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SOURCE TERM EXPERIMENTS PROJECT (STEP): AEROSOL CHARACTERIZATION SYSTEM

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MASTER

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INTRODUCTION

A series of four experiments has been conducted at Argonne National Laboratory's TREAT Reactor. These experiments, which are sponsored by an international consortium organized by the Electric Power Research Institute, are designed to investigate the source term, i.e., the type, quantity and timing of release of radioactive fission products from a light water reactor to the environment in the event of a severe accident in which the core is insufficiently cooled. In such a situation radioactive fission products that would ordinarily remain in the fuel pins are released as the cladding and fuel degrade and melt. Current source term estimating procedures appear to be overly conservative based on information gathered during actual reactor accidents, most notably TMI-2. Experiments are required to confirm this, and provide information and data from which to construct more accurate estimating procedures.

The STEP tests have been designed to provide some of the necessary data regarding the magnitude and release rates of volatile fission products from degraded fuel pins, their physical and chemical characteristics, and aerosol formation and transport phenomena of those fission products that condense to form particles in the cooler regions of the reactor beyond the core. These are in-pile experiments, whereby the test fuels are heated in a nuclear test reactor by neutron induced fission and subsequent cladding oxidation in steam environments that simulate as closely as practical predicted severe reactor accident conditions.

The test sequences cover a range of pressure and fuel heatup rate, and include the effect of Ag/In/Cd control rod material Table 1 shows the test parameters as well as the type of hypothetical accident simulated.

EXPERIMENTAL SYSTEMS

Identical experimental systems consisting of a primary vessel, secondary containment, aerosol characterization system and associated plumbing and instrumentation are used in each test. See Figures 1 and 2. Four previously irradiated 1.3 m long fuel pins (plus control rod material in STEP-4) are located in the lower section of the primary vessel, which is suspended into the core of the TREAT Reactor. The reactor is operated in a manner that produces a prescribed transient neutron flux at the test vehicle location. Induced fission in the test fuel raises its temperature to the melting point of the cladding while the fuel in the reactor core remains at safe temperature levels. The

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TABLE 1. Step Test Conditions

Test	Pressure (psia)	$(\frac{\Delta T}{\Delta t})_{avg}$[a] (K/min)	Duration (min)	Range of Steam Flow (lbm/h)	Accident Scenario
STEP-1	~45	120	21	5.5-1.9	PWR-large coolant pipe break, failure of ECC
STEP-2	~45	40	22	2.7-1.8	BWR-loss of heat removal capability, successful depressurization
STEP-3	1150	80	21.5	4.0-1.9	PWR-loss of heat removal capability, no depressurization
STEP-4	1120	80	24	4.0-1.9	Like 3 but with control rod material present

[a]design values, prior to oxidation

fuel is surrounded by an insulating flow tube. Steam is introduced at the bottom of the primary vessel at a variable rate by means of a metering pump. As the steam flows between the pins it oxides the cladding, yielding hydrogen. The steam/hydrogen mixture flows to the top of the primary vessel, carrying the volatile fission products. Aerosols form as the steam cools beyond the fuel region, where the vessel and aerosol characterization system temperatures are maintained at a nominal 644K.

Aerosol Sampling Canisters

Approximately thirteen percent of the fission product laden steam/hydrogen mixture is directed in equal proportions to two aerosol canisters, whose inlets are located approximately 1.0 and 2.6 m above the fuel centerline. These locations allow sampling at the minimum and maximum distances above the fuel pins given the space limitations of the vehicle. The canisters are attached to the outside of the primary vessel, within the confines of the secondary containment. Each canister contains three chambers of fourteen collection stages. The stages, which are partitioned to create a labyrinthine channel (.9 cm^2 flow cross-sectional area), are stacked to create a long flow path (3.2 m), enhancing particle collection efficiency and size stratification. See Figures 3 and 4. Flow to the different chambers is controlled by solenoid valves, which are operated sequentially to allow for temporal separation of the particles.

The collection devices in the stages are removable settling plates and frames containing fine wires. See Figure 5. The stainless steel plates sit on the floor of the stages, and are intended to collect particles that settle by gravity and diffusion. The fine wires range from 0.1 to 10 mil (2.54 to 254 μm) in diameter, and are made of various metals. They are positioned perpendicular to the gas flow such that they collect particles by impaction, interception and diffusion. Coupons of various metals are also located on the floor of the stages. They will be studied for chemical interaction with the gaseous fission products.

FIGURE 1. STEP In-Pile Vehicle

Filters

Filters located in the six lines downstream of each of the canister chambers collect aerosol particles that are not removed in the canisters. These filters are attached to the primary vessel at a height that allows them to be viewed by a gamma detection system, enabling real-time identification of a portion of the radioactive fission products. The system also contains a filter to capture particles that pass through the primary.

FIGURE 2. STEP Vehicle and Auxiliary Equipment Schematic

FIGURE 3. Aerosol Sampling Canister

FIGURE 4. Aerosol Sampling Canister Stage

FIGURE 5. Sampling Devices

FIGURE 6. Sample Tree

Sample Tree

Particulate and gaseous fission products entrained in the bulk of the steam-hydrogen mixture are collected on metal coupons located on the sample tree that hangs in the center of the primary above the fuel pins. The coupons are attached at various axial locations. The tree also contains cone-shaped traps that collect liquid that condenses on the body of the tree. See Figure 6.

FLOW CONDITIONS

In order to analyze the test data it is necessary to know the gas velocities. Because of the low flows and space limitations, flow meters and controllers were not installed in the lines from the primary and the canisters. Only the total inlet steam flow is metered.

The method employed for determining the velocities is based on maintaining a constant flow split between the aerosol sampling and main effluent lines, which are in parallel. This is done using porous metal elements in the primary outlet and the aerosol sampling system lines that have pressure drops that are directly proportional to the gas velocity. Refer to Figure 2. The pressure drop across each leg is the same so the proportion of flow through each is a function of the relative resistances of the flow balancer elements, which were selected such that their resistances would be sufficiently greater than other resistances in the lines.

The flow balancer elements are sintered porous metal filters The particular porosities were selected based on laboratory determination of their coefficients of resistance. A combination of 2 and 15 μm filters yield the desired 13/87 flow split.

Flow through the canister chambers is laminar, with Reynolds numbers (Re) on the order of 75 and 25 for the low pressure and high pressure tests, respectively. Re in the primary vessel ranges from 500 to 50.

Because of the low Re, it was questionable whether aerosols formed in stream lines above the breaches in the fuel pins would sufficiently mix radially in the gas prior to reaching the level of the lower sampling port, which is flush with the primary vessel wall. Sufficient mixing is required to achieve a representative aerosol sample. Flow visualization experiments were conducted in a full-scale Plexiglas mock-up of the system. A visible hydrocarbon vapor, "fog juice", was injected into air that was pulled into the mock-up. Re were matched; heat transfer affects were not simulated. It was observed that sufficient mixing does occur provided the sample tree is in place. The radial and axial locations of smoke injection were found not to have any effect upon the level of mixing.

AEROSOL COLLECTION

Theoretical values of particle collection efficiencies for the canisters for the low and high pressure tests appear in Figures 7 and 8. The collection mechanisms include gravitational settling, impaction around bends and diffusion. Laboratory confirmation of the collection mechanisms of the canisters is being conducted using monodispurse polystyrene latex (PSL) particles suspended in air. A TSI, Inc, Tri-jet aerosol generator (Model 3640) is being used in conjunction with a Climet optical particle counter (Model 225), whose output signal is displayed on a multichannel analyzer. Initial experiments have con-

FIGURE 7 Attenuation Through Canister-Steam

FIGURE 8 Attenuation Through Canister-H_2

firmed the collection efficiencies of the fine wires [1]. Theory and experiment are in agreement for larger wires, but solid particle bounce significantly affected the data for smaller wires.

POST-TEST EXAMINATION

The fission product samples collected during the tests are being retrieved and prepared for examination at Argonne's Hot Fuel Examination Facility. The level of radioactive contamination requires that the samples be handled using master-slave manipulators. The stages are photographed, and then the settling plates and wires are removed and mounted. Radiation measurements are taken. They are then examined using a scanning electron microscope. Particle size distributions and elemental compositions are obtained for representative samples. The metal coupons from the sample tree and the canisters are examined to determine element and compound composition, including the products of reactions with the various metals, by spectroscopic means.

Data obtained on particle size and composition will be combined with thermal-hydraulic data taken during the tests to determine the main stream aerosol composition and hence fission product release rates and characteristics.

REFERENCES

1. Renken, K. J., Impaction of Solid Aerosol Particles on Fine Wires, Master of Science Thesis, University of Illinois at Chicago, 1984.

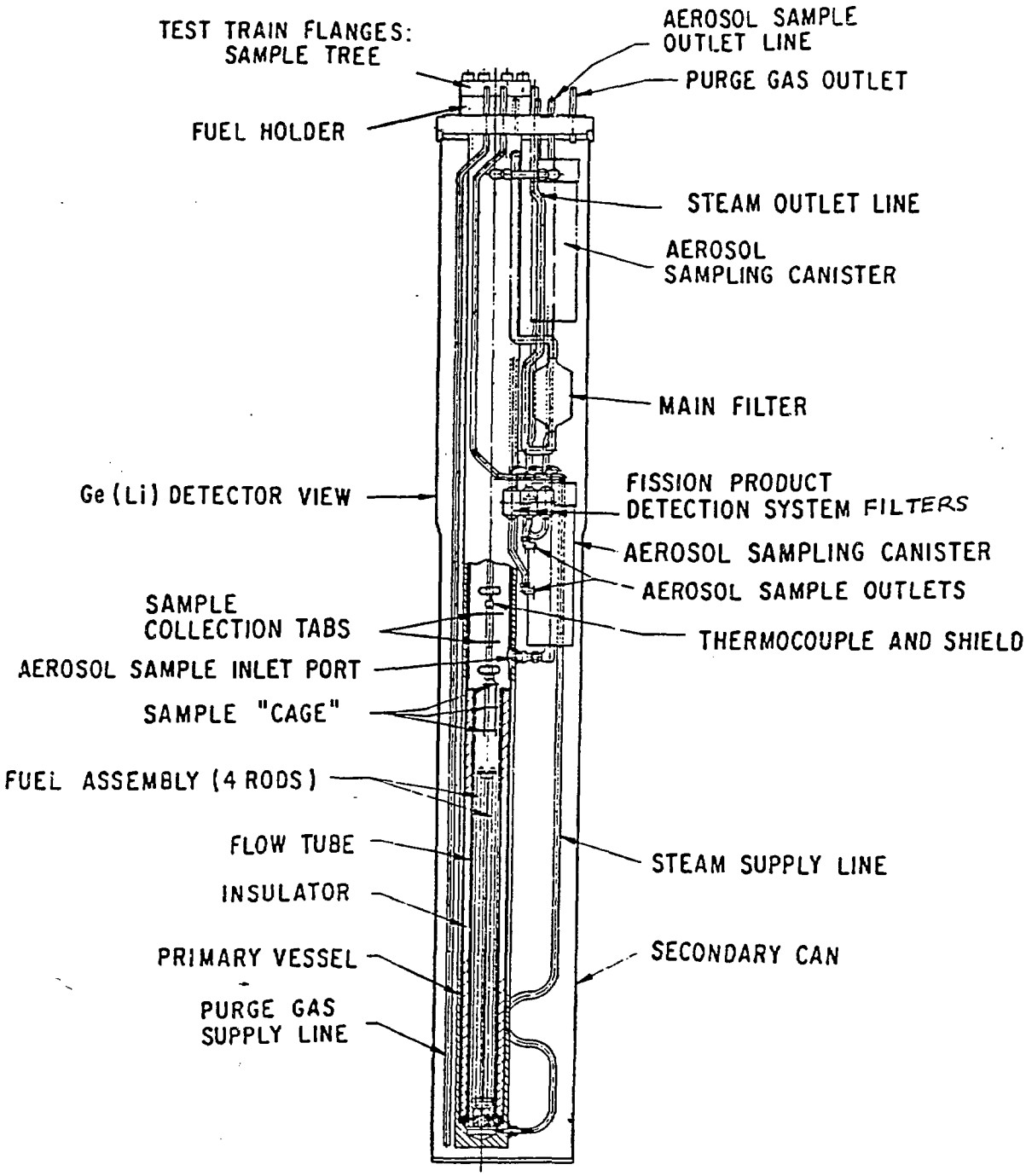

Figure 1. STEP In-Pile Vehicle

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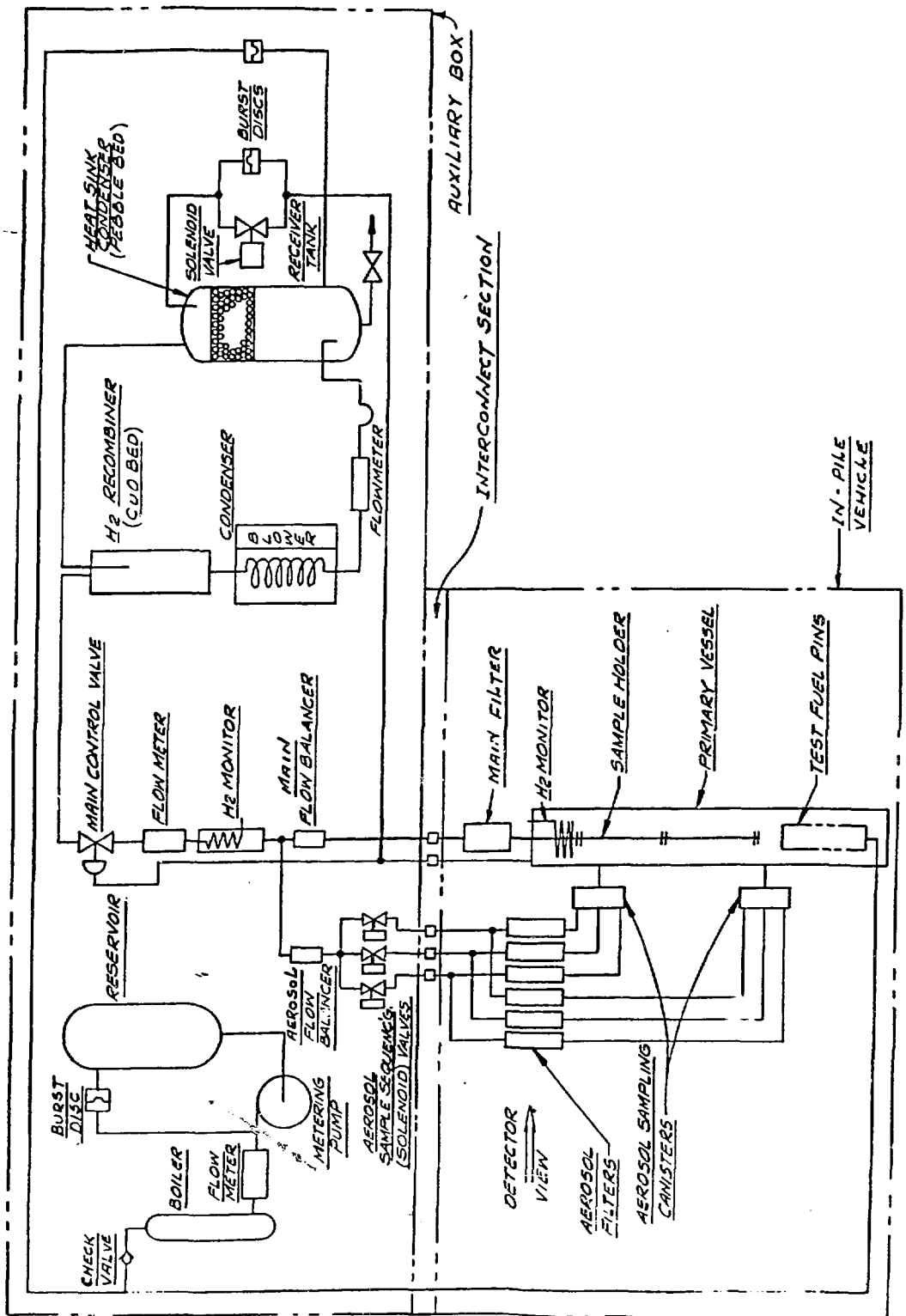

Figure 2. STEP Vehicle and Auxiliary Equipment Schematic

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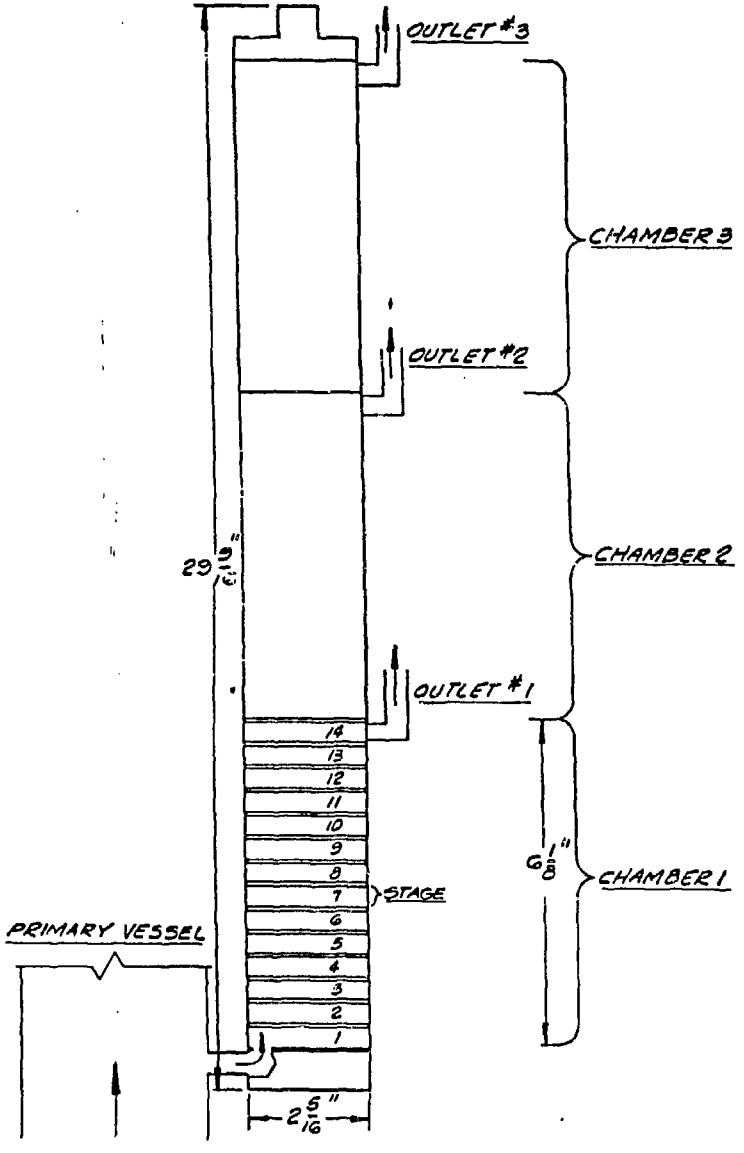

Figure 3. Aerosol Sampling Canister

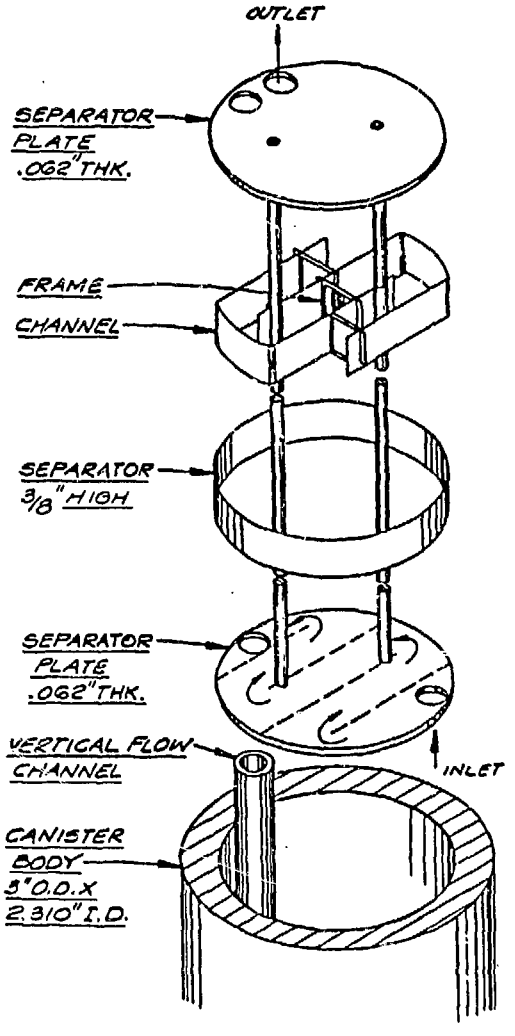

Figure 4. Aerosol Sampling Canister Stage

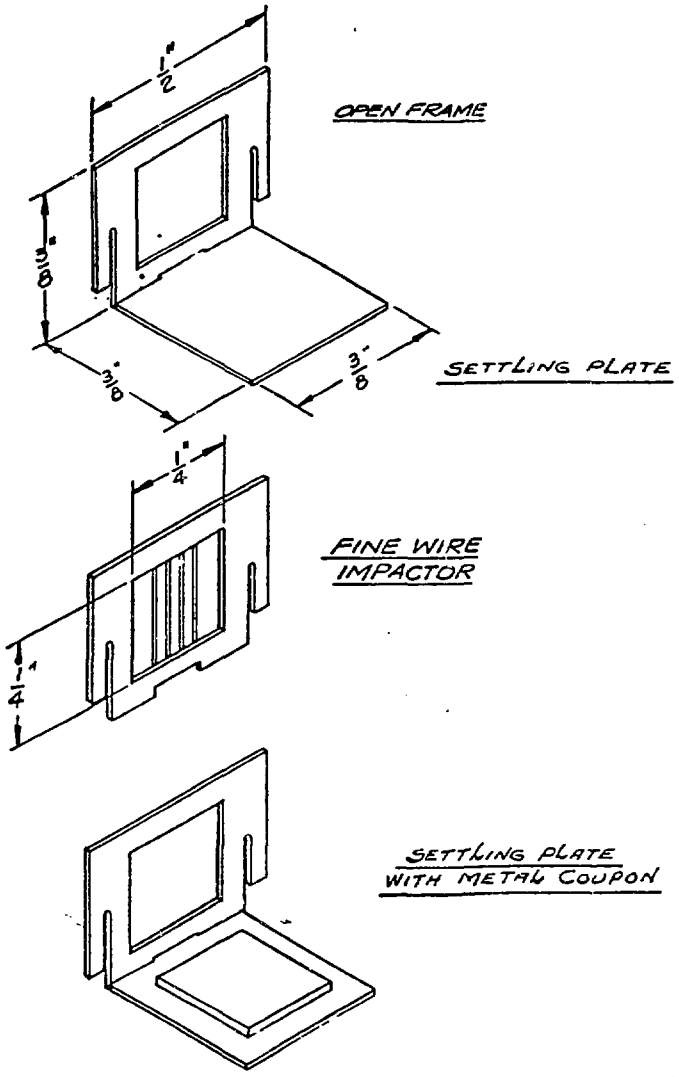

Figure 5. Sampling Devices

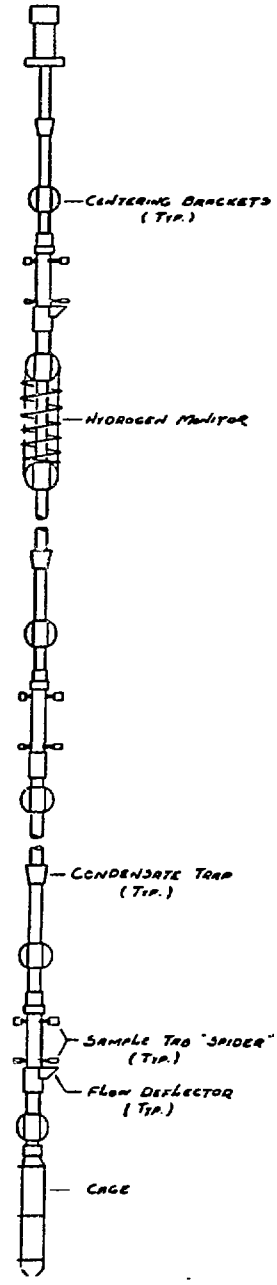

Figure 6. Sample Tree

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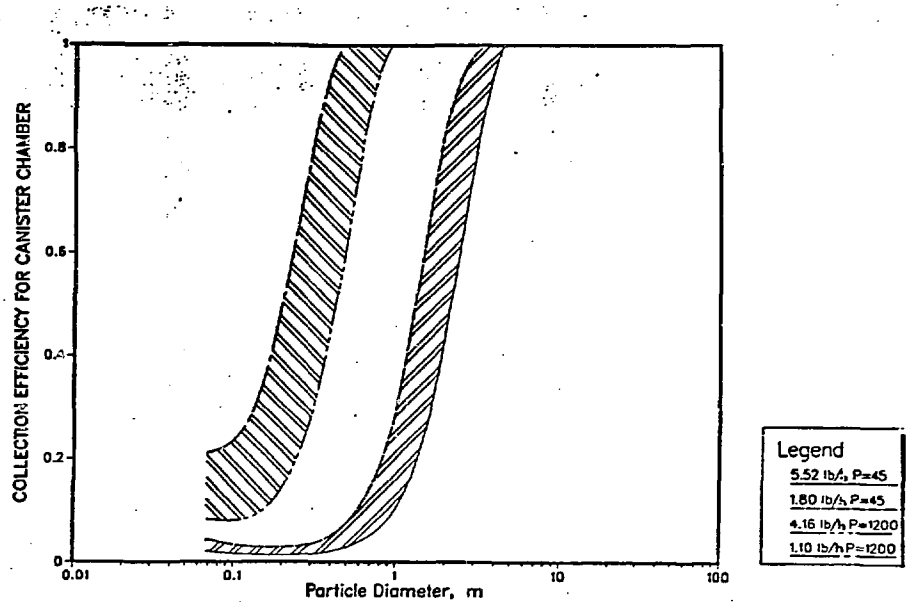

Figure 7. Attenuation Through Canister-Steam

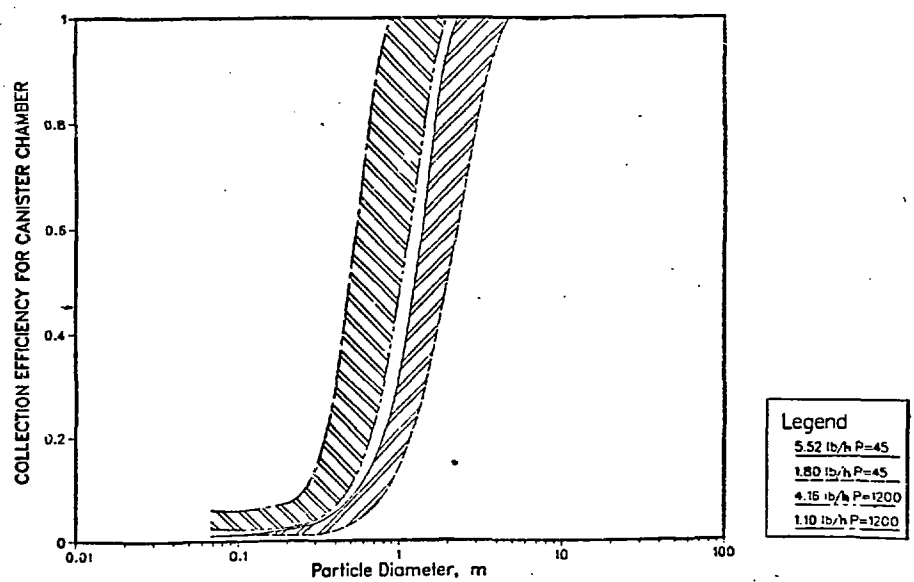

Figure 8. Attenuation Through Canister-H_2

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