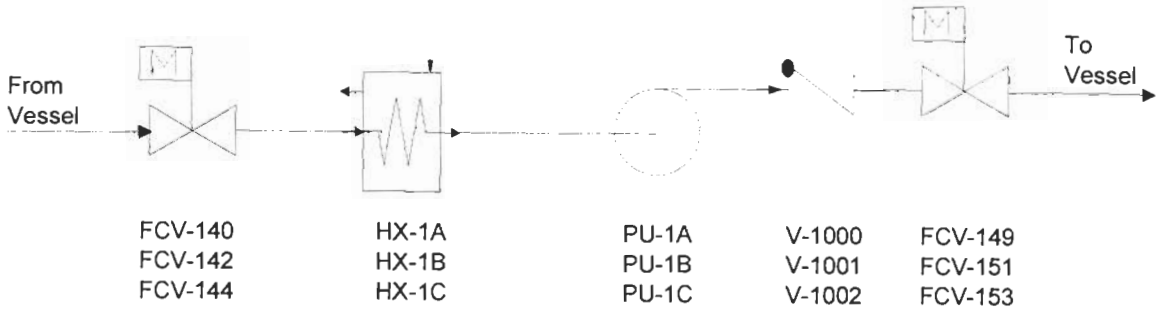
HFIR Water Hammer Transient Scenario

Definition of Event

- Normal operation on 3 main coolant pumps
- One pump spuriously trips
- Pump discharge check valve initially fails to close on reverse flow
- Check valve slams shut after full reverse flow is achieved creating pressure transient far above piping design pressure & TSR P-T limits
- Assume 70% plant availability

HFIR Water Hammer Transient Scenario

Path to Evaluate



- $P_{\text{WATER HAMMER}} = P_{\text{PUMP TRIP}} * P_{\text{CV FAIL ON DEMAND}}$

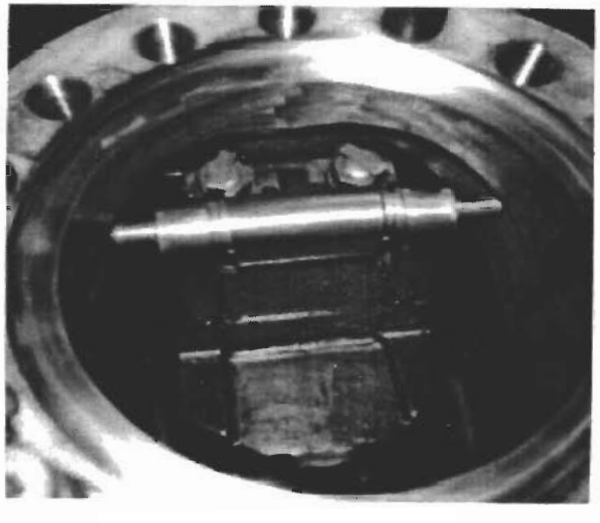
  Baseline failure rates: (3.5E-5 per hour) (2.7E-4 per demand)

- Causes for the check valve problem
  - trapped debris
  - corrosion buildup

HFIR Water Hammer Transient Scenario

Evaluation of Check Valve Failure Causes

1. Corrosion



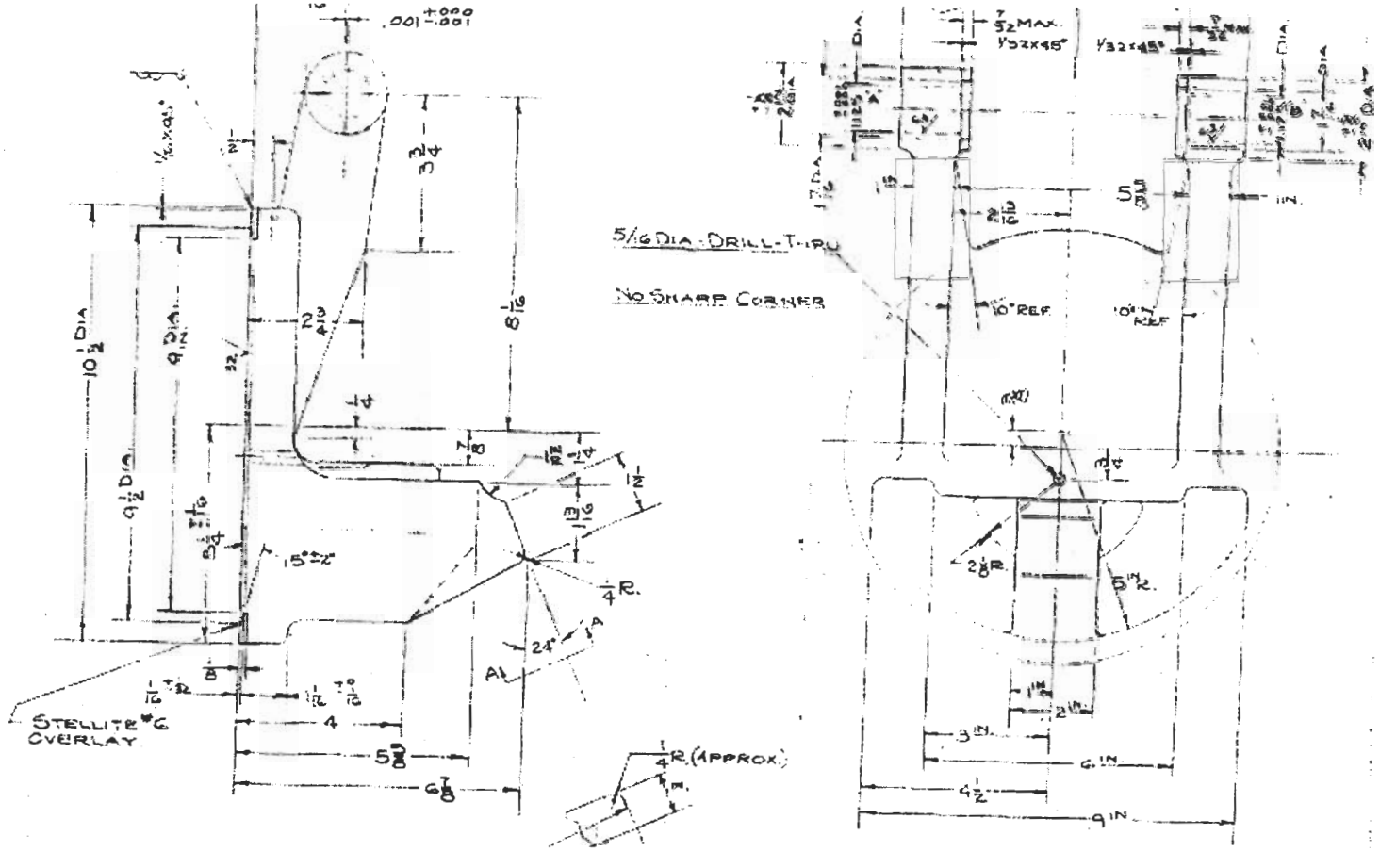
1988 QA Inspection

- Per NUREG/CR-5944, about 28% of all check valve failures are stuck open
- Corrosion Mitigating factors:
  - SST Valve with Stellite rod and bushing
  - Primary water chemistry (low pH & conductivity)
  - Low op. temp. means lower dissolved O_2
- Inspection photo shows excellent valve condition
- Factor of 0.1 assigned
- $P_{CORROSION} = 4.6E\text{-}6/y$

HFIR Water Hammer Transient Scenario

Evaluation of Check Valve Failure Causes

2. Debris



HFIR Water Hammer Transient Scenario

Evaluation of Check Valve Failure Causes
2. Debris

- Can originate within or from out of the system
- Valve geometry dictates debris must be 2.5”
- Area for debris lodging approx 5 in^2 out of 64 in^2
- Hydraulic force of reverse flow for 5000 gpm exceeds 500 lbf plus friction & disk weight
- Debris must pass through 5/8” dia Hx tubes
- Thermowells eliminated as contributor

HFIR Water Hammer Transient Scenario

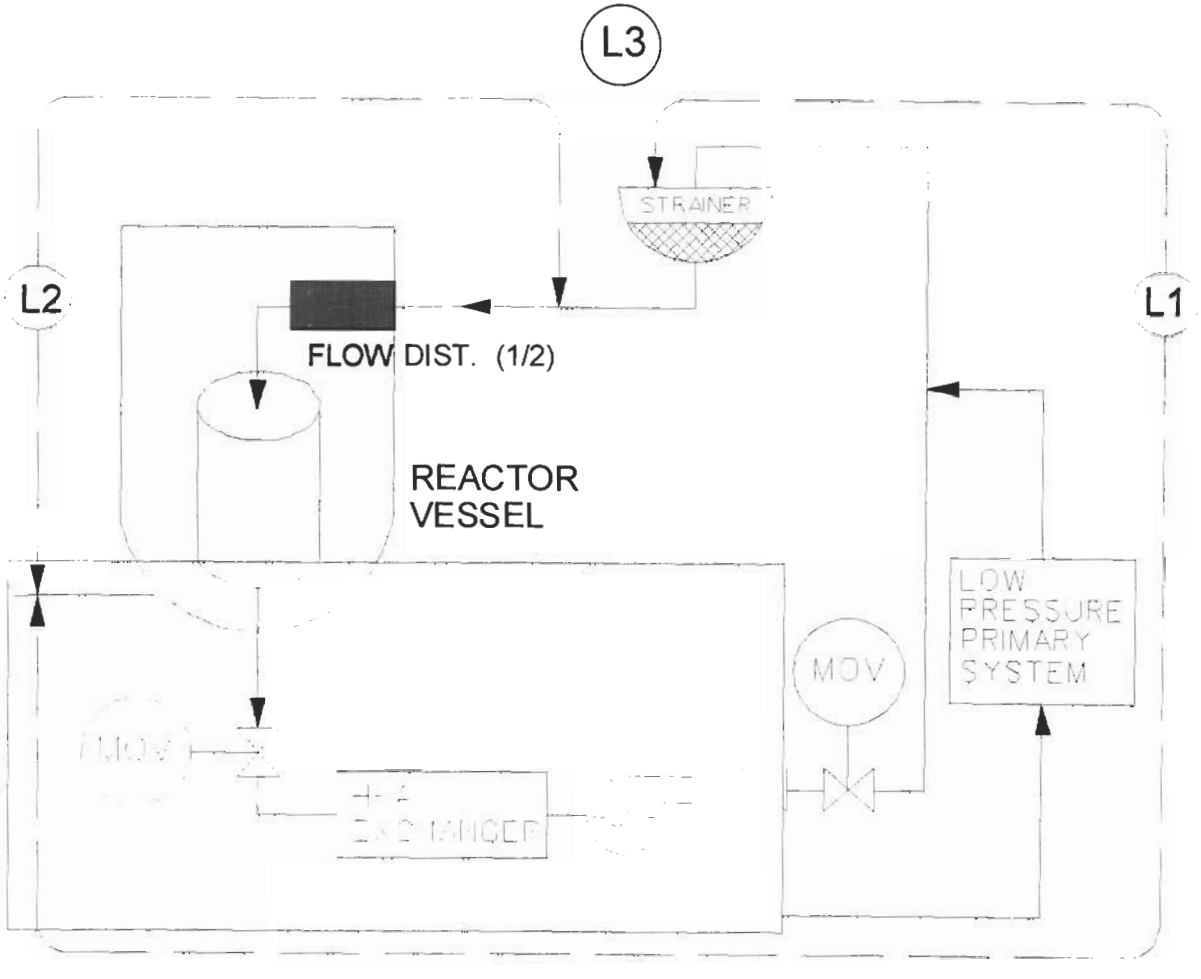
Evaluation of Check Valve Failure Causes

2. Debris

Relied on PRA flow blockage analysis

Debris must be in in the shaded area at startup

Hx tubes are 5.8-in dia.



HFIR Water Hammer Transient Scenario

Evaluation of Check Valve Failure Causes
2. Debris

- Equation considered the following
  - Probability of debris availability
  - Probability of debris size ≈ 2.5 in.
  - Probability of entering the leg of the tripped pump
  - Probability of passing through main heat exchanger
  - Probability of lodging in check valve and failing under force of reverse flow

- $P_{DEBRIS} = 3.8E\text{-}6/y$

HFIR Water Hammer Transient Scenario

Final Results

- Considering the effect of semi-annual TSR required functional CV test AND pre-startup CV operational test resets scenario probability to a per-cycle basis.

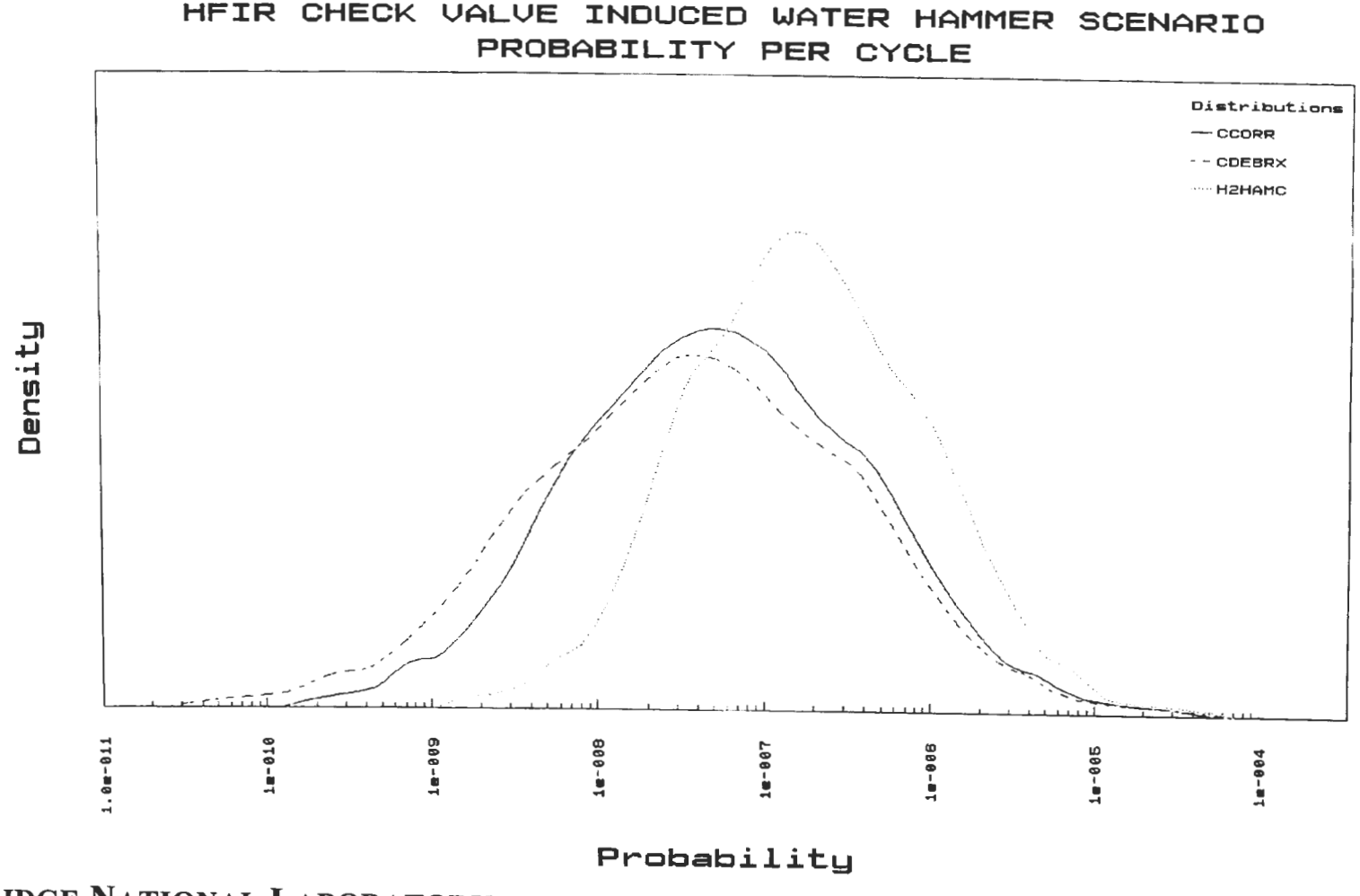
- **Final result:**

$$P_{TOTAL} = (P_{DEBRIS} + P_{CORROSION}) \times (24/365) / 0.7$$
$$= 7.8E\text{-}7 \text{ per cycle}$$

- Uncertainties modeled in RISKMAN data module with Monte Carlo equations. (5^{th} : 1.2E-7, 95^{th} : 2.5E-5)

HFIR Water Hammer Transient Scenario

Final Results – Uncertainty Analysis



HFIR Water Hammer Transient Scenario

Conclusions

- Very low probability. Uncertainty indicates possible credibility.
- Maintaining high water quality and continuing frequent testing ensures low valve failure rates
- Foreign object exclusion programs limit debris
- Follow-on stress analysis by ABS will update ANSYS HFIR primary piping model to ensure no increase in LLOCA probability