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ROUTINE AND POST-ACCIDENT SAMPLING IN NUCLEAR REACTORS

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ABSTRACT

Review of the Three Mile Island accident by NRC has resulted in new post-accident-sampling-capability requirements for utilities that operate pressurized water reactors and/or boiling water reactors. Several vendors are offering equipment that they hope will suffice to meet both the new NRC regulations and an operational deadline of January 1, 1981. The advantages and disadvantages of these systems and projected future-new-system needs for TVA reactors are being evaluated in light of TMI experience.

ROUTINE AND POST-ACCIDENT SAMPLING IN NUCLEAR REACTORS

1. INTRODUCTION

Before the accident at Three Mile Island, the requirements for post-accident sampling were not well defined. Only the need to monitor hydrogen concentration in the reactor containment atmosphere had been clearly established.

The absence of timely post-accident sampling capability and resulting information during the Three Mile Island accident proved to be a serious handicap. Early analysis for radioactivity and hydrogen in the reactor coolant water and containment atmosphere would have helped substantially in establishing the extent of the reactor fuel damage. An early determination of the boron level in the reactor coolant water could have removed fears that the reactor might be in a critical state. An early analysis of the dissolved oxygen in the reactor coolant water would have shown that the fears of a hydrogen explosion in the reactor vessel were totally unwarranted.

None of these needs was fulfilled in a timely manner at Three Mile Island because the means to obtain such data were not operational. Airborne radioactivity levels enroute to the sample stations were well above tolerable safe limits for operating personnel and, from an administrative standpoint, made the sample stations inaccessible. No radiation shielding was present at the sample stations to attenuate radiation from the highly radioactive water in the sample piping and valves. No capabilities existed to obtain a water sample from the reactor containment building sump. No means existed to transport highly radioactive samples from the sample station to the on-site radiochemistry analysis laboratory. No capabilities existed to reduce the background radiation levels in the radiochemistry analysis laboratory to levels needed for the radiation sensing instrumentation to be effective.

These experiences, the dilligent effort to obtain the facts, and the analysis of the findings form the bases for the required post-accident sampling equipment and facilities that must be incorporated into all of the commercial nuclear power plants in this country.

2. NRC REQUIREMENTS

One of the reports of the "Lessons Learned Task Force,"[1] created within the NRC after the Three Mile Island accident, list a set of requirements for post-accident sampling. These requirements specify that each commercial nuclear plant shall have a capability to sample and to analyze reactor coolant water and the containment atmosphere within specified time limits under post-accident conditions. A summary of these requirements is shown in Table 1. The NRC also specified that operating personnel and analysts shall not receive radiation doses in excess of 3 and 18-3/4 rems to the whole body and extremities, respectively, during sampling and analyses. Also, these post-accident operations shall not cause personnel to receive doses exceeding the radiation limits specified in 10CFR100.

3. SAMPLES REQUIRED[2]

In operating LWRs, both liquid samples (primarily reactor coolant) and gaseous samples (containment atmosphere and stripped gases) will be collected periodically and analyzed. Under routine conditions, undiluted RC (reactor coolant) samples can be handled on site; under post-accident conditions, undiluted RC will be shipped off-site and only diluted RC (1000/1) will be analyzed on site.

3.1 Liquid Samples

The liquid samples to be taken in light water reactors under both routine and post-accident conditions are listed in Table 2. RC samples are taken to determine the extent of core damage. In PWRs, the boron content is important in estimating reactivity. The other liquid samples indicate the radiation levels throughout the plant and verify the performance of clean-up and chemical conditioning components and systems.

The analyses to be obtained and the frequency of sampling under post-accident conditions are shown in Table 1. These samples indicate damage to the core and detect any leakage from equipment inside containment. Again, boron is important for determining and verifying subcriticality.

3.2 Gaseous Samples

The gaseous samples analyzed periodically are the containment atmosphere and the gas stripped from one RC sample that will be taken at operating pressure. Routinely, these gas samples are analyzed for hydrogen and oxygen; under post-accident conditions, the fission gases and iodine become important.

4. FACILITIES FOR ROUTINE AND POST-ACCIDENT SAMPLING AND ANALYSIS

These facilities were designed to provide a capability for on-site analyses of reactor coolant and containment atmosphere during routine operations and under post-accident conditions and to obtain post-accident samples suitable for off-site analysis. The enclosures, ventilation facilities, and equipment for post-accident usage were designed to handle reactor coolant and containment air contaminated by a TID-14844 release.

Facilities for routine sampling were designed to comply with Regulatory Guides 8.8 and 8.10, and those for post-accident usage were designed to satisfy needs specified in NUREG-0578, section 2.1.8.a, and Regulatory Guide 1.97. The equipment is installed in structures constructed so they will not damage safety-related structures or equipment during a design basis earthquake.

Under post-accident conditions, these facilities shall:

1. obtain the needed liquid and gas samples,
2. transport the samples to a transfer and packaging station or analysis laboratory on site,
3. perform radiological spectrum, chemical, and physical chemistry analyses on liquid and gas samples,
4. safely dispose of the sampling fluids, and
5. provide a capability to package samples for shipment to an off-site analytical facility.

4.1 The Sampling Station

This is the area where samples are taken and on-line analyses are made. Fluids are piped to this area from containment and other areas of the plant at operating pressures and temperatures. Here the sample stream is cooled, reduced in pressure, and directed to a sample waste tank. The area must have appropriate shielding, reliable ventilation, off-gas and cooling water supplies, and be accessible under accident conditions. It is desirable, but not compulsory, that all the sampling equipment (both liquid and gas) be located in a single station, and that some equipment intended for post-accident use also be used for routine sampling so the operators will be familiar with the equipment should a stressful situation arise.

4.2 The Sentry Equipment

The Tennessee Valley Authority has contracted to purchase from the Sentry Equipment Company of Oconomowoc, Wisconsin, seven sets of sample processing equipment to be installed in three BWR units and four PWR units. This shielded equipment accomplishes the cooling, pressure reduction and dilution of liquid samples, the on-line analysis of RC samples, the degassing of high-pressure liquid, the sampling of containment atmosphere, and the safe transportation of all types of samples to the on-site analytical laboratory.

4.2.1 Reactor coolant sampling equipment

The reactor coolant sampling equipment is intended for use during routine plant operations and during accidents. It is installed in the manner shown in Fig. 1. Upstream from the panels are heat exchangers that cool all of the liquids to at least 100°F. Downstream from the panels is a piping network that provides the various flow paths needed to properly dispose of the sampling wastes during routine and accident operations.

The reactor coolant water sampling panel is a rectangular shield structure installed on top of concrete pedestals in the manner shown in Fig. 2. The sampling panel contains a series of stepped penetrations for manual valves needed to get post-accident water samples and leaded glass windows to view certain key operations behind the shield panel. The sampling panel also contains standard valve and sink installations on the front face to allow grab samples to be taken during normal plant operations. Ventilation and flushing features are included in the panel design to control airborne radiation arising from valve leakage. The air cleanup unit used to process the exhaust air was designed in accordance with reference 3. This air cleanup unit has a 2-in.-thick carbon adsorber bed. A manometer is installed to measure and display the pressure differential across the shielded panel.

One sampling panel is provided for each reactor unit. This panel provides the sampling capabilities described in Table 2. This sampling panel has features to obtain an undiluted sample and a 1000-to-1 diluted sample during post-accident operations. This sample panel also has features to obtain samples needed to determine, by testing, the nature and extent of dissolved gases in the reactor coolant water in its pressurized state in the reactor coolant system.

4.2.2 The in-line sample analysis panel

The in-line sample analysis panel is installed downstream from the sampling panels. This panel contains equipment needed to conduct oxygen, pH, conductivity, and chloride analyses on the reactor coolant water samples. A schematic of this panel is shown in Fig. 3. Details on the design and operation of this panel are provided in reference 2.

4.2.3 Reactor coolant water sample handling equipment

A transporter-elevator cart is used to handle the post-accident samples within the plant. This cart has mechanical features which:

1. allow it to be indexed precisely to the sample panel,
2. raise the sample vial vertically until the sampling needles penetrate the septum at the top of the sample vial,
3. lower the sample vial into the cask held by the transporter-elevator,

4. allow the transporter-elevator to be manually towed within the plant, and
5. open and close the sample cask cover.

The transporter-elevator is capable of positioning the sample vial cap septum during the vial elevating process to ±0.03 inch horizontally and ±0.06 inch vertically. This cart is easy to decontaminate. The cart and cask as a unit have a capability to completely retain an accidently spilled sample.

4.2.4 Post-accident sampling equipment operations

The transporter-elevator cart and the sampling panel have features which allow post-accident samples to be obtained in a safe manner. Fully equipped transporter-elevator carts are indexed to this sampling panel at each accident sampling position during all routine operations to assure that an operational capacity will be present if an accident should occur. A 15-ml sample vial is installed within a lead cask that is held by the transporter-elevator. In the event of an accident, mechanical devices on the transporter-elevator are operated by a sampling technician to open the sample cask cover and lift the sample vial in a precise manner to have sampling needles, identical to those used at the ORNL Transuranium Processing Plant, puncture a rubber septum in the sample vial cap. Features incorporated into the sampling panel are then actuated to deliver a representative liquid sample. After this is done, the sampling technician will then lower the sample vial with the hydraulically-operated linkage, withdraw the precision indexing mechanism between the transporter-elevator and the sample panel by mechanical linkage, and pull the transporter-elevator and its contents to its intended destination with the plant. The entire sampling operation can be done in about 10 minutes. Features built into the sampling panels and its shielding will keep the dose rate, at 1 meter distance, to 450 mrem per hour in the worst case sample (a no-line break in a BWR). To keep the sampling technician's radiation doses ALARA,* 3-ft-long reach rods will be provided to allow the technician to actuate all of the sample panel valves during the high radiation period during the first hours of the accident.

4.2.5 Containment atmosphere sampling equipment

The containment atmosphere sampling equipment is used during accidents to obtain representative samples of the containment atmosphere. The sample panel provided is shown schematically in Fig. 4. The transporter-elevator carts, described in Sect. 4.1.2, herein are used to hold and transport the sample flasks and their shielding casks. Four transporter-elevator carts fully equipped and coupled by quick disconnects to the sampling lines are kept in position ready for use. Not shown is a remote control panel which provides a capability to automatically draw three representative samples and a particulate/iodine filter sample at predetermined times after receipt of the accident signal. The sample panel shown in Fig. 4 is a 3-in.-thick steel panel designed to keep personnel radiation doses within acceptable levels.

4.3 On-site Post-Accident Laboratory Equipment

Some of the NRC required on-site post-accident analyses will be performed in a nearby laboratory. The analyses conducted therein, described

*ALARA, as low as reasonably achievable.

in Table 3, are performed with commercially available equipment having the range and sensitivities shown in the table. Design of the laboratory facility has not yet progressed to the final stage.

5. POST-ACCIDENT OPERATIONAL AND ENVIRONMENTAL CONTROL FEATURES

Several features in the nuclear plant were incorporated to assure that effective post-accident sampling operations can be performed without exceeding established radiation dose guidelines for in-plant operations or at off-site locations.

5.1 Locating the Post-Accident Sampling Facility

The post-accident sampling facilities were located within the plant to assure in-plant personnel accessibility and the capability to obtain representative samples. Access to the post-accident sampling facilities for plant personnel is assured without excessive radiation exposure by avoiding access routes subject to high airborne radiation and high containment gamma radiation shine. Assurance that representative samples can be obtained is provided by locating the sample station as close as possible to the reactor containment and by heat tracing the containment atmosphere sample line to minimize plate-out of activity as the sample is brought to the sample station.

5.2 Post-Accident Facility—Ventilation and Shielding

The post-accident sample stations and sample analysis facilities have ventilation systems and shielding suitable for post-accident operations. Ventilation systems serving just the post-accident sampling facilities are provided to avoid contaminated air from other parts of the plant. These draw the supply air through air filtration equipment before entering the plant, and draw all exhaust air through another set of air filtration equipment prior to the air being directed to an effluent release station. These sample stations and sample analysis facilities also contain adequate shielding for in-plant personnel and the post accident instrumentation.

5.3 Sampling Facility Effluent Release Control

The ventilation system exhaust air from the post-accident sample stations and sample analysis laboratories is monitored by a radioactive effluent monitor prior to its release to the environment. Such a practice assures that the maximum radioactive effluent from the plant during post-accident operations does not leave the site.

5.4 Operational Control of Post Accident Sampling Activities

Communication and control facilities between the main control room of the nuclear plant and the sample station and sample analysis laboratory are provided to assure that post-accident sampling operations are performed effectively and safely. Direct telephone linkage between these areas is provided to assure effective communications. To assure adequate control, a containment isolation value override, enabled by control room operator action, is provided at each sample station. This control feature assures that the main control room operator has control over these operations at all times. This feature then allows the sample station operator to open and close containment isolation valves closed by the plant accident detection system and get the samples needed during the post-accident period. Main control room operator control is further assured because operator action ending the enabling status returns all affected containment isolation valves to the closed status. Safety is further assured because the override equipment is designed to close any open valve if any failure in that valve override equipment occurs.

6. REFERENCES

1. TMI-2 Lessons Learned Take Force Status Report..., NUREG-0578 (July 1979).

2. W. Nestel et al., "Analyses for pH, Chlorides, Dissolved Oxygen, Conductivity and Boron under 'Post-Accident' Conditions" (February 1980).

3. ANSI N509, Standard for Nuclear Power Plant Air Cleaning Units and Components (1976).

Table 1. NRC post-accident sample analysis requirements

Sample	Sample source	Type of analysis	Time limit
Reactor coolant water (pressurized)	Primary coolant envelope	Dissolved hydrogen	>1 hour
		Dissolved oxygen	>1 hour
Reactor coolant water (unpressurized)	Primary coolant envelope	Gamma radiation spectrum	>2 hours
		Dissolved oxygen	>1 hour
	Containment sump	pH	>1 hour
		Conductivity	>1 hour
		Boron*	>1 hour
		Chlorides**	>1 shift
Containment atmosphere	Two or more envelopes in containment	Gamma radiation spectrum	>1 hour
		Hydrogen content	>1 hour

*Required on pressurized water reactors only.

**Required on seawater cooled plants only.

Table 2. LWR liquid sampling points

Sample point	Routine operations*	Post-accident operations**
BWR		
Recirc loop	X	X
Cleanup demin inlet	X	
Cleanup demin outlet	X	
RHR	X	X
Drywell sumps		X
Suppression pool	X	X
Sample system waste tank	X	
PWR		
Reactor coolant loops	X	X
Pressurized steam space	X	
Pressurized liquid space	X	
CVCS inlet	X	X
CVCS outlet	X	X
Accumulator (core flood tank)	X	
RHR (DHR)	X	X
Containment sumps		X
Holdup tanks	X	
RB equipment & floor drain tanks	X	
Sample system waste tank	X	
Chemical drain tank	X	
Reactor coolant drain tank	X	

*The sample points for routine operations may be varied to suit operational convenience.

**The sample points shown above the post-accident operations are mandatory.

Table [illegible]. Analyses required on-site

Sample	Type of analysis	Sample analysis rate	Range and sensitivity
Reactor coolant water	Gamma spectrum	1/hr	Note a
	Dissolved hydrogen	1/hr	Note b
Containment atmosphere	Gamma spectrum	1/hr	Note a
	Hydrogen fraction*	1/hr	Note c

*This analysis is accomplished with the existing inline hydrogen analyzer.

NOTES

a. Identify any individual nuclides in the sample which emit 10 percent or more of the total gamma radiation from the sample, range 0.01 μCi/cc to 0.01 Ci/cc.

b. 0.2 percent to 5.0 percent hydrogen, ±5 percent of value.

c. ±1.0 volume percent, 0 percent to 10 percent hydrogen.

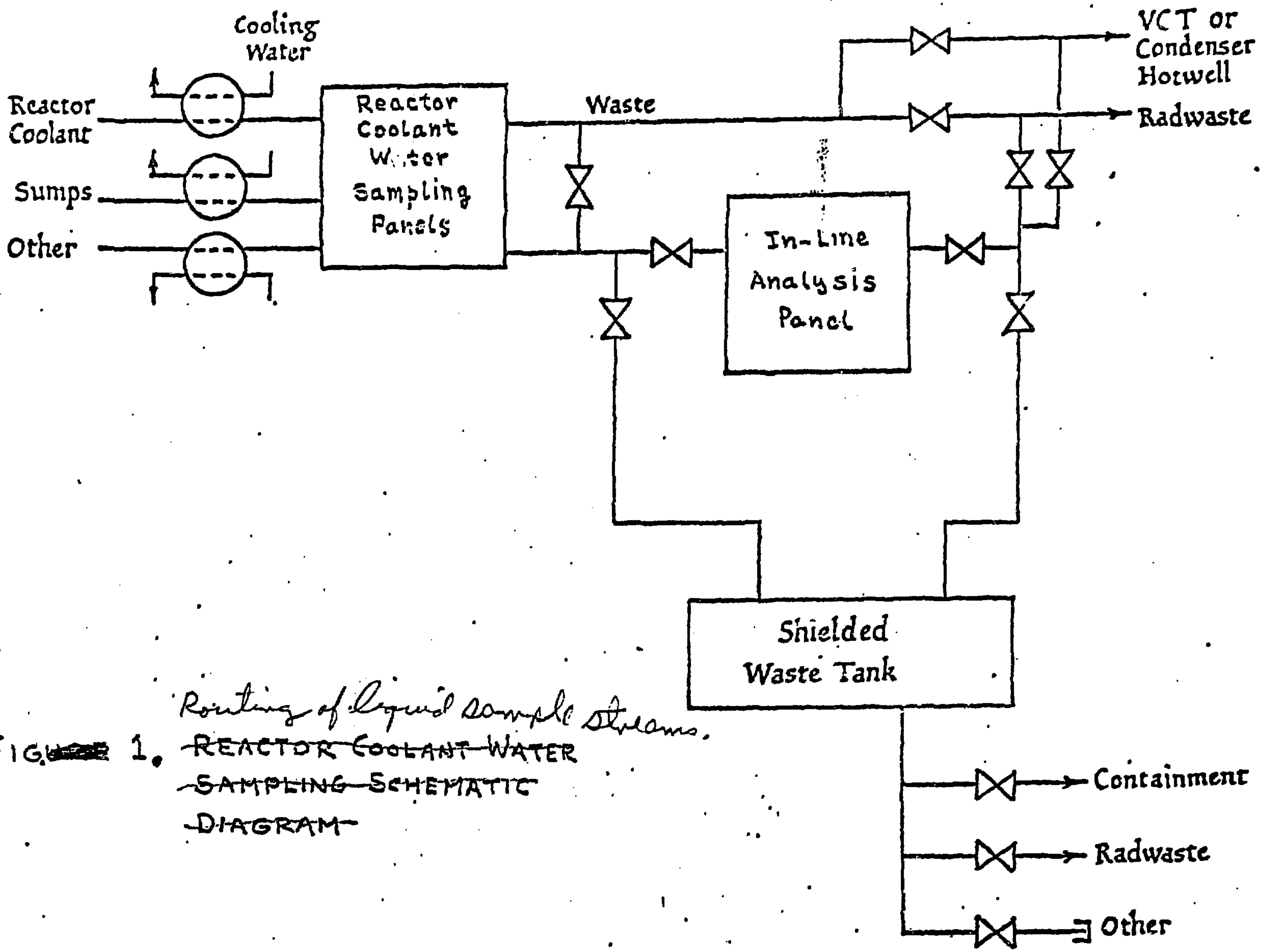
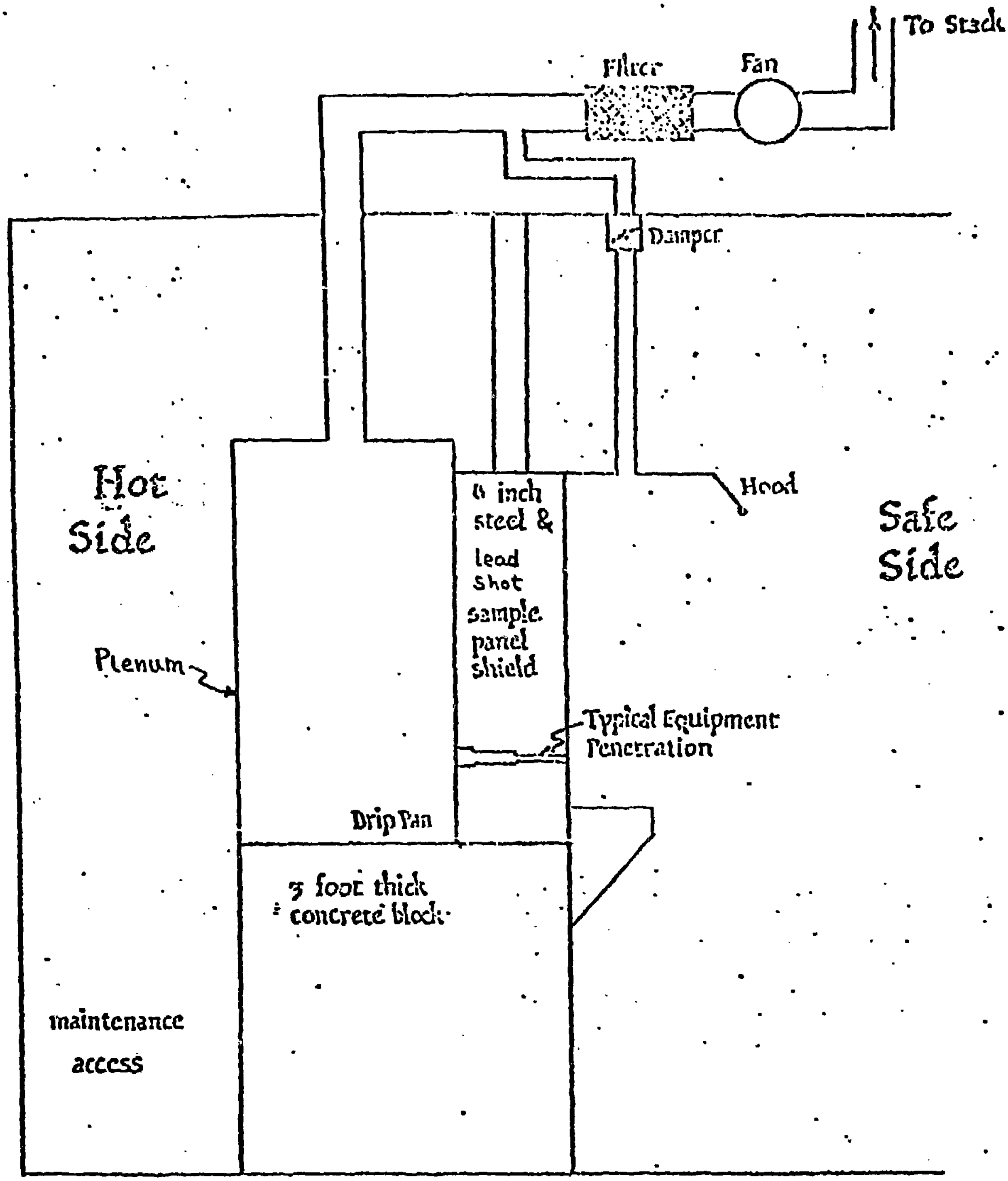


FIGURE 1. ~~REACTOR COOLANT WATER SAMPLING SCHEMATIC DIAGRAM~~ Routing of liquid sample streams.



~~FIGURE 2, REACTOR COOLANT WATER SAMPLE STATION CROSS SECTION~~ ~~OF LIQUID~~

Fig. 2. Cross section of liquid sample station.

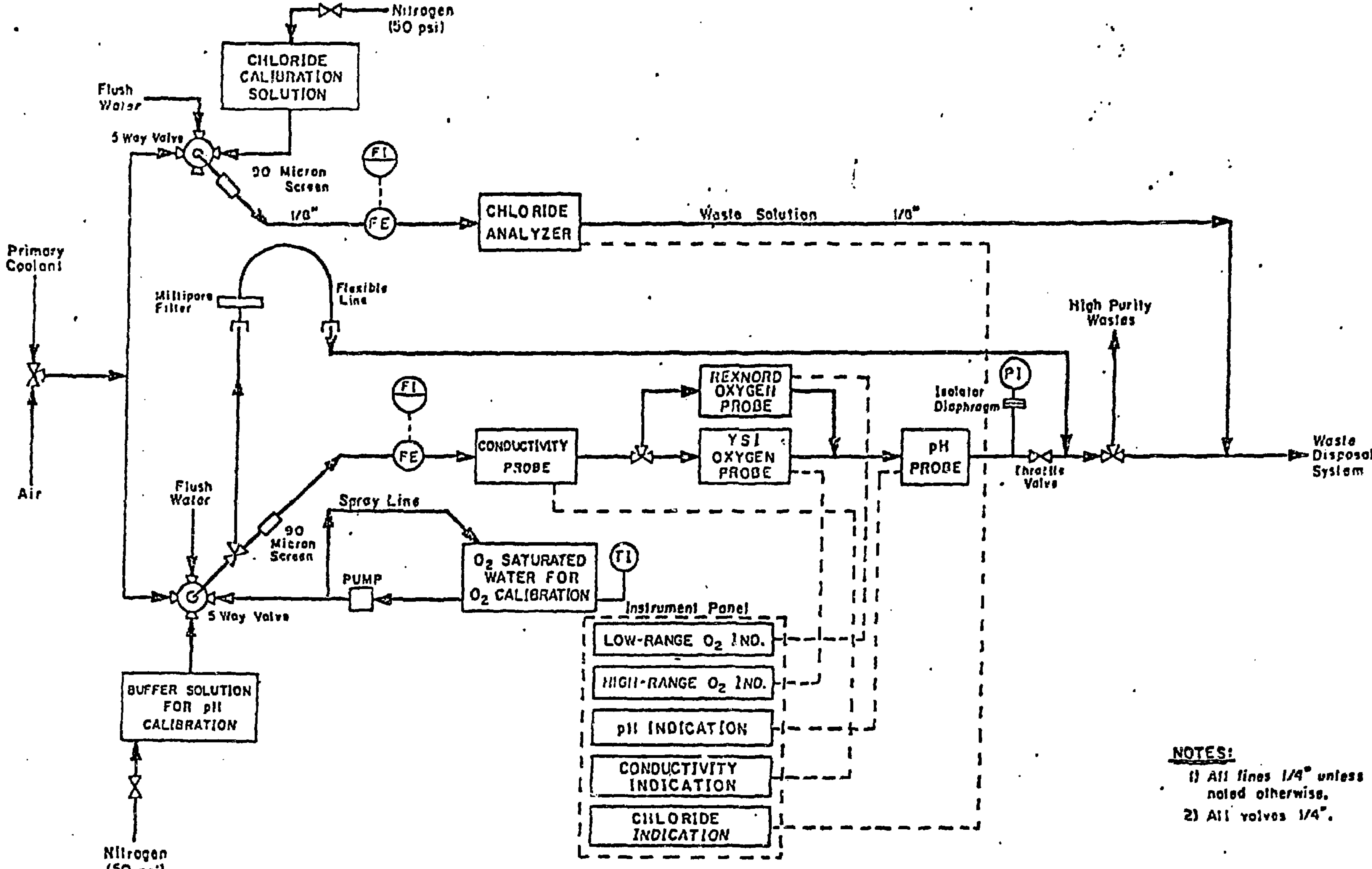
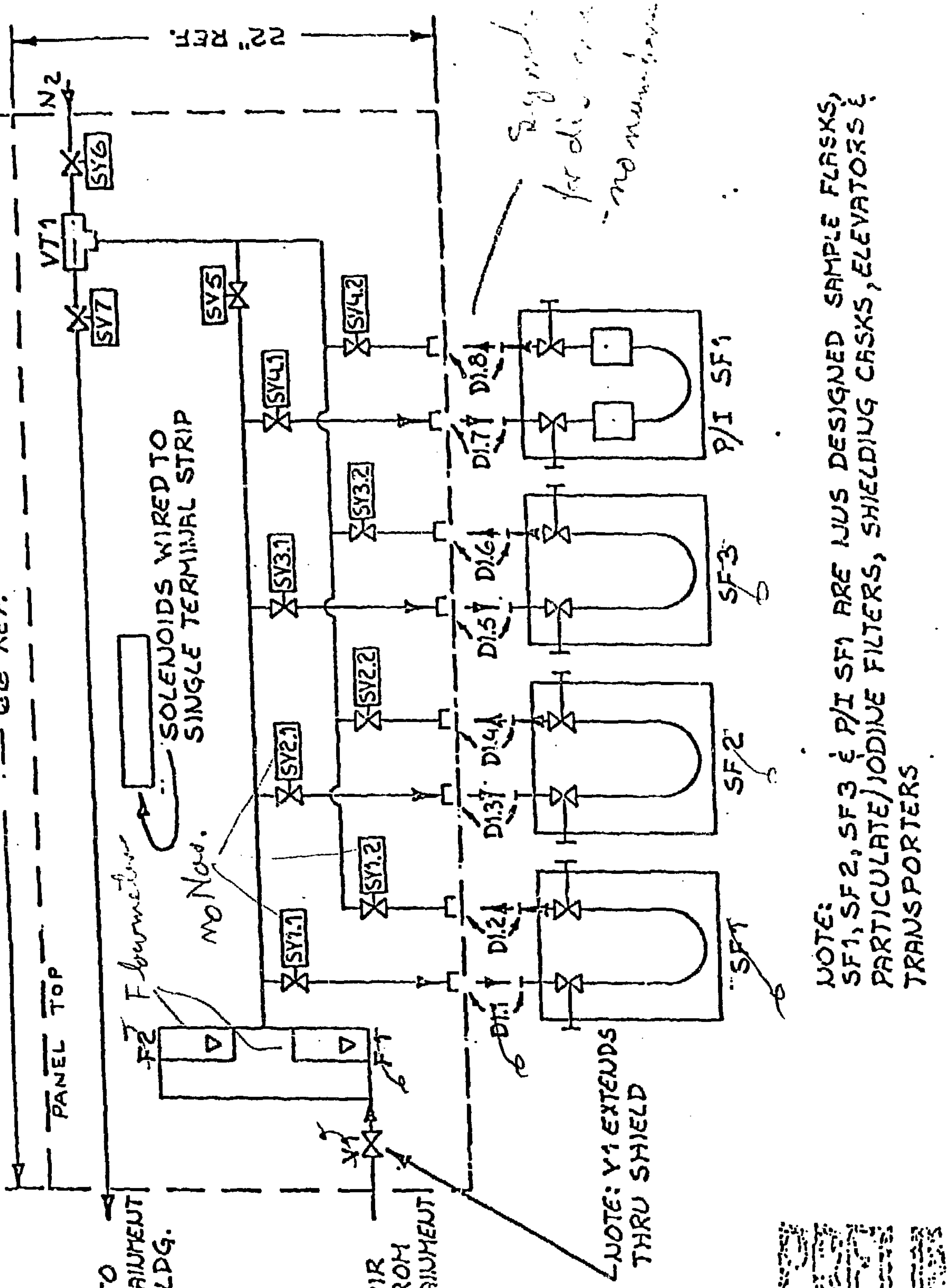


Fig. 3. INLINE COOLANT ANALYSIS SYSTEM.

~~FIGURE X-3~~



PRELIMINARY

FIGURE 4. CONTAINMENT ATMOSPHERE SAMPLING PANEL -