PASSIVE AND ENGINEERED SAFETY FEATURES OF THE PROTOTYPE FAST REACTOR (PFR), DOUNREAY.

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INTRODUCTION

PFR combines passive and engineered safety features. Natural circulation, a strong negative power coefficient, the decay heat removal system, and a fuel design able to operate beyond failure are all inherent and passive safety features of the PFR. The reliable shutdown system and the protection provided against SGU leaks are examples of engineered protection.

PASSIVE FEATURES

(i) Natural Circulation

Between 1975 and 1979 a series of natural circulation experiments were carried out on PFR. The results are shown in Figure 1 and demonstrate that under loss of pumped flow PFR can remove the decay heat (20 MW) from the core through natural circulation without exceeding normal operating temperatures.

Detailed interpretation of the data from PFR using the ASTEC code showed that the flow patterns were not straightforward and indeed within certain sub assemblies flow recirculation was occurring. This implied that even if the inlet flow to the sub assembly was totally blocked heat could still be removed. Further calculations confirmed this conclusion. See figures 2-5.

(ii) Power Coefficient

PFR has a strong negative power and isothermal temperature coefficients.

One implication of this is that were PFR to lose forced coolant flow in its primary circuit and fail to trip, an exceptionally low probability event, the coolant outlet temperature would rise initially but plateau then decrease as the reactor power decreased as a result of the power and temperature coefficients. For PFR the mean coolant outlet temperature under these circumstances is less than saturation, ie large scale coolant boiling would not occur.

A second implication is that were PFR to lose its heat sink, again without tripping, the reactor would shut down at an average pool temperature of between 600 and 650 deg C.

(iii) Decay Heat Rejection

In PFR decay heat can be removed via the secondary circuits and the steam plant or via a decay heat rejection (DHR) system. The DHR system is comprised of coils in the upper part of the intermediate heat exchangers through which NaK passes and is piped to air heat exchangers on the side of the reactor hall. The system is almost completely passive, there are no valves, no pumps and no trace heating.

(iv) Failed Fuel

There have been 21 separate fuel failure incidents in PFR (in some cases several pins have been involved). PFR allows operation to continue with failed fuel in the core subject to the delayed neutron signal being below previously determined limits (several hundred cm^2 equivalent recoil area).

The failures typically behave as gas leakers for between 1 day and more than 3 weeks before emitting delayed neutron precursors. Fuel has remained in the core until the next planned shutdown, typically 5-30 efpd after first providing a delayed neutron signal.

Examination of the fuel shows only very little sign of fuel loss and no evidence of propagation of failure from one pin to adjacent pins

At the end of DFR's life a series of experiments were carried out using PFR fuel. In these experiments sub assemblies were subjected to load boiling (downstream of a partial plate blockage in the fuel bundles) and to bulk boiling (throttling of the inlet flow to the sub assembly) for many hours. After each period of boiling the experiment was allowed to remain in the reactor until the completion of the run. Whilst boiling led to fuel failures there were no signs of a 'sub assembly incident' developing through further blockage.

ENGINEERED SAFEGUARDS

(i) Shutdown system

Shutdown systems have to be reliable. PFR's absorber rods have been called upon approximately 3000 times without once failing to insert all their reactivity.

It is necessary to test the rods once per week to ensure that build up of aerosol does not interfere with performance.

In order to provide diversity the PFR rods have a spectron of ages, it is not permitted to change all the rods at once.

(ii) Steam Generator Leak Protection

Following the large under sodium leak in superheater 2 in 1987 PFR thoroughly reviewed its engineered safeguards related to sodium/water reactions.

Figure 5 shows the outcome of that review. In particular it was necessary to provide diverse designs of bursting discs in the effluent system, to install a very high reliability isolation system between the steam drums and the evaporators, and to install a working under sodium hydrogen detection system.

SUMMARY

Experience at PFR demonstrates the worth and potential of a range of passive and engineered safeguards.

FIGURE 1

Indicated core temperature rise from central sub–assemblies during natural circulation experiments

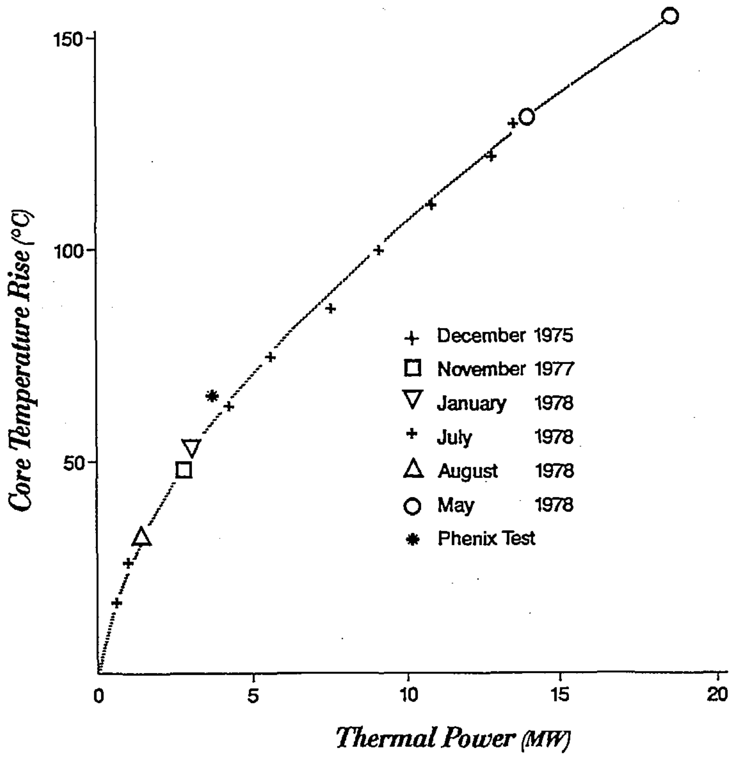

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FIGURE 2

Convective flows within a fuel subassembly (schematic)

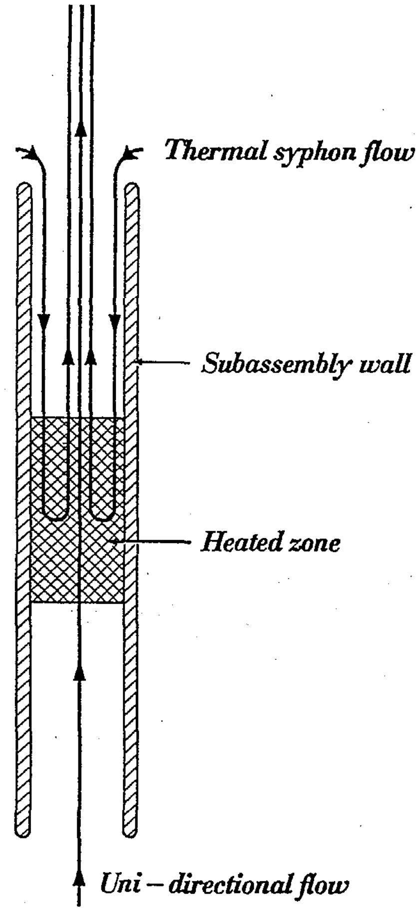

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FIGURE 3

Peak coolant temperature versus forced flow rate for a radial breeder fuel subassembly generating 170 kW

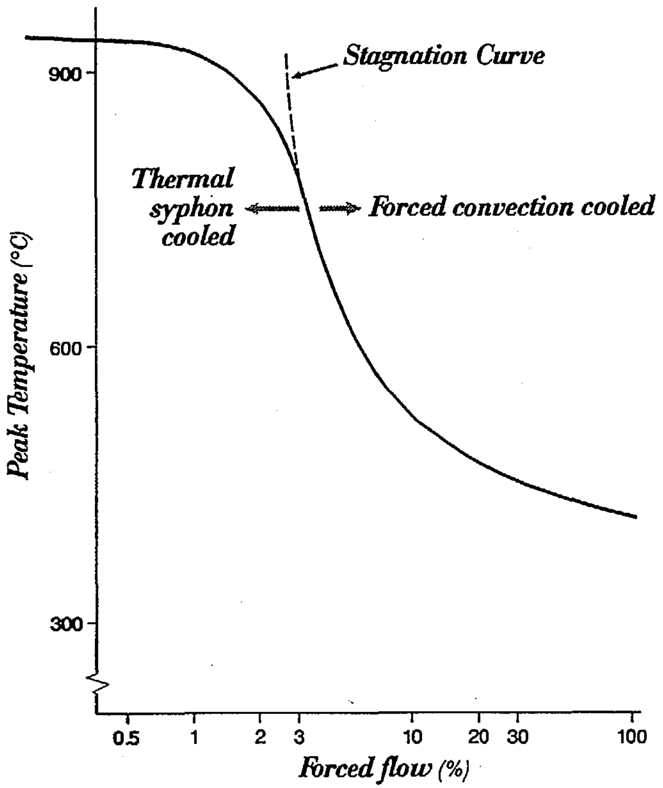

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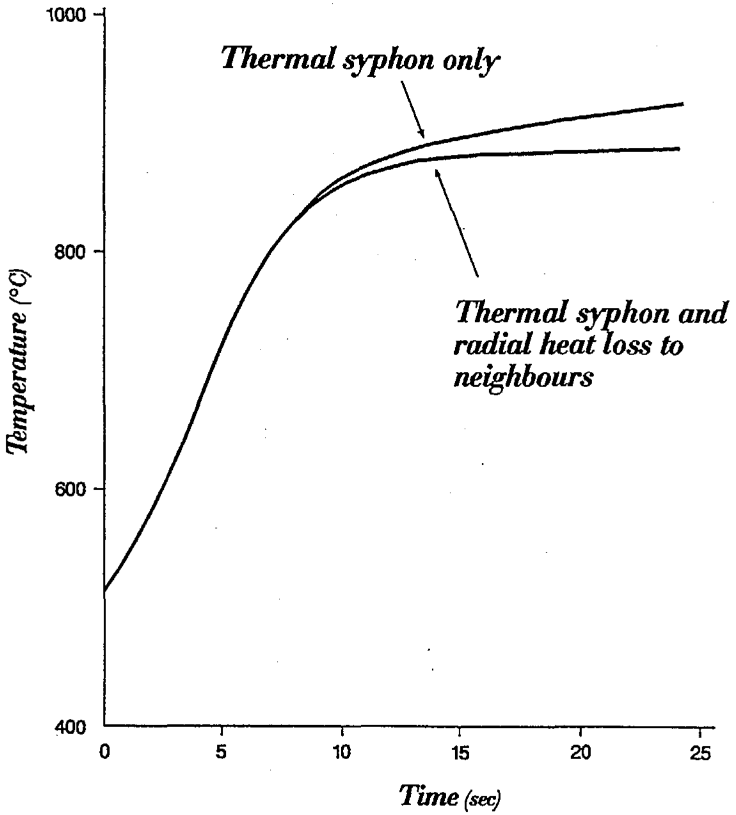
FIGURE 4

Peak temperatures for a blocked core subassembly generating 300kW of decay heat



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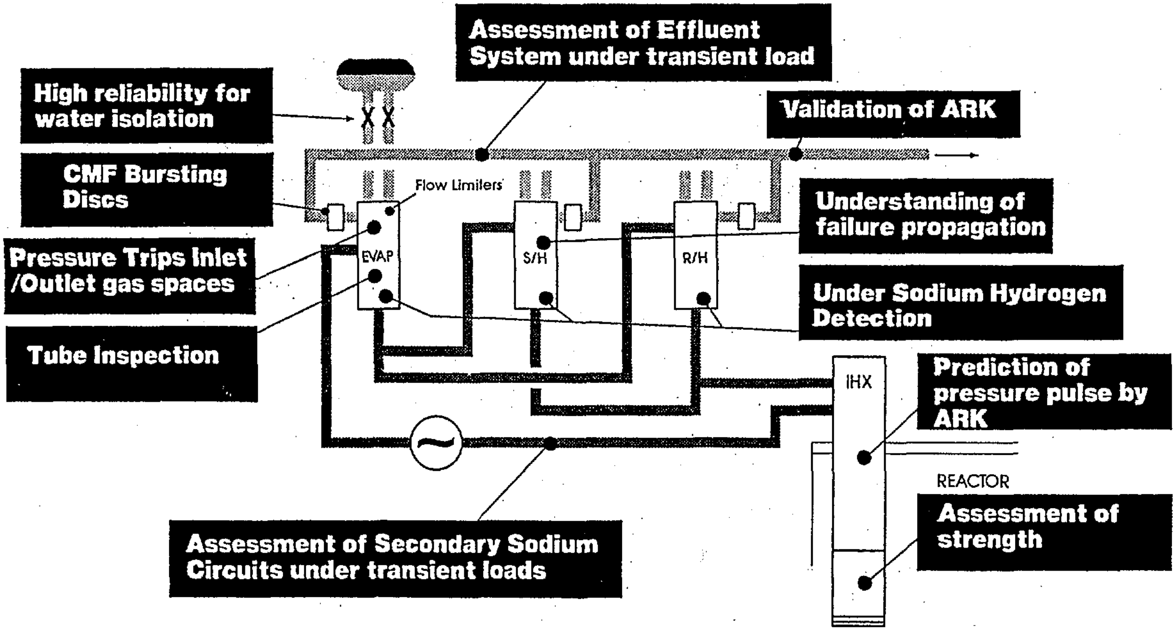
Superheater II Follow Up



Assessment of Effluent System under transient load

High reliability for water isolation

Validation of ARK

CMF Bursting Discs

Understanding of failure propagation

Pressure Trips Inlet /Outlet gas spaces

Under Sodium Hydrogen Detection

Tube Inspection

Prediction of pressure pulse by ARK

Assessment of strength

Assessment of Secondary Sodium Circuits under transient loads

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FIGURE 5