IWGFR Specialists meeting "Heat and mass transfer in the reactor cover gas"

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CONTENTS

1. Introduction

In the development of reactor systems, if cost penalties are not too great, direct testing of reactor components is usually undertaken. When the financial burden of such direct testing becomes too severe, ensuring the adequate performance of reactor components entails the use of proven design methods.

The establishment of such methods involves:

a. the carrying out of basic generic work to determine the physical phenomena and physical principles involved in component performance.

b. the use of this generic data in the generation of mathematical models by means of which reactor situations can be assessed.

c. the validation of these models against experimental data (produced at a reasonable cost) in fairly complex situations representative of the reactor configurations.

This paper describes the present position, in the UK, in respect of the development of such design methods for the CDFR above sodium environment.

2. Design features

The layout of the upper structure of CDFR is as shown in Fig 1. The general disposition of the reactor is such that the reactor cold pool (at a temperature of 370°C) is separated from the hot pool (at 540°C) by an intermediate plenum. The cold pool is contained beneath the intermediate plenum deck plate, as shown. The intermediate plenum and the reactor hot pool are contained within an inner tank, the upper wall of the primary tank (above the deck plate) being open to the reactor cover gas.

In order to maintain reasonable stress levels within the roof membrane of the primary vessel, both during steady state operation, and during certain specified fault conditions, this membrane is cooled over its upper surface, and insulated from the hot cover gas environment over its lower surface.

Membrane cooling is achieved by a flow of nitrogen at an inlet temperature of 25°C. The nitrogen is fed through a ducting system within the roof structure, being eventually forced on to the upper surface of the roof through a series of nozzles positioned 0.15 m above the membrane (see Fig 2). After cooling the roof, the gas is drawn off through a large collection duct, and passed to the roof cooling circuit heat exchangers. The cooling extends not only over the roof membrane itself, but also over the conical support feature attached to the primary vessel.

The roof membrane is insulated on its underside by a system composed of packs of insulation. Each pack consists basically of five light gauge stainless steel sheets, spaced 20 mm apart. The packs are supported by finned edge supports clipped to the walls of the penetrations provided for IHX and pump, access and removal. The finned structure, as well as providing support also acts as a seal preventing convective gas flow within the insulation system.

The primary vessel wall temperature is of the order of 70°C at the roof/wall junction, and of the order of 370°C at the deck plate wall junction. To ensure adequate stress levels in the primary vessel wall and at the roof/wall junction, it is necessary to control the temperature gradients along the wall. This is achieved with a wall insulation system within, and a cooling system outside, the primary vessel as shown in Fig 1.

The wall insulation, covering the area between the deck plate and the roof, consists of vertical packs of insulation 9 m high and 2 m wide. Each pack comprises 20 corrugated light weight stainless steel sheets contained within plane front and back plates. Adjacent sheets are maintained at a spacing of 10 mms by the insertion between them of 0.1 m thick dimpled foil. Outside the primary vessel there is a guard vessel which itself lies within the reactor vault. Removal of heat passing through both the wall insulation, and the guard vessel is accomplished by the cooling circuit over the conical support feature, and further cooling circuits lining the surface of the vault. To control the thermal gradients within the primary vessel wall, it is necessary to curtail gross convection between the primary and guard vessels; and between guard vessel and vault. This is achieved by the use of baffles between primary vessel, guard vessel, and vault as shown in Fig 1.

To permit the insertion and removal of a number of components such as IHX's and pumps, there is a variety of penetrations through the roof structure. Some of these penetrations are insulated; others are not. A typical insulated penetration round an IHX is shown in Fig 3. Cooling for the penetration system is provided by the ducted nitrogen system used for the plane roof areas.

3. Heat and mass transfer throughout the above sodium environment

3.1 Convection heat transfer

Convective heat transfer within the primary vessel may be regarded as taking place from the pool horizontal surface, and the inner tank vertical surface, to the cover gas; and thence, from the cover gas to the roof insulation, wall insulation, and penetrations. Turbulent convective processes within the cover gas will ensure that the bulk gas temperature will be essentially constant everywhere, except for regions in the annular space between the inner tank and wall insulation.

Heat transfer from the pool and inner tank to the cover gas requires the determination of the relevant heat transfer coefficients. Correlations for these coefficients have been established using both published data, and data deduced from models in which heat is transferred between,

a) horizontal surfaces at different temperatures.

b) vertical and horizontal heated surfaces, to cooled vertical surfaces, the thermal input being variable over the heated surfaces.

Heat transfer to the hot faces of both the wall and roof insulants from the cover gas can be established by correlations similar to those mentioned above. In addition however, a further convective mechanism works within the roof and wall insulation. Since the wall and roof insulation are structures in which the cover gas can move, additional heat is transferred by convective gas flow arising from,

a) local motion within the pack as a consequence of temperature differences between adjacent surfaces.

b) a gross movement of gas into and out of the insulant arising from temperature differences between the insulant as a whole, and the cover gas itself.

Methods for the prediction of such heat transfer processes, based upon porous solid approximations have been developed for use in gas cooled reactor design. The relevant data for the implementation of such methods (e.g. insulant permeabilities, local thermal conductivities etc) have been measured and used in CDFR insulation studies. In order to check the validity of the calculational methods [as mentioned in section 1(c)] a large scale model of the wall insulant, based upon manufactured wall insulation packs, has been thermally tested in air.

The remaining mechanism by which convective heat transfer within the primary vessel takes place is by way of the penetrations. Generic work has been carried out on idealised penetrations

a) of annular geometry

b) comprising open cylindrical tubes

Temperature distributions and heat transfer coefficients have been measured for a variety of penetrations. The work has established that thermal syphon systems, either stationary or time dependant, can be set up within annular penetrations. Within open tube penetrations, however, the phenomona, though very turbulent appear to be stationary.

Calculational methods have been developed for the open tube type penetrations; methods for the determination of annular penetration performance are under development.

3.2 Mass transfer

The heat transferred by mass transfer processes occurring in the system is complicated by the prescence of aerosols within the cover gas. Aerosol generation arises whenever saturated gas, at an elevated temperature, is suddenly subjected to an appreciable temperature drop. Temperature differences of sufficient magnitude to cause aerosol generation may exist between pool and cover gas; cover gas and wall/roof insulation; and during gas flow into and out of penetrations.

Evaporation from the pool surface will be influenced by the aerosol density within the cover gas. For those surfaces over which the cover gas can flow, condensation of sodium vapour will occur on surfaces cooler than the adjacent gas. In addition, these surfaces will be subject to heat transfer phenomena arising from the plating out of aerosols. Thus on surfaces within penetrations, insulation packs etc., as well as on those surfaces bounding the cover gas space proper, enhanced heat transfer is likely due to condensation and aerosol deposition.

Experimental investigations of the transport of water vapour along penetrations, and its condensation on the penetration walls, was carried out in conjunction with the heat transfer studies on penetrations, mentioned in section 3.1. Theoretical models of the process have been set up and reasonable agreement between theory and experiment has been reached.

As can be seen from the above discussion, knowledge of aerosol concentration within the cover gas is of importance. Theoretical studies on aerosol generation, growth and decay are in progress, and have been for some time. Basic generic experimental work in connection with the growth and decay of aerosols in an air/water system has started in order to provide experimental support for the theoretical studies. Further experimental work, concerning the nature of the aerosols generated in a sodium/argon system, under a variety of thermal conditionsl is being formulated.

3.3 Radiative heat transfer

The third component of importance in the flow of heat within the primary tank, is radiation transfer. Significant radiative transfer takes place from the pool to the roof insulation; from the inner tank to the wall insulation; and within the roof and wall insulation packs themselves. The amount of radiation transferred depends upon the emissivities of the surfaces involved in the transfer, and the transfer characteristics of the aerosol laden medium between them.

Theoretical studies and experimental measurements have been carried out in connection with the emissivity of clean sodium surfaces. Good agreement between theory and experiment has been achieved. The emissivity of a range of stainless steels used in fast reactor technology, under a variety of surface conditions, has been measured. Since the prescence of sodium on surfaces is likely to appreciably affect surface emissivity, measurements have been, and are continuing to be, made of sodium affected steel surfaces.

The transmission of radiation through aerosol clouds has been studied theoretically. Measurements of the radiation transmission factor have been inferred from measurements on a sodium/argon rig, though there is no detailed knowledge of the characteristics of the aerosol within the rig. Experimental work is under way to study the transmission of radiation in sodium aerosols of known size and density.

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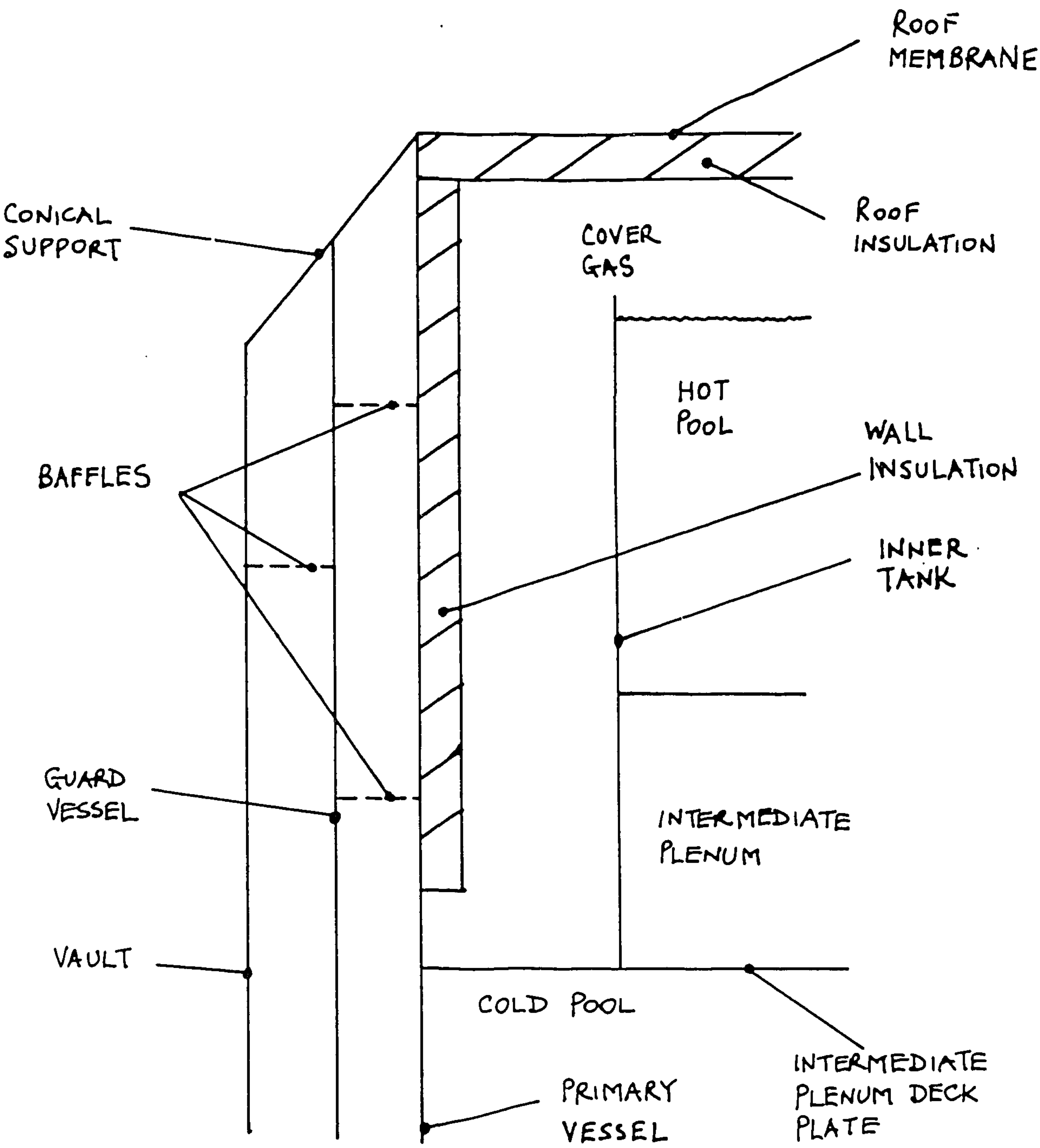


LAYOUT OF THE REACTOR UPPER STRUCTURE

FIG. 1

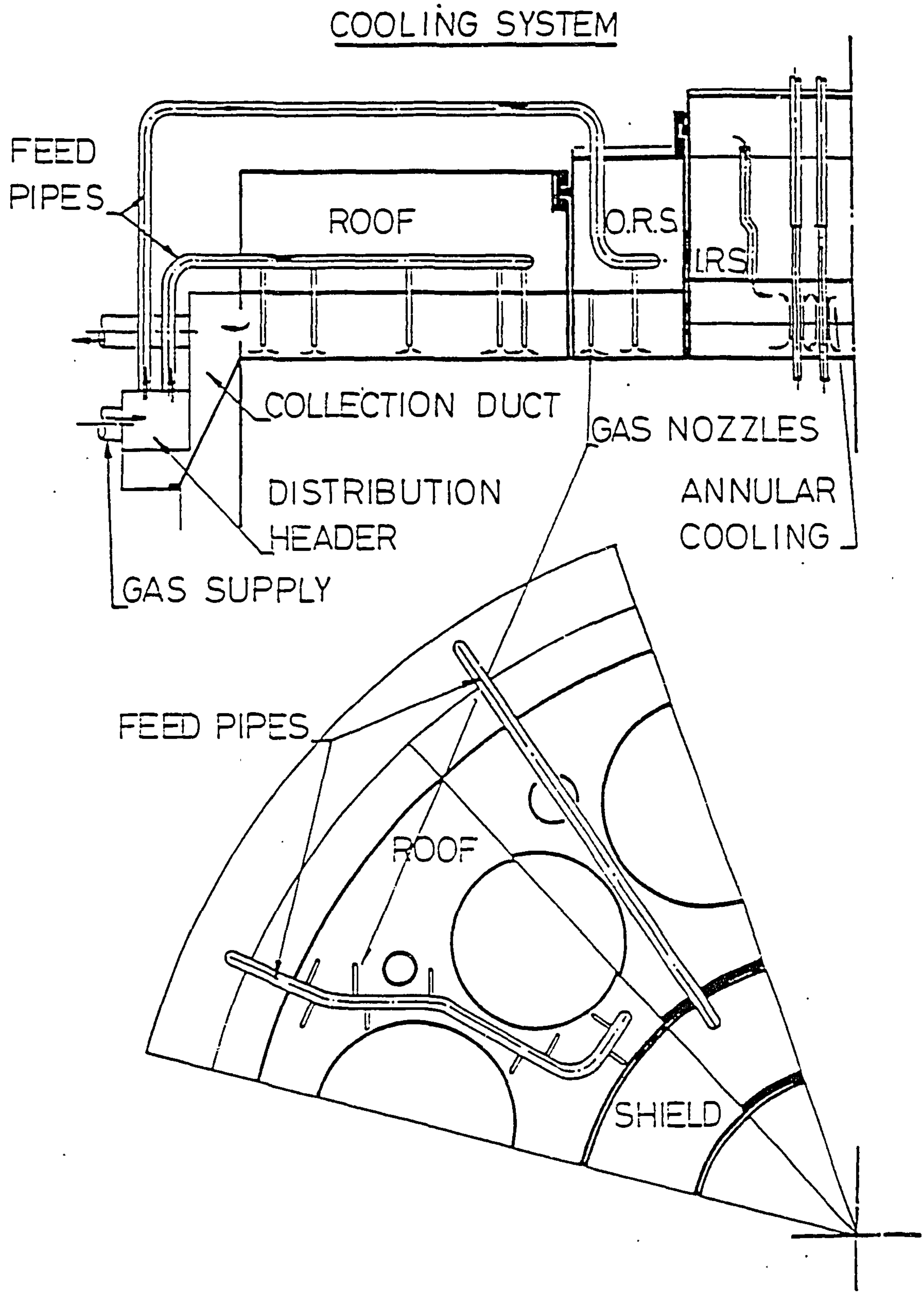
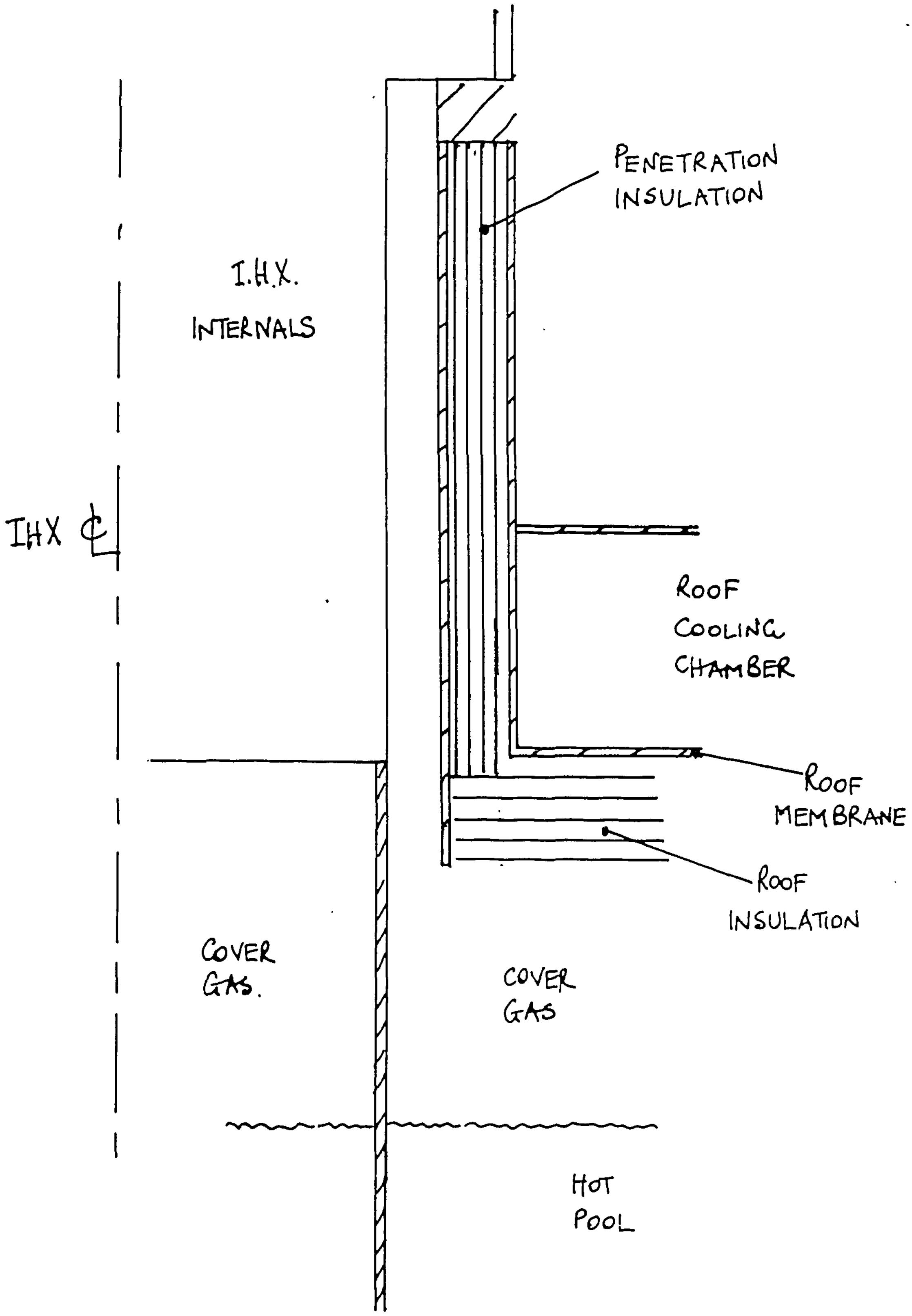

COOLING SYSTEM
FEED PIPES
ROOF
O.R.S
I.R.S
COLLECTION DUCT
GAS NOZZLES
DISTRIBUTION HEADER
ANNULAR COOLING
GAS SUPPLY
FEED PIPES
ROOF
SHIELD

FIG. 2



I.H.X PENETRATION LAYOUT

FIG. 3