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AN OUTLINE OF THE CRBRP REACTOR INSTRUMENTATION SYSTEM

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## CRBRP REACTOR INSTRUMENTATION

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## 1.0 INTRODUCTION

This paper outlines the design of the principal reactor instrumentation systems associated with the Clinch River Breeder Reactor Plant (CRBRP). In the case of the systems external to the vessel, the design is largely conventional and relies heavily on experience arising from the design of the Fast Flux Test Facility (FFTF). In the case of the In-Vessel systems, the design process was the vehicle for an active debate as to the cost-benefit to be obtained from in-vessel instruments.

A brief account is presented of the resulting conclusions about the importance and function of the in-vessel instrumentation in a commercial LMFBR.

The system design activities reported in this paper were carried out by Westinghouse, General Electric and Atomic International under the direction of the CRBRP Oak Ridge Project Office.

## 2.0 FUNCTIONAL REQUIREMENTS OF IN-VESSEL INSTRUMENTATION

The three principal functional requirements of control, safety and surveillance were studied extensively as part of the conceptual design process. Alternative in-vessel instrumentation configurations were reviewed ranging from the FFTF arrangement of 3 dry thermocouples and a flow meter over every fuel assembly to EBR II type arrangements where only occasional channels were monitored with thermocouples in tubes (originally dry, now wet). Out of these activities the thermocouples have emerged as the main source of reactor information. The absence of a practicable in-core flux monitor and the relative inaccuracy and installation problems of flow meters have eliminated them from consideration.

Interest has tended to focus on alternative configurations and installation details of the in-vessel thermocouples. Although final choices have not been made the likely pattern of usage is now emerging. The following proposals for functional dispositions of core exit thermocouples have been made at this time.

### Control

About 27 thermocouples will be used to provide temperature regulating feedback for the Reactor Rod Control System. These thermocouples are located on an array of fuel assemblies selected because they show a minimum change in output between refueling cycles.

Signals from these thermocouples will be averaged and used in the reactor control system. A reject circuit will automatically remove out-of-limit signals from the system down to a minimum acceptable level for automatic control in the region of 12. Operator control action will of course still be feasible with smaller numbers of thermocouples in operation.

## Fuel Assembly Surveillance

Surveillance of core fuel assemblies is required to confirm the existence of calculated margins, to meet licensing requirements, to show the availability of additional burnup margins arising from uncertainty in cladding temperatures (and any consequent changes required in refueling procedure) and finally to provide surveillance of long term trends in core behavior.

Two systems are currently under discussion: firstly, a whole core system where one thermocouple would be provided on every fuel assembly channel; secondly, a sector coverage of selected channels which would provide indication of whole core behavior from symmetrical considerations.

Figure 1 shows the reduction in exit temperature design uncertainties that can be achieved by the use of an increasing number of symmetrical temperature measurement positions in a typical design calculation.

It is seen that a reduction of the order of 50°F is possible by the use of four symmetrical positions. The corresponding reduction in maximum cladding temperature can be of the order of 100°F which in turn would make available an increase in burnup of up to 70,000 MWD/Ton.

Although these figures represent an upper bound, there is no doubt as to the cost benefits arising from the use of fuel assembly core exit instrumentation.

With regard to the extent of coverage the choice would seem to lie between three sector coverage and complete coverage. Three sector coverage

provides virtually as much savings as would be possible by means of complete coverage. On the other hand, complete coverage would both avoid problems arising from unanticipated changes in fuel loading which destroy the original symmetry and also minimize requirements for maintenance arising from the failure of thermocouples.

At this moment the predominant view favors complete coverage of fuel assemblies.

#### Blanket Assembly Surveillance

There are three rows of blanket assemblies surrounding the core. The inner of these rows is of major importance as misshuffling of blanket elements in this row could lead to fuel melting taking place in certain highly rated pins. As a consequence, the provision of thermocouples located at the exit of the inner row of blanket assemblies is under consideration.

The relatively low flow rate and the existence of extensive cross flow reduce the accuracy of thermocouples located in the blanket to values far less than that of those installed above the core. For this reason, the installation of more than occasional sample thermocouples at the exit of the outer rows cannot be justified.

#### Safety

Extensive analysis of the consequence of both local blockages and whole core incidents have shown that thermocouples are ineffective for preventing damage, following such incidents.

In the case of local blockage, the thermocouple is relatively insensitive and blockage is best prevented by means of a reactor design which avoids features which could lead to blockages.

In the case of whole core incidents, the thermocouple is relatively slow in operation and such incidents are better protected against by the use of flux and flux/flow instrumentation.

As a consequence, no use is made of core exit thermocouples in the Reactor Protection System.

## 2.2 In-Vessel Instrumentation Design

This In-Vessel Instrumentation System consists of an array of thermocouples and level detectors located in the Upper Internals System. Figure 2 shows the location of this equipment. The Upper Internal System is a single structural unit consisting of arrangements of flow chimneys, control rod supports and fuel assembly hold down units. It is connected to the intermediate of three eccentric rotating plugs by means of four jacking posts. The jacking posts allow the upper internal system to be raised so that the plugs can be rotated during refueling.

The jacking posts also provide a conduit by means of which the thermocouple thimbles are connected through the head to their location above the core and blanket. This arrangement is shown in Figure 3. The thimbles containing the level detectors are connected directly to the rotating plug.

The Upper Internals structure has presented a sophisticated design problem arising from the wide steady state ranges of temperature, the steep thermal transients following reactor trips and the thermal cycling (or stripping) effects resulting from the intermixing of streams of sodium at widely differing temperatures from adjacent core positions.

To accommodate these thermal cycles, structures located in the vicinity of steep thermal gradients and thermal stripping are clad in inconel. The instrument posts for instance, consist of a central stainless steel pillar to which inconel cladding is held by pins. The thermocouples themselves are located within steel thimbles. The tips of the steel thimbles are held within inconel thimbles to withstand thermal stripping.

Although these thermocouples are now dry, means are being sought for improving their response and thus the controllability of the reactor. Alternatives include the use of high conductivity filler media, machined tips and wet mounting.

Reactor vessel sodium level will be measured by five induction type level detectors. There are four short and one long detectors mounted in four plugs located symmetrically within the reactor vessel - two plugs are located on the intermediate rotating plug and two are located on the large rotating plug. Three small detectors are used in the protection system with a fourth unit as a spare. The long level detector is used to monitor sodium filling operation and sodium level during refueling. Figure 4 shows the mounting arrangements for the level sensors within the plugs. The sensors are contained within dry thimbles which are seated to the tops of the plugs by conax type fittings. An outer tube supports the thimble and associated heat shielding and radiation shielding fittings.

### 3.0 FLUX MONITORING SYSTEM

The CRBRP flux monitoring system is a conventional ex-vessel 3 range system based on the FFTF design. The capability to use commercial flux monitoring systems operating at ambient temperature is one of the advantages of conventional pipe and vessel primary circuits. Figure 5 shows the layout of the principal items of equipment included in this system. The detectors are located in three sets of three thimbles located within the Reactor Vault. The thimbles will be surrounded by graphite moderator, provided with gamma shielding and neutron shielding for backscatter from the reactor cavity wall. The thimbles are serviced from the Head Access Area where junction boxes and preamps are located. From these positions cabling runs directly to the Central Control Room where the instrument racks are located and from where connections are made to the Plant Protection System, to the refueling control room in the Reactor Service Building and to the Data Handling System. Figure 6 illustrates the instrument range coverage provided by the three channels. Figure 7 shows the principal components of the three channels. These are further described as follows:

#### Source Range

The Source Range channels use high sensitivity (30 cps/nv)  $\text{BF}_3$  proportional counters to sense neutron flux over the range  $4 \times 10^{-1}$  to  $10^4$  nv (equivalent to a power range of 130 milliwatts to 3.25 KW). Available counters considered for this application include the WL-7429A. It is anticipated that when the reactor is loaded with fresh fuel and fully shutdown this counter will provide a count rate of 10 cps.

### Wide Range

The Wide Range channels are U235 fission chambers to sense neutron flux over 10 decades from 2 to  $10^{10}$  nv. Each wide range channel will consist of a fission counter and electronics counting portion (for the lower six decades), an MSV portion (for the upper seven decades) and a 0-125% reactor power linear d-c portion for accuracy and fast response in the power range. This latter linear portion will provide outputs to the Secondary Shutdown System of the Plant Protection System for initiating protective trips.

### Power Range

The Power Range uses three compensated ion chambers and signal conditioning electronics covering the 0-125% reactor power range. This channel drives fast responding linear d-c amplifiers which provide output to the Primary Shutdown System of the Plant Protection System (PPS). The PPS provides buffered outputs for the Plant Control System, desk indicators and the data logging system.

### Overall Design

The equipment was designed to RDT standards developed in the course of the FFTF project.

Those components of the Flux Monitoring Systems which form part of the Reactor Protection System have stringent reliability requirements placed on them. The total array of Reactor Protection Systems are being designed to meet a requirement that the probability of exceeding 10CFR100 guideline values for the release of activity to the general public be less than one

change in a million per year. An unavailability goal of  $10^{-4}$  has been established for the Primary Reactor Shutdown Systems and  $5 \times 10^{-4}$  for the Secondary Shutdown System. These numbers have been further split between the components of these systems. As a consequence, the linear power drawers for both wide range and power range are being designed for an unavailability rate of  $20 \times 10^{-6}$  per hr. In support of this program, twelve drawers will be purchased and tested for five years prior to reactor operation to demonstrate the designed reliability for this and other electrical and mechanical components of the protection system.

#### 4.0 FUEL FAILURE MONITORING

A fuel failure monitoring system provides for both the detection and location of leakers in the core and blanket. Detection is carried out by monitoring the gamma activity levels of specific fission gases in the cover gas by means of single channel count rate circuits.

Signals from this germanium detector are also supplied to a multi-channel analyzer which displays the amount of activity from most of the fission gases. By "characterising" the gases in this way, information is provided as to the age and burnup of the leaking pin.

Location of failed fuel elements is provided by the use of individual tag gases in all core and blanket elements. Specific ratios of stable isotopes of Xenon & Krypton can be trapped in a cryogenic bed and identified by the use of a mass spectrometer.

This location system will be activated when the cover gas monitoring system indicates the presence of a change in activity level in the cover gas. It is anticipated that this system will be able to differentiate between 5 fuel elements leaking gas at the same time. Various techniques are being investigated to increase the number of simultaneous failures which can be differentiated. Tradeoff studies will determine the combination of tag gases to be used.

Presence of exposed fuel or fuel particles in the sodium will be alarmed by means of conventional  $\text{BF}_3$  delayed neutron monitors located adjacent to the vessel outlet pipes.

## 5.0 LEAK DETECTION

The Reactor Vessel is contained within a guard vessel itself supported within the inerted Reactor Cavity. The guard vessel will be monitored for sodium leakage by means of radiation monitors, aerosol detectors and conventional contact detectors. Two types of aerosol detectors are currently being developed by Atomics International under an ERDA contract as part of the leak detection system. The first of these, a differential pressure detector, measures the pressure difference across a filter through which a sample of the atmosphere under surveillance is drawn. The presence of sodium hydroxide causes the filter pressure drop to rise and so give indication of the presence of a leak. This system has the advantage that where the filters are located in an accessible area they can be removed and the presence of sodium confirmed by chemical analysis.

The second type of detector is a sodium ionization detector. This utilizes the low ionization potential of sodium (5.12V) which allows its presence to be clearly differentiated from that of other gases present in the containment (e.g. N<sub>2</sub> 14.54 V or Argon 15.76 V).

In this detector, the sample gas is drawn between the electrodes of a simple diode whose anode is maintained at the ionization potential. The anode current is measured and provides indication of the presence of sodium. This detector is extremely sensitive and can detect aerosols containing  $10^{-12}$  gm/cc of sodium.

A selection between these two alternate systems will be made in the coming year.

## 6.0 OTHER RELATED HEAT TRANSPORT INSTRUMENTATION

A number of other instrumentation systems located in the Primary Heat Transport System piping play an important part in the operation of the reactor.

### Temperature Measurement

Two double element Resistance Temperature Detectors (RTDs) will be located in separate pockets in each hot leg between the pumps and the Intermediate Heat Exchanger (IHX). Two similar units will be located in each cold leg at the inlet to the reactor vessel.

The RTD instruments will be used to calibrate the Permanent Magnet (PM) flowmeters and the core exit thermocouples when the plant is at a steady state condition. Both hot and cold leg sensors are required to calibrate the flowmeter, while calibration of the core exit thermocouples can be achieved with only the hot leg RTDs.

### Flow Measurement

Permanent magnetic flow meters will be located in the cold leg pipes. These instruments are used to provide Power/Flow Trip functions to the protection system as well as regulating signals for plant control.

These flow meters will be similar in design to those used in FFTF.

A permanent magnet will be mounted so as to straddle the pipe. Three pairs of electrodes will be welded to the pipe and will be used in the three redundant protection channels and for providing a flow control system for plant operation.

### Pressure Measurement

Pressure in the sodium system will be sensed by a system consisting of an isolating chamber welded directly to the pipe. Inside this chamber a stainless steel diaphragm isolates the sodium from the NaK which is used as a transmission fluid to operate the remotely located pressure sensor. The actual pressure sensor is a strain gauge type transducer which will provide an electrical signal to the protection and control systems. These pressure sensors will be located at the IHX inlet and outlet and at the reactor inlet piping.

## 7.0 CABLING ARRANGEMENTS FOR REACTOR VESSEL INSTRUMENTATION

Figure 8 shows the complete layout of equipment in the head access area. The principal complicating factors are the use of three eccentric rotating plugs for refueling, the two diverse rod shutdown systems and the criteria that present designs should allow for the possible subsequent installation of an inner containment barrier directly over the Head Access Area within the main containment.

As a result, all cables coming into the head access area do so through penetrations which can be sealed by the use of transit frames. Specially designed elongated termination boxes provide facilities to meet separation criteria. The cables leave the bottom of these termination boxes and enter under flow channels which circumscribe the Head Access Area. The cables leave these channels to enter either three removable bridges or alternatively cable ways which carry those signals which cannot be disconnected. The three removable bridges carry cables which are required for plant operation but not for refueling. Systems supplied by this means include the control drive and most of the in-vessel instrumentation. Plugs attached to both ends of the cables carried by the bridges allow the complete bridges to be expeditiously disconnected and removed by the over head containment crane prior to refueling.

The cable ways transmit power and signals between the rotating plugs while the plugs are in motion. Systems fed by this means include the plug drive systems, refueling equipment, riser seal leakage monitoring systems and the head heating system. These cableways also carry inert gas and pneumatic air by means of flexible tubes.

## 8.0 CONCLUSION

The Clinch River Breeder Reactor marks a shift from the design objectives of experimental reactors such as FFTF and EBR II to objectives which are just short of commercial application.

Emphasis has shifted from new development to manufacturing, licensing and operating procedures needed for direct commercial application. The plant will be part of the Tennessee Valley Authority system and will be operated as a commercial facility rather than as a test reactor concerned mainly with feasibility, verification of test data, and experimentation.

As a general rule, instrumentation aimed at monitoring structures, anticipating postulated failure mechanisms or providing new insights into plant behavior has been excluded.

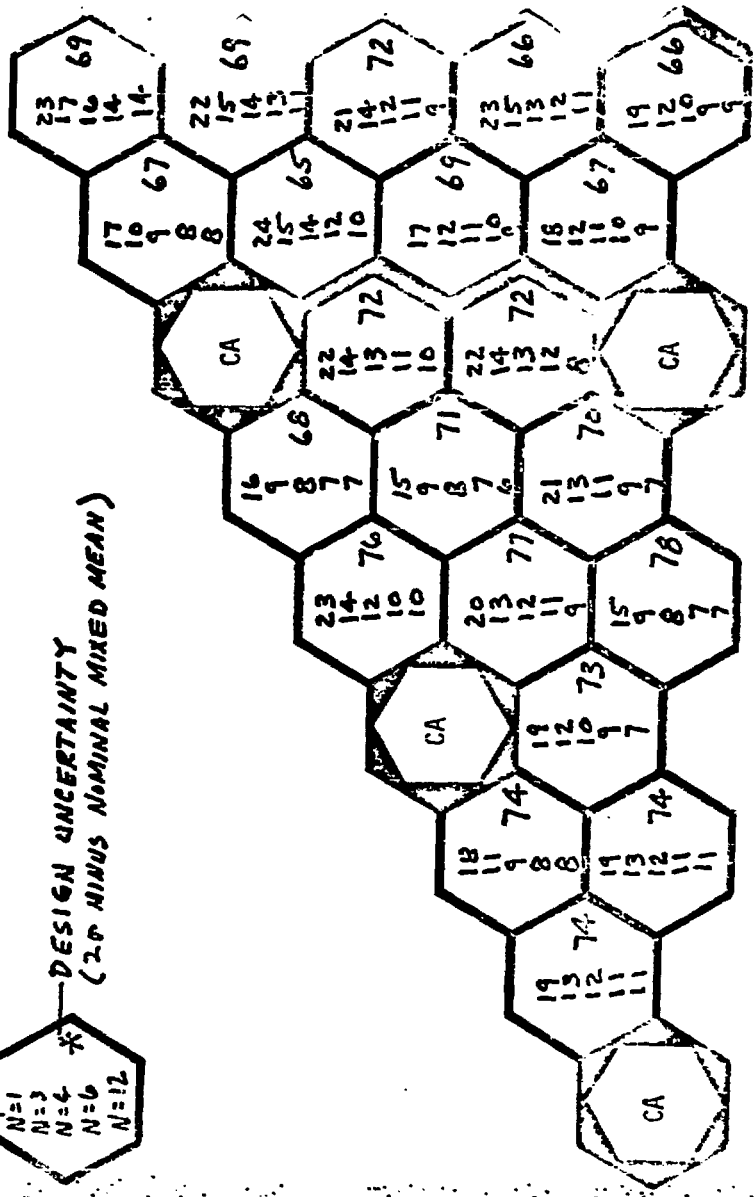
The overriding consideration in the choice of instrumentation has been the need to provide an economic power producing system.

MEASUREMENT UNCERTAINTY  
(N = NUMBER OF SENSORS IN  
SYMMETRICAL POSITIONS)



DESIGN UNCERTAINTY  
(2σ MINUS NOMINAL MIXED MEAN)

TEMPERATURES IN °F

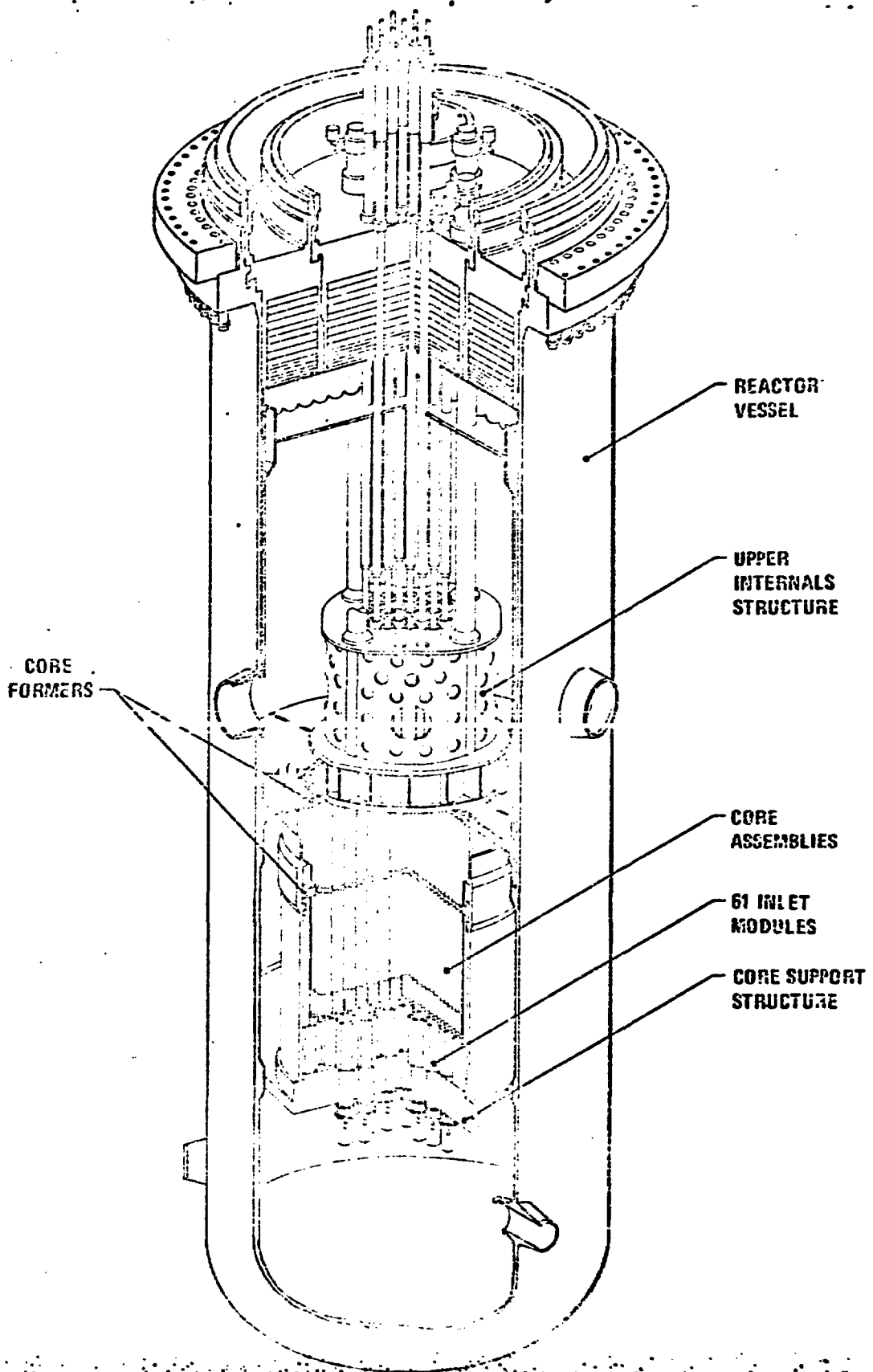


UPPER ZONE

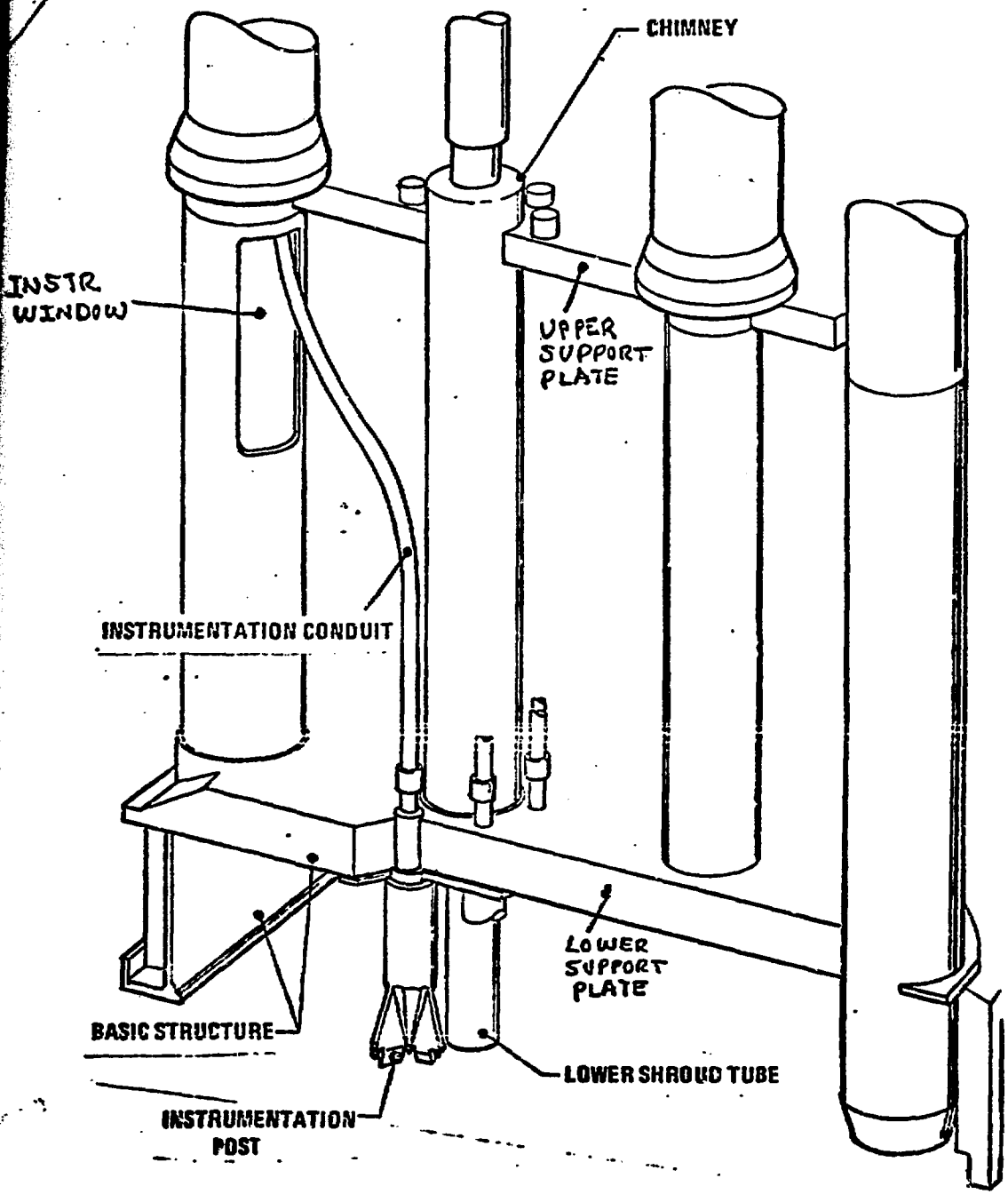
LOWER ZONE

PA.

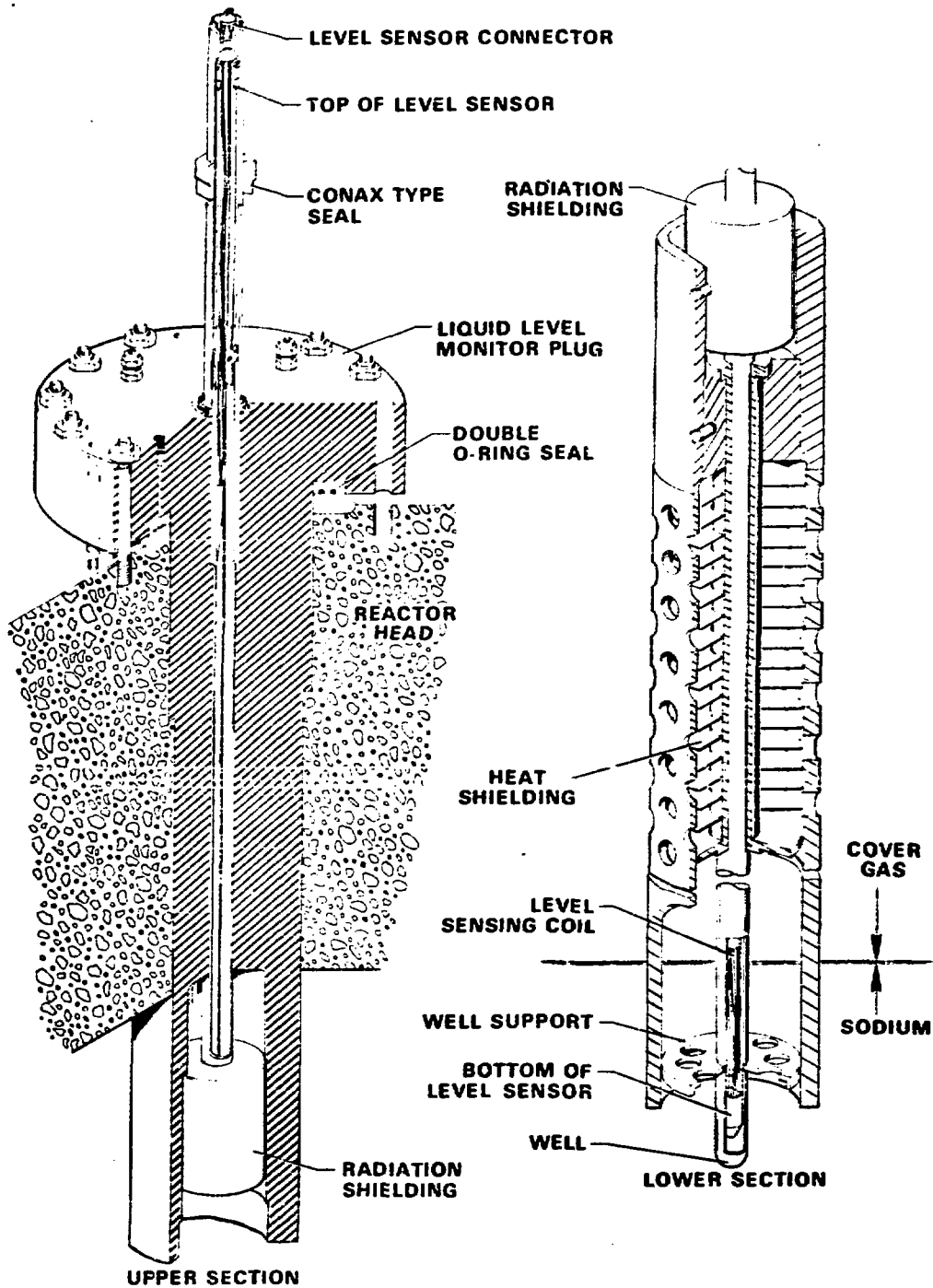
FIGURE 1 COMPARISON OF MEASUREMENT AND DESIGN UNCERTAINTIES IN Test Assembly exit Temp. for Various Symmetrical Coverage Angles



2. Reactor Vessel and Upper Internals Pictorial View



3. Thermocouple Location in Upper Internals



Sodium Liquid Level Monitor Plug And Sensor

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4. Reactor Vessel Sodium Level Sensor Mounting Arrangements

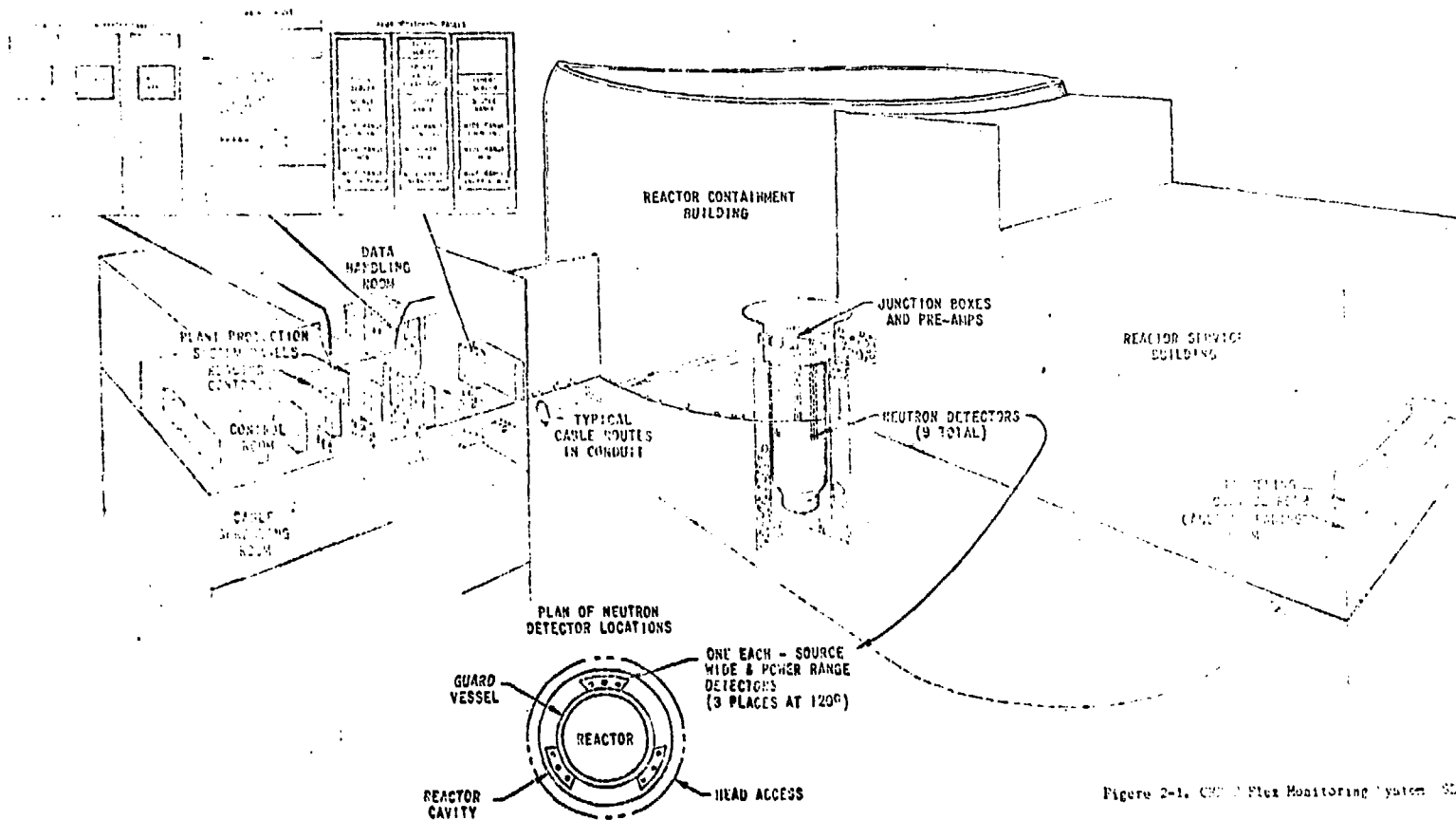


Figure 2-1. CRP Flux Monitoring System SDR 95

### 5. Flux Monitoring System Pictorial View

B-2

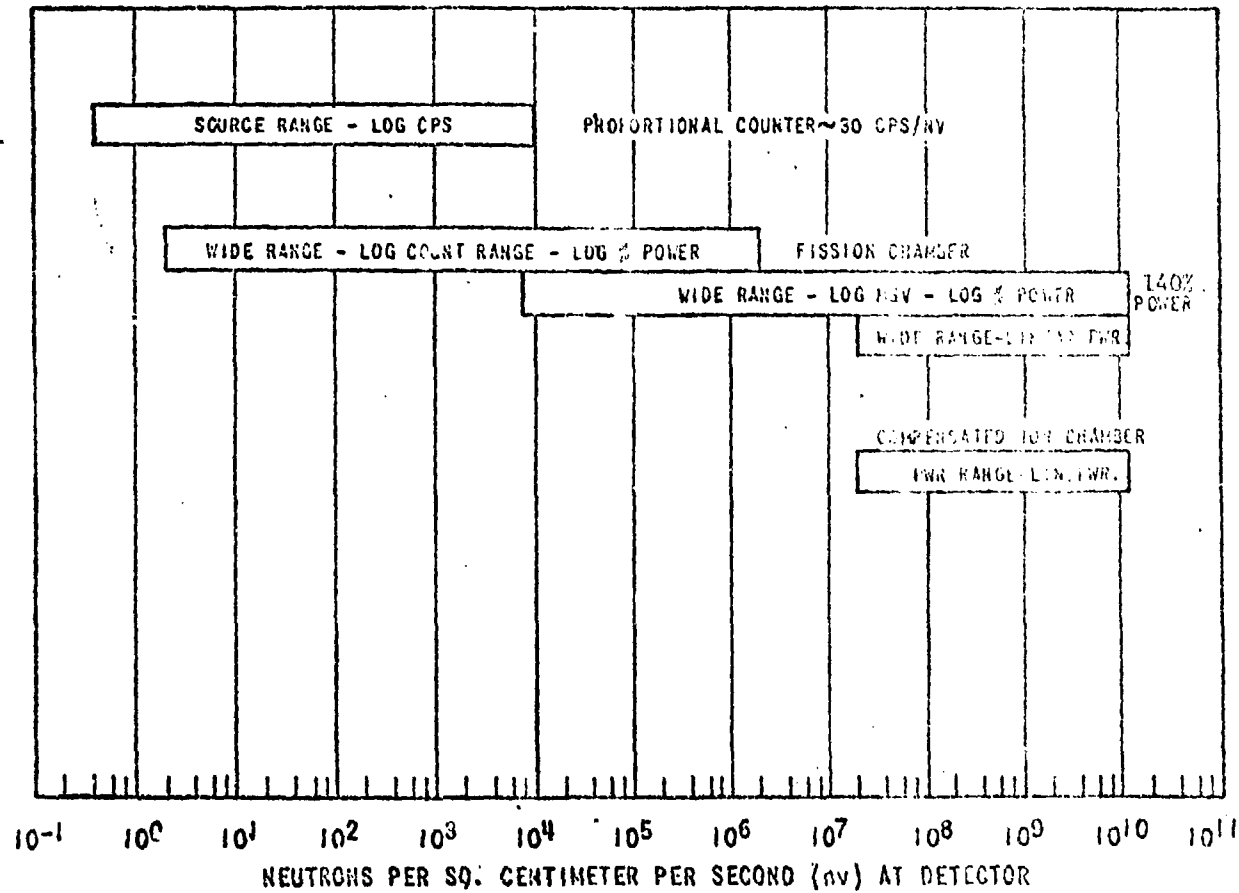


Figure 6. Flux Monitoring System Instrument Range Coverage

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7.5-43

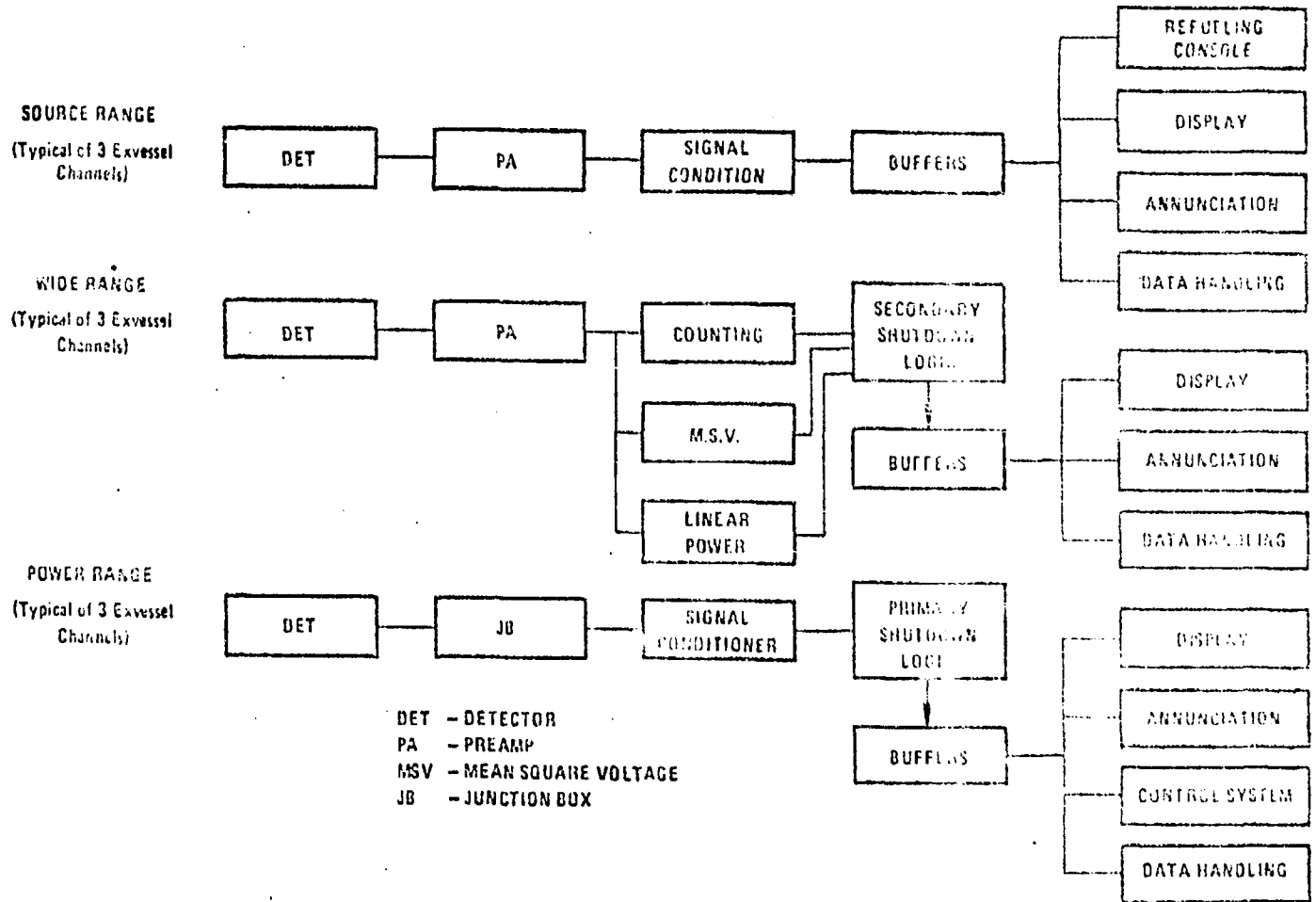
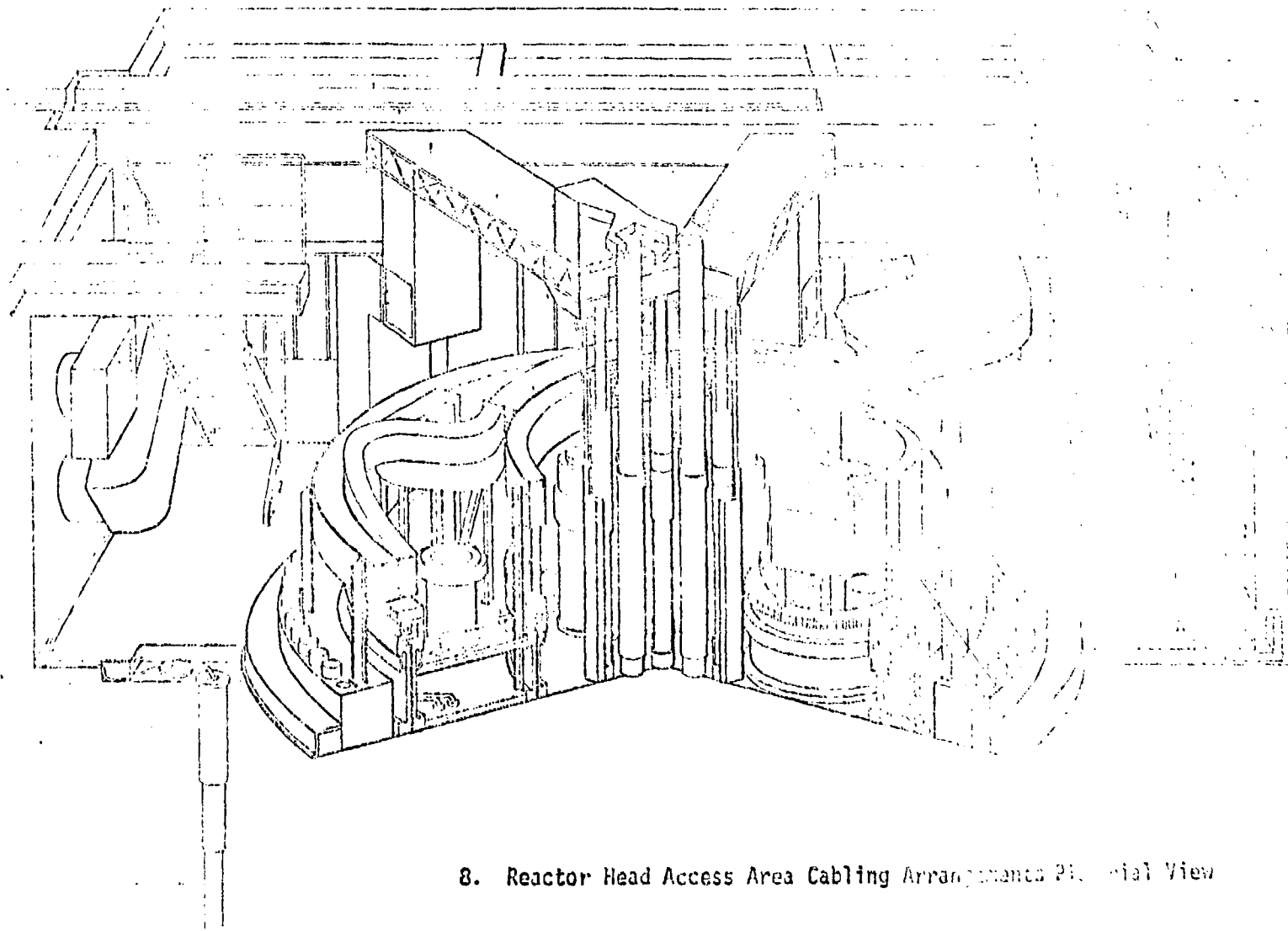


Figure 7. Flux Monitoring System Block Diagram



8. Reactor Head Access Area Cabling Arrangements Partial View