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THE EBR-II COVER-GAS CLEANUP SYSTEM

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The EBR-II Cover-Gas Cleanup System*

by

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Introduction

Operation of EBR-II with breached elements results in the continuous release of fission gases to the argon cover gas. To control activity in the reactor, a cover-gas cleanup system (CGCS) was installed to remove xenon and krypton from the cover gas by cryogenic distillation. Although only one breached fuel element will, by intention, be in-core during the early stages of the run-beyond-cladding-breach (RBCB) program now under way, the CGCS is designed to handle the activity released by up to 12 mixed-oxide elements.

System Description

A. Cover-Gas Cleanup System

The principle design criteria for the CGCS are listed in Table 1.

The major components and flow paths of the CGCS are shown in Figs. 1 and 2. Basically .0005 - 0.005 m^3/s flow of argon is extracted from the 8.5-m^3 cover-gas space in the EBR-II primary tank and returned to the primary tank after treatment. The treatment removes (1) sodium vapor and aerosols; (2) xenon, krypton, and condensible impurities; and (3) any xenon tags [1] released in-reactor. A compressor system in a building adjacent to the reactor building supplies the driving force for the flow of cover gas. When required, a bypass flow of this gas can be routed through cooled charcoal beds to remove and identify released xenon tags.

In the cleaning process, the argon cover gas -- containing xenon

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and krypton, sodium vapor and aerosol, sodium oxide particulate, and gaseous impurities -- is removed from the primary tank through the H-1 nozzle (Fig. 1). After being removed from the primary tank, the gas is passed first through a preheater, where its temperature is increased to 495°C to vaporize entrained sodium. The stream of gas is then introduced into the bottom of a controlled-temperature-profile (CTP) condenser (Fig. 3), where it passes upward through an annulus filled with Raschig rings. The annulus has seven zones of decreasing temperatures. The vaporized sodium is condensed on the surfaces of the Raschig rings as it cools to 170° before leaving the condenser. The condensed sodium flows to the bottom of the condenser, through a sodium trap, and back to the primary tank. The sodium trap also prevents argon from bypassing the preheater.

The argon, now at 170°C and containing less than 1 ppm of sodium, is passed through an aerosol filter (Fig. 4) to remove any remaining particulate. The shielded preheater, condenser, and filter are on the main floor of the reactor building next to the H-1 nozzle.

The cooled sodium-free cover gas leaves the reactor containment building through shielded pipes and appropriate isolation valves and goes to an auxiliary process building that is 6 m away from the containment shell. This building contains, among many other components, the compressor containment vessel, which houses a surge tank and eight compressors. Six of these compressors supply the suction pressure to extract argon from the primary tank, and two serve the xenon tag trapping system. The compressor discharge pressure drives the cover gas through the remaining components and back to the primary tank.

From the compressors, the gas is then introduced into an insulation-filled containment vessel called the cold-box (Fig. 5). In the cold-box, the gas passes through a regenerative heat exchanger (economizer) enroute to the bottom sump of a cryogenic distillation column where it is bubbled through liquid argon at -182°C and condensed. Liquid entering the distillation column overflow is vaporized by heaters, and the gas passes up through the reflux portion of the column to a nitrogen-cooled condenser, where further condensation occurs. Condensate draining back to the bottom of the column provides the necessary reflux to strip xenon and krypton from the gaseous argon. The overflow line heaters at the sump provide the required vaporization for reflux action.

Cleaned gaseous argon flows from the distillation column through the economizer to be warmed and routed through flow control valves to the EBR-II primary tank through the R-nozzle (Fig. 1). The R-nozzle is oriented approximately 120° from the H-1 nozzle. A reheater raises the argon temperature to approximately 315°C before the argon enters the primary tank;

The containment vessel (cold-box), which houses the regenerative heat exchanger and cryogenic distillation column, is capable of holding the contained inventory of liquid argon and nitrogen should it vaporize and escape to the cold-box; isolation valves would then seal the cold-box. The cold-box atmosphere or the distillation column inventory may be sent to an emergency charcoal adsorber containing 284 kg activated charcoal. From the charcoal adsorber the gas can be returned to the site suspect exhaust stack. Gas chromatographs and special oxygen analyzers continuously analyze samples of the inlet gas, the compressor discharge gas, and the returning clean argon for H_2, He, O_2, and N_2. Oxygen concentrations of <0.5 ppm can be monitored.

System conditions are continuously monitored by the EBR-II data acquisition system (DAS). Automatic isolation of the CGCS from the EBR-II primary tank occurs when pertinent control parameters are not satisfied. The cleanup system is capable of operation with minimal surveillance except for startup, shutdown, and periodic maintenance.

B. Xenon-Tag Trapping System

The CGCS contains a xenon-tag trapping system (Fig. 2). This system separates samples of xenon isotopes from the cover gas and analyzes these samples to identify specific fuel elements tagged by stable isotopes. The fuel elements are tagged to facilitate identification in the event of the release of these isotopes by the failure of a fuel-element cladding. The design of the xenon-tag trapping system incorporates automatic or manual sequencing of controls to sample, concentrate, and analyze cover gas for xenon tags.

Three primary tag beds are used to concentrate xenon isotopes from the cover gas so that specific fuel subassemblies can be identified if an element cladding breach occurs. To obtain measurable quantities of xenon tags, 10% of the tag in one fuel element must be released. These isotopes are separated by adsorption of a sample stream for one hour on the charcoal adsorber, which is cooled to -78°C with liquid nitrogen. Each primary bed contains approximately 2.1 kg (4.25 liters) of charcoal.

After the one-hour collection time, valving isolates the inlet from the cleanup system and connects the bed to a transfer line leading to a secondary tag bed. During transfer, the primary bed is heated to 200°C to desorb xenon, krypton, and argon from the charcoal. During this heating, the gas is eluted, transferred, and trapped on a secondary bed as the second step in the xenon concentration process. Because the required quantity of charcoal is only 12.5 g (25 ml), the trap is small. Trapping on the secondary bed takes place at -173°C. Following a one-hour collection time, the secondary bed is heated to -78°C and held there for 30 minutes to allow the removal of unwanted argon, krypton, etc. The secondary bed is then heated to 200°C to transfer the sample to a precooled, evacuated sample vial for retention until introduction to the on-line mass spectrometer or transfer to the laboratory for analysis and tag identification.

The tag trap sequence is controlled by a Nova 2/10 computer that is also used to control the mass spectrometer. The controller will interrupt its sequence and provide an alarm signal to the DAS whenever pertinent variables are out of limits. Manual control of the sequencing is also possible.

C. Operational Experience

The basic cleanup loop of the CGCS became operational in June 1977, and has been used, as needed, since that time. Cleanup efficiencies of >99.9% have been demonstrated for krypton and xenon. The rate of radioisotopes removal is shown in Fig. 6.

The xenon-tag trapping system became operational in March 1978; therefore, very little operational information is available to date.

REFERENCE

[1] B. Y. C. So, et al., "Changes in Xenon Tag Composition with Exposure--EBR-II Experience," Trans. ANS, 23, p. 473 (1976).

TABLE I

PRINCIPAL DESIGN CRITERIA

EBR-II COVER-GAS CLEANUP SYSTEM

1. THE MAXIMUM RUN-BEYOND-CLADDING-BREACH EXPERIMENT IS 12, HIGH BURNUP, (U Pu)O_2 ELEMENTS. 34.3 cm/LONG @ 52.5 kW/m.
2. THE CGCS MUST MAINTAIN REACTOR BUILDING ATMOSPHERE AT $\leq$ 1 MAXIMUM PERMISSIBLE CONCENTRATION (MPC).
3. THE COVER GAS LEAKAGE RATE TO REACTOR BUILDING MUST BE REDUCED FROM $\sim$ 1 LITER/MIN AT PRESENT TO .3 LITER/MIN.
4. THE COMBINATION OF FLOW RATE AND DECONTAMINATION FACTOR MUST MAINTAIN COVER GAS ACTIVITY AT A LEVEL LOW ENOUGH (3.7 x 10^{10}Bq/ml OF ^{133}Xe). TO PERMIT THE DETECTION AND IDENTIFICATION OF SUBSEQUENT ELEMENT FAILURES.
5. THE CGCS FLOW RATE REQUIRED TO ACCOMPLISH THE ABOVE IS .005 m^3/s FROM THE PRIMARY TANK.
6. THE DECONTAMINATION FACTOR FOR XENON AND KRYPTON > 10 (THE DESIGN REMOVAL VALUE FOR XENON IS 99.9%).
7. MEASURABLE QUANTITIES OF XENON TAG MUST BE REMOVED ASSUMING RELEASE OF 10% OF THE TAG IN ONE FUEL ELEMENT. THE SAMPLE RATE FOR THE XENON-TAG TRAPPING SYSTEM IS .0005 m^3/s. PROVISIONS SHALL BE MADE FOR BOTH ON-LINE AND LABORATORY ANALYSIS OF XENON TAG.
8. THE SODIUM AEROSOL CONTENT OF THE COVER GAS SHALL BE REDUCED FROM A MAXIMUM OF 1400 wppm TO < 1 wppm. PARTICULATES IN THE COVER GAS STREAM SHALL BE REMOVED.

TABLE I (CONTINUED)

9. A RECIRCULATING, CRYOGENIC DISTILLATION SYSTEM WILL BE USED TO REMOVE RADIOACTIVE XENON AND KRYPTON FROM THE COVER GAS.

10. THE CGCS SHALL MAINTAIN STRUCTURAL INTEGRITY DURING THE POSTULATED EBR-II DESIGN-BASIS NUCLEAR ACCIDENT AND EARTHQUAKE GROUND ACCELERATIONS OF 0.25 g IN BOTH HORIZONTAL AND VERTICAL PLANES.

11. THE CGCS SHALL MEET THE REQUIREMENTS OF THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS (ASME) BOILER AND PRESSURE VESSEL CODE, SECTION III, NUCLEAR POWER PLANT COMPONENTS (WITH MINOR EXCEPTIONS) AND CERTAIN SPECIFIED REACTOR DEVELOPMENT AND TECHNOLOGY (RDT) STANDARD.

12. ANY RADIOACTIVE EFFLUENT GASES AND BUILDING VENTILATION SHALL BE EXHAUSTED THROUGH HEPA FILTERS TO THE EBR-II SUSPECT-EXHAUST SYSTEM AND SITE STACK.

13. PROVISIONS SHALL BE MADE FOR THE SAFE DISPOSAL OF RADIOACTIVE LIQUID WASTE.

14. RADIATION EXPOSURE TO SITE PERSONNEL AND NEARBY POPULATION AREAS IS LIMITED TO THE LOWEST LEVELS PRACTICAL (NEAR-ZERO RELEASE).

15. PROVISIONS WILL BE MADE FOR AUTOMATIC AND MANUAL ISOLATION OF THE CGCS AT THE PRIMARY-TANK NOZZLES AND AT THE REACTOR BUILDING SHELL.

16. THE EBR-II DATA AQUISITION SYSTEM (DAS) WILL BE USED FOR DATA COLLECTION, INDICATION, RECORDING, AND ALARMS. ADEQUATE RADIATION, PRESSURE, TEMPERATURE, AND LIQUID LEVEL MONITORS AND ALARMS WILL BE PROVIDED.

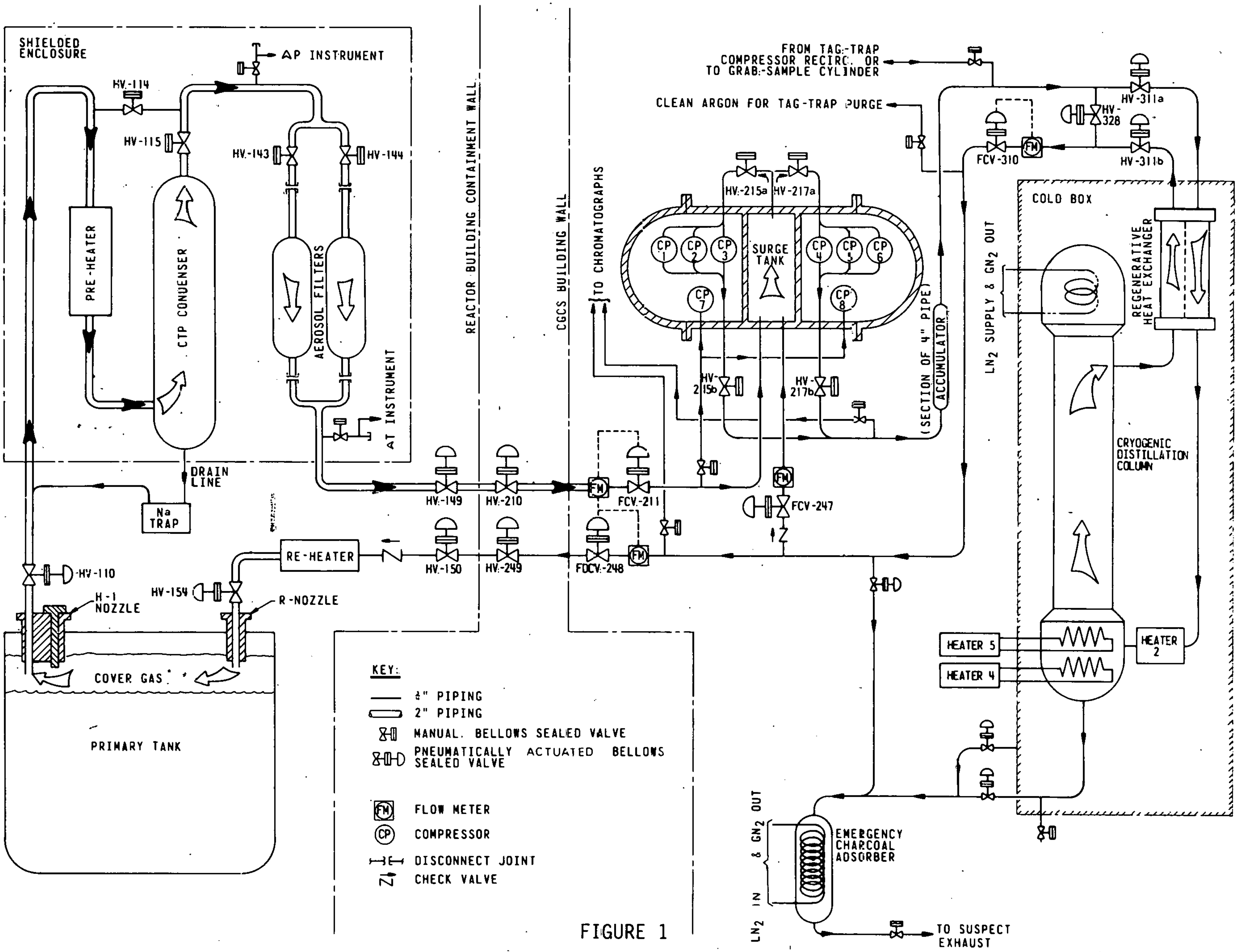


FIGURE 1

CGCS MAIN LOOP (SIMPLIFIED)

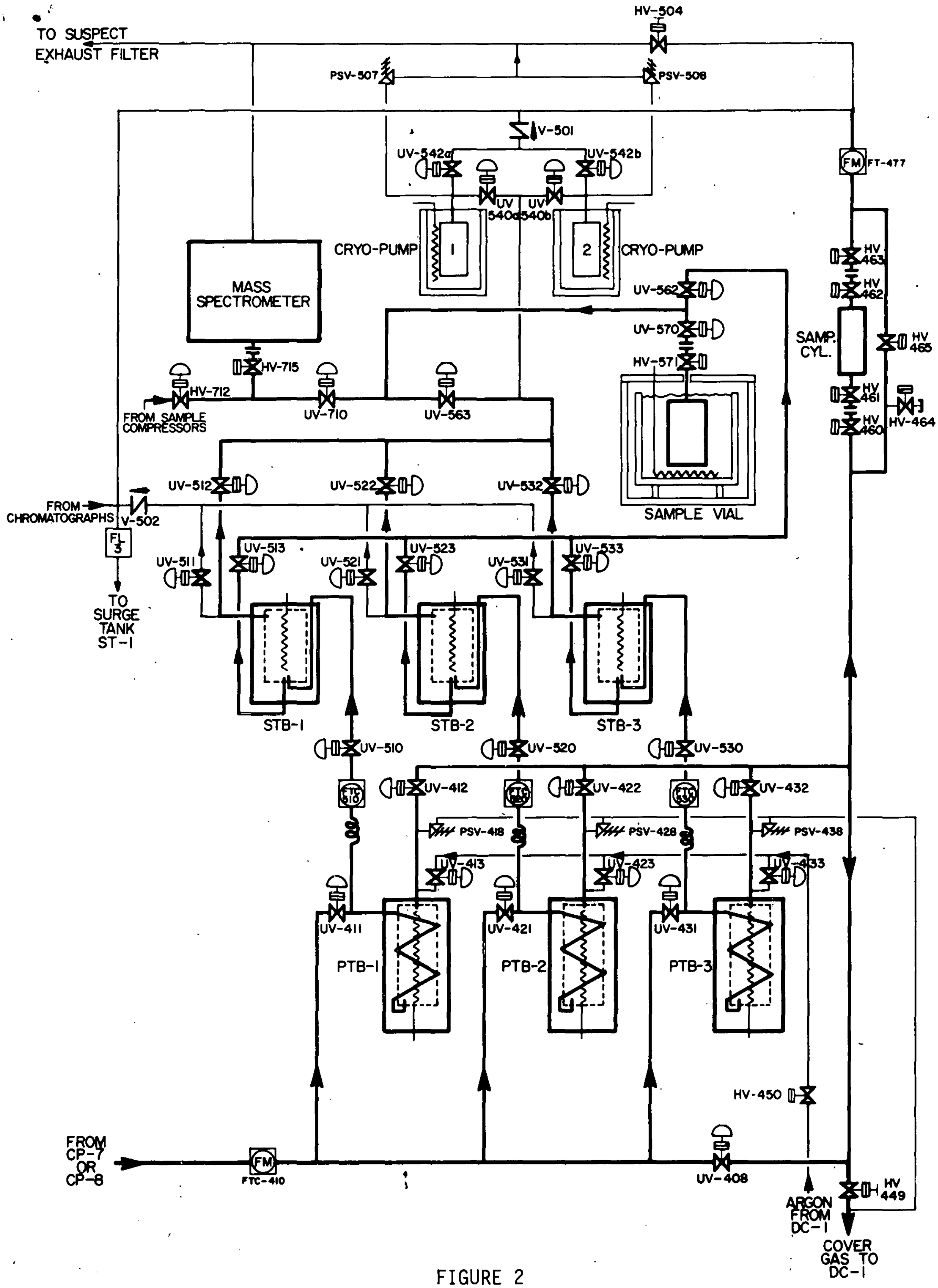


FIGURE 2

CGCS XENON-TAG TRAPPING AND ANALYSIS SYSTEM

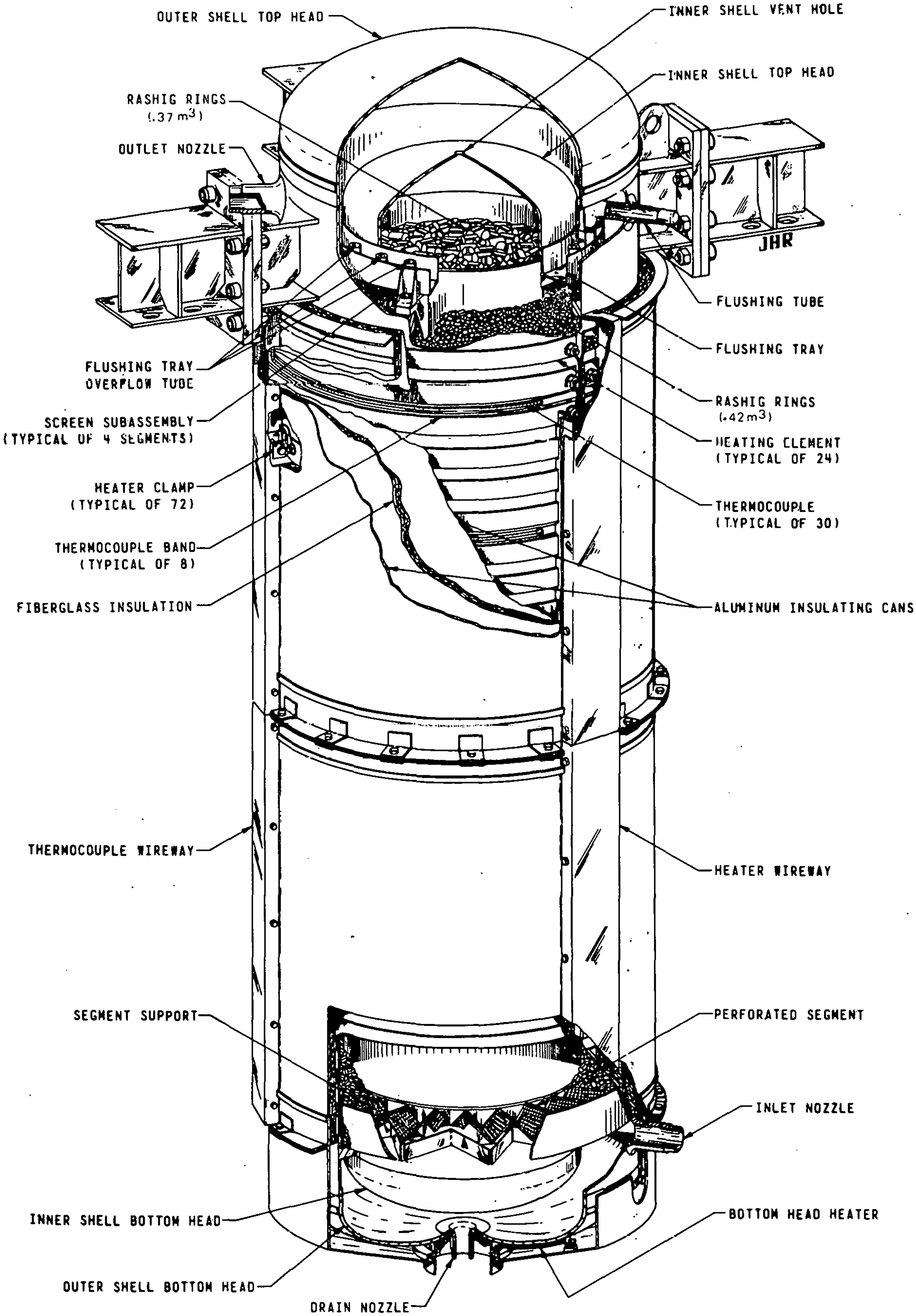
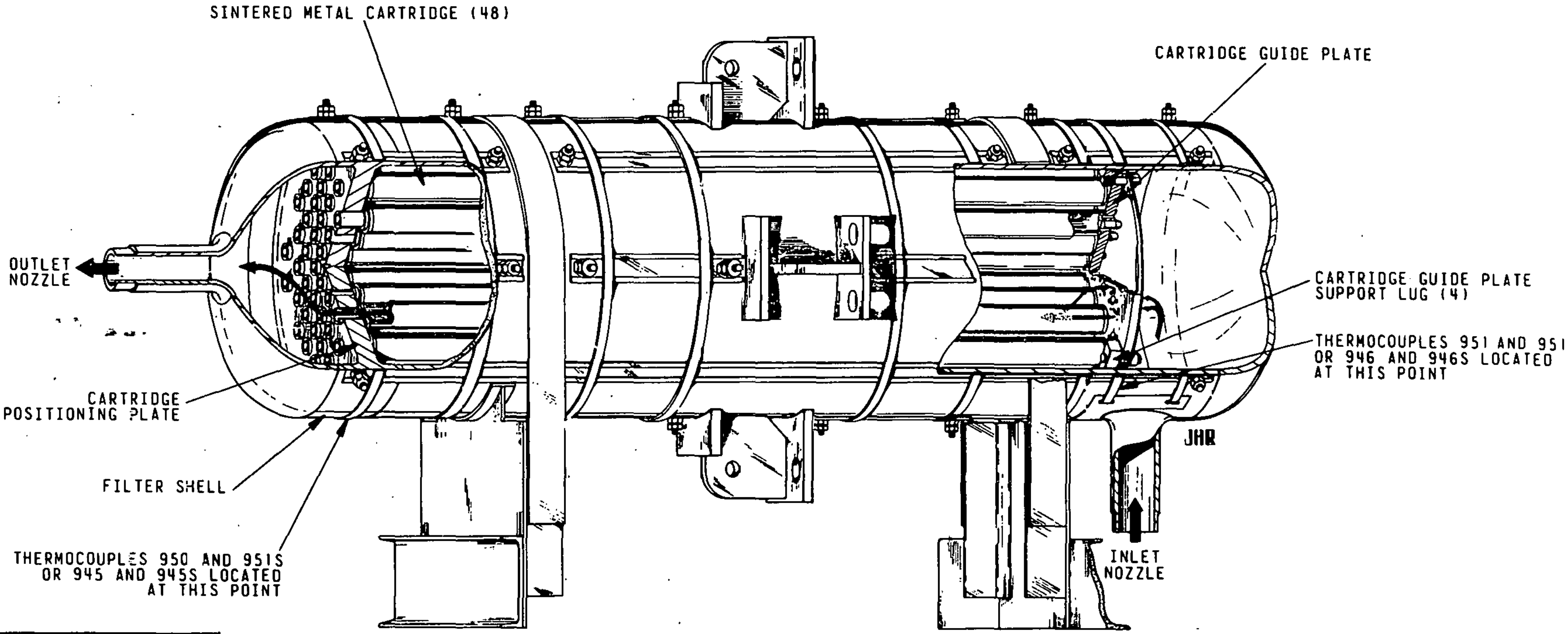


FIGURE 3

CGCS CTP CONDENSER



THERMOCOUPLES	
FL1	FL2
TC 950	TC 945
TC 950S	TC 945S
TC 951	TC 946
TC 951S	TC 946S

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FIGURE 4

COVER GAS CLEANUP SYSTEM
AEROSOL FILTERS FL1 & FL2

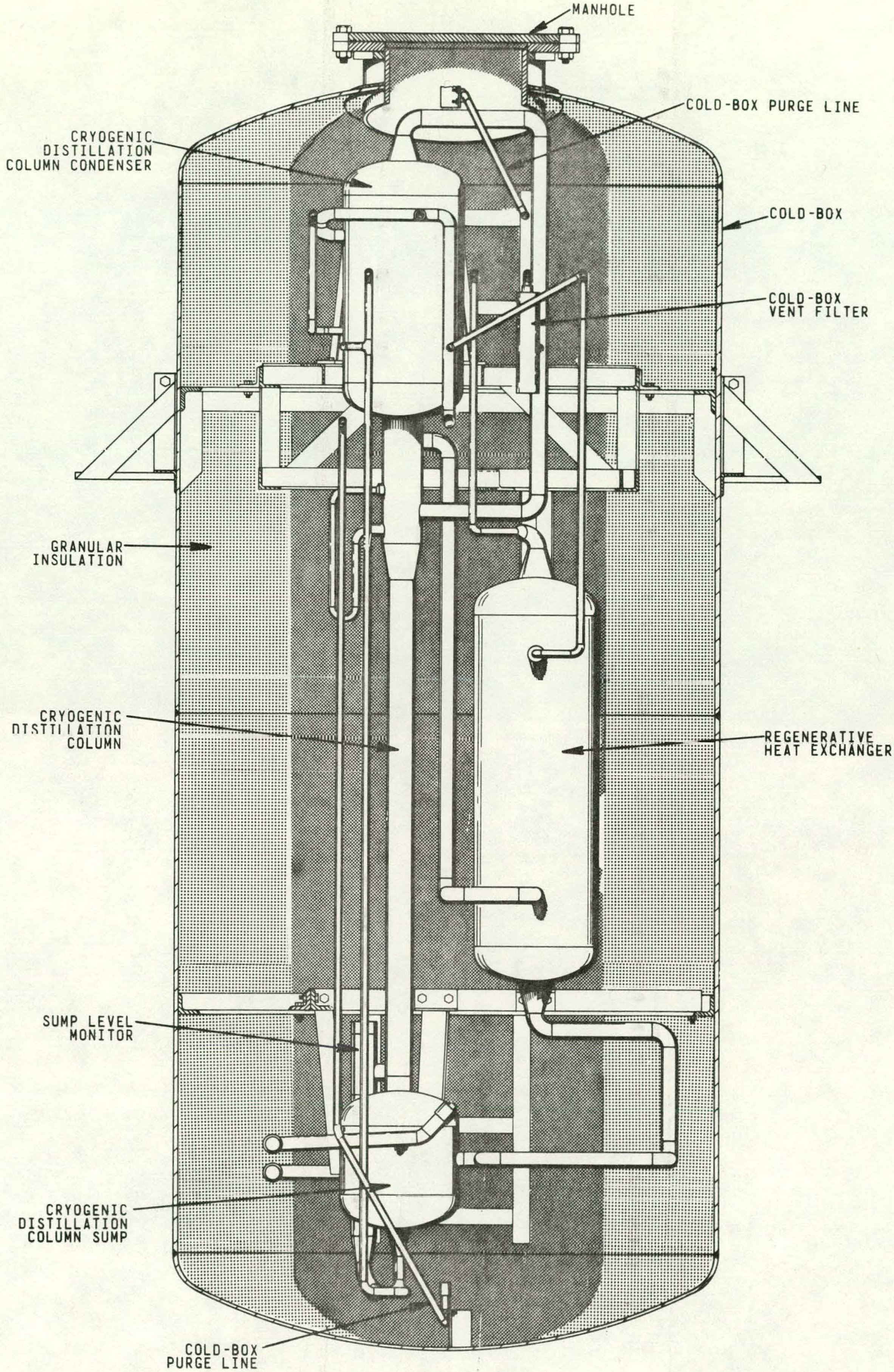

FIGURE 5

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CGCS COLD-BOX W/COMPONENTS

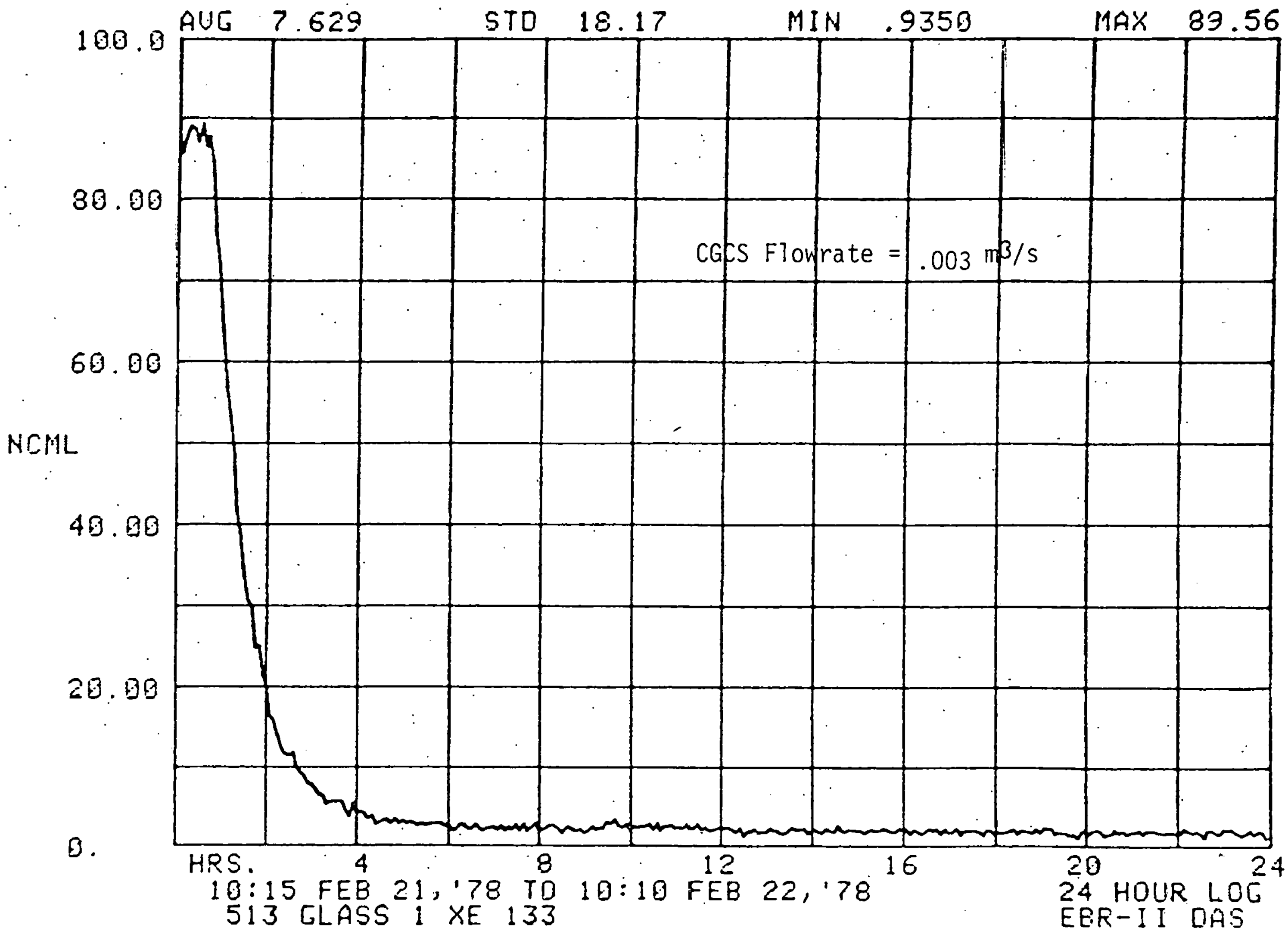

FIGURE 6

CGCS Radioisotope Removal Plot