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NUCLEAR REGULATORY COMMISSION
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MEMORANDUM FOR: Guy Arlotto, Director
Division of Engineering
Office of Nuclear Regulatory Research

Brian Sheron, Director
Division of Reactor & Plant Systems
Office of Nuclear Regulatory Research

Bill Morris, Director
Division of Regulatory Applications
Office of Nuclear Regulatory Research

Frank Congel, Director
Division of Radiation Protection and Emergency Preparedness
Office of Nuclear Reactor Regulation

Larry Shao, Director
Division of Engineering & System Technology
Office of Nuclear Reactor Regulation

FROM: R. W. Houston, Acting Director
Division of Reactor Accident Analysis
Office of Nuclear Regulatory Research

SUBJECT: FILTERED VENT "WHITE PAPER"

Enclosed is a draft paper on filtered vents that is intended to be a brief summary of the subject, including identification of key technical and regulatory issues. The paper is not intended to be a detailed technical discussion.

Your comments and suggestions by COB December 18 would be appreciated.

The paper was drafted by L. Soffer, J. Read, J. Lane and J. Hulman.

R. W. Houston, Acting Director
Division of Reactor Accident Analysis
Office of Nuclear Regulatory Research

encl:
Draft Filtered Vent White Paper

cc: w/encl.
E. Beckjord
T. Murley
D. Ross
T. Speis
R. Barrett
J. Craig
J. Murphy
M. Silberberg
L. Soffer
J. Read
J. Lane
J. Hulman

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FILTERED VENTED CONTAINMENTS

- A REGULATORY PERSPECTIVE

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1. Introduction

In view of the current interest in filtered vented containments, the staff has prepared a short survey paper summarizing key developments. The developments include both those in Europe, where several designs have been developed and installed, as well as in the U. S., where significant research as well as implementation efforts have also occurred. Since this discussion is also intended to give the reader a regulatory perspective, sections on technical and regulatory issues are also included.

2. Essentials of Filtered Vent Design and Operations

A filtered vent is a device that is intended to prevent or delay containment failure by overpressurization for accidents more severe than those for which the containment was designed, and to filter out or retain a large fraction of any radioactivity.

In essence, the containment atmosphere created by an accident is passed through filtration material such as water, sand or gravel. Much of the particulate activity (such as iodine and cesium) would be trapped by the filter. The radioactive noble gases (xenon and krypton), small fractions of condensible and much of the non-condensible gases are released to the environment, thereby relieving containment pressure.

Initiation of the system either can be automatic, at a preset containment pressure, or can be accomplished manually. The design can be passive in nature, requiring no electrical power since it may utilize the pressure difference between the containment and the atmosphere as the driving force for valve operation.

Filtered vent designs in a number of countries (e.g. Sweden, France) employ systems whose components are located primarily outside and separate from the reactor building. This is not an essential feature however. It is important to recognize that the essential elements of a filtered vent already exist in many U. S. reactors. The most notable example are the 40 boiling water reactors (BWR) in U. S. operation. For these reactors, the water in the existing suppression pool can serve as an excellent filter. However, questions still remain regarding the effectiveness of the hardware and procedures under severe accident conditions.

3. Accident Considerations

There are a number of important challenges to containment and failure modes arising from severe accident conditions. These are as follows:

1) Containment bypass (including failure to isolate containment on demand, suppression pool bypass, and interfacing system LOCAs);
2) Early overpressure/overtemperature failures (including sequences involving melt quenching in-vessel, direct containment heating, and non-condensible gas generation and potential ignition);

3) Rapid steam pressure spikes and missiles;
4) Core debris attack on the steel containment liner resulting in liner melt through;
5) Later overtemperature/overpressure failure; and
6) Basemat penetration.

The feasibility and potential benefits of filtered containment venting have been studied by the NRC and its contractors as well as the nuclear industry. These indicate that the benefits are sequence specific. Filtered venting may have benefits for those sequences where containment failure is predicted to occur relatively slowly (after a period of hours), primarily as a result of overtemperature, overpressure or basemat penetration. Filtered venting is less feasible for those sequences resulting in early overtemperature or overpressure conditions, primarily because of the larger containment penetration lines which would be required to assure relief for rapid increases in containment pressure. However, the benefits may be greater if the containment atmosphere contains a high percentage of particulate radioactivity at early times; hence filtration could achieve a greater degree of mitigation. Venting has also been shown to be important in preventing core melting for accident sequences involving loss of decay heat removal capability and some anticipated transient without scram sequences. For other sequences, venting has been shown to hasten core damage. Finally, filtered venting using either existing features such as suppression pools or separate systems is not regarded as effective against sequences leading to containment bypass for all containment types, or core debris attack on the steel containment shell (for MARK I containments). Some have argued, however, that filtered venting could be beneficial in reducing the driving force for such releases.

4. U. S. Research

U. S. research and use of post-accident filtered vented systems for nuclear facilities originated in connection with breeder reactors. Three such facilities are the Zero-Power Plutonium Reactor (ZPPR), constructed in 1966-1968, the DOE Fast Flux Test Facility (FFTF), and the now abandoned construction of the Clinch River Breeder Reactor (CRBR). These are discussed further in Section 6.

In support of research on a number of alternate containment concepts, Sandia Laboratories performed several studies (Refs. 1,2) beginning in 1978 which examined filtered venting. A study applied to large dry PWR containments (Zion and Indian Pt.) (Ref. 3) was also performed in 1980. These studies generally concluded that filtered venting was feasible for large dry PWR containments, but uncertainties in the degree of risk reduction, potential impacts on other safety systems and relatively high cost warranted additional study.

Venting for BWR's through the suppression pool has also been investigated (Ref. 4) for Peach Bottom (with a MARK I containment) by Idaho National Engineering Laboratory (INEL). They investigated the extent to which venting may be an effective means of preventing or mitigating the consequences of overpressurization. Factors considered included operator and equipment performance. Three major accident sequences were considered, two ATWS and one station blackout. The results indicated that, although venting might be effective, current operating procedures and equipment do not appear adequate to successfully implement a venting strategy in a severe accident situation. INEL is also evaluating the types of improvements in procedures and hardware that could improve the effectiveness of venting. ORNL is evaluating core melt progression and containment performance parameters for two station blackout scenarios at Peach Bottom. Various venting assumptions are to be considered in this evaluation.

Considerable research on the effectiveness of suppression pools and melting ice (Refs. 5, 6) as filtering mediums has been undertaken in the U. S. The U. S. research has included activities sponsored by DOE, industry, NRC and others. The bulk of the research has been aimed at estimating decontamination factors under a variety of operating conditions. To the staff's knowledge, no completely prototypical tests, or actual use at an operating facility has been used to evaluate the effectiveness of filtered vents over the range of accident conditions they may be expected to operate.

5. Foreign Applications

The governments of Sweden, France and the Federal Republic of Germany (FRG), (Refs. 7, 8, 9) all have issued guidelines that have resulted in the installation of filtered vented containments. These activities are briefly described below:

a) Sweden

The Swedish government in 1981 required the owner of the Barsebeck plant, a two unit BWR, to install a filtered venting system as a condition for continued operation after Sept. 1986. A major factor noted in the government's decision was that special priority was to be given to prevention of ground contamination in the event of an uncontrolled release due to the extensive social consequences that might be anticipated in connection with large-scale evacuation. Priority was put on measures for the two unit Barsebeck site, which is situated closest to large urban areas (within 30 km from large parts of the Danish capital of Copenhagen as well as the third largest Swedish City of Malmoe). Venting for the remaining ten Swedish reactors was to be studied.

Consideration of filtered vents for the Barsebeck site began in 1980 as a research project known as FILTRA. The FILTRA system was completed and declared operational at Barsebeck on October 31, 1985. The main features and mode of operation of the FILTRA system (see Figure 1) are given below.

A separate silo-like concrete filter building serves both units. It is about 40 meters high, 20 meters in diameter, and contains 10,000 cubic meters of 25-35 mm diameter gravel. The gravel serves both as a filter and as a passive heat sink, stated as being able to condense steam from a primary pipe rupture and from residual heat for 24 hours. The passive heat sink requirement is used to determine the dimensions as much as the required filtering efficiency. Radioactivity releases to the atmosphere after passing thru the FILTRA system have been estimated to be 100 percent of the noble gases, about 1 percent of any organic iodide (e.g. CH_3I), and less than one one-hundredth of one percent of any remaining particulate activity.

Vent pipes with a diameter of 60 cm are connected from the wetwells of each of the two containments to the filter building, with a rupture disk in each line set to open at 0.65 Mpa (95 psi). The design basis pressure for the Barsebeck containments is 0.5 Mpa (75 psi). Data indicate that the 0.15 Mpa overpressure on the containment would not result in excessive leakage. A separate manually operated shut off valve is installed downstream of the rupture disk to permit re-isolation of the containment, if necessary. The gravel is arranged in the form of an annulus within the filter building. Steam and any radioactivity from the containment enters the center of the annulus and proceeds through the gravel bed in a downflow mode. Effluent from the outlet of the gravel bed is ducted to a stack to be released to the environment. Allowance is made for the collection of steam condensate (which may also contain radioactivity) in the bottom of the gravel bed, and by condensate drain tanks as well. The venting system and the gravel bed are inerted with nitrogen to prevent hydrogen burning (and also to prevent biological growth). The system is also capable of manual venting when any of the following events occur:

1) containment pressures reaches 0.45 Mpa (67 psi) and continues to rise;
2) pool temperature rises above 95°C;
3) simultaneous high pressure and high activity in containment; and
4) high containment water level.

The Swedish government in February 1986 promulgated basic guidelines and criteria with regard to severe accident management and release mitigation measures for all Swedish nuclear powerplants. These reiterated the earlier position that "ground contamination that would make it impossible to use large areas for long periods of time shall be prevented. This means that areas where ground contamination consists of long-lived radioactive substances that provide annual doses exceeding what is permitted for radiation work should be limited to some tens of square kilometers." It was also stated that to protect the reactor containment against overpressure damage, "it must be possible to carry out controlled containment pressure relief."

A multi-venturi scrubber system (MVSS) (see Figure 2) is the selected design for the remaining ten Swedish plants, consisting of both BWR's and PWR's. The functions of the MVSS, water scrubbing and packed bed filtration, are integrated into a single unit which can be located in the vicinity of either a BWR or PWR containment.

The MVSS is located in a 10 meter diameter, 20 meter high cylindrical pressure vessel containing a 200 cubic meter water pool in the bottom and equipment for pressure relief, with moisture separation in a packed bed in the top of the vessel. The MVSS is postulated to perform the following functions:

a) pressure relief;
b) venturi aerosol scrubbing;
c) pool iodine retention; and
d) moisture separation.

The operation of the pressure relief valve can be provided by either manual or automatic valve operation.

The gas and steam flow is vented from the containment into the distribution chamber which passively engages the required number of nozzles in relation to the actual containment pressure independently of any external control or energy source.

The MVSS pressure vessel can be designed to accommodate the effects of hydrogen combustion. However, no detailed ignition design data is available.

The designers estimate that the MVSS can result in a DF of 100 for a BWR, and 500 for PWR plants. Most of the design input came from non-nuclear applications of the venturi scrubbing concept.

Current cost estimates for nine units ordered is a total of $18 million.

b. France

The French government reached a decision in about 1980 to require the installation of a filtered vent system on all PWR's in France. This was stated to be based upon French insights gained from WASH-1400 that indicated that instantaneous containment failure due to steam or hydrogen explosions was not realistic, but that delayed (after about 1 day) containment failure, such as could be caused by core-concrete interactions, was sufficiently likely to require consideration. Since the estimated radiological consequences for a containment failure at about 1 day appeared to be incompatible with the then current French emergency plans (evacuation within 5 km and controls within 10 km of the plant), a decision was reached to mitigate the releases until they were considered compatible.

The filter portion of the design (see Figure 3) consists of a flat circular cylinder having a diameter of about 7.3 meters (a 42 square meter cross-sectional area) and employs sand as the filtration media. A sand bed 80 cm thick rests upon a 20 cm bed of coarse clay particles. This is enclosed within a steel shell that is located on the roof of the auxiliary building. One sand filter is to be shared for each two 900 MWE PWR's, and one unit each added for each 1300 MWE PWR.

The design employs existing containment penetration lines with a diameter of 25 cm, and are intended to ensure containment pressure relief at the end of the periodic tests. Two containment isolation valves, remotely manually controlled, are located in series just outside the containment. These valves are to be opened when the internal containment pressure reaches the design pressure of 5 atmospheres (74 psi) above ambient. These valves, together with the containment penetration itself, are regarded as safety-related. A downstream orificing device reduces the pressure down to about 1 atmosphere through the filter. Flow is downward through the sand, and the effluent is collected via a peripheral ring and released to the atmosphere via a stack. Although the system is estimated to have a filter effectiveness, or decontamination factor (DF), of 10 to 100, it does not consider the heat removal or heat sink requirements for many accident scenarios. In addition, no special provisions for water condensation and collection have been identified.

Information indicates that small quantities of water condensed at the end of the filter downstream path are drawn up the stack. The system is equipped to continuously monitor the activity of iodines and cesiums that are released. The system is periodically checked, especially with respect to pressure relief, following the periodic containment pressure test. Finally, a small air flow is continuously maintained to prevent buildup of moisture, corrosion and frost.

The installation of these systems has begun, with the first ones expected to be installed by the end of 1987 at the Chinon, Paluel and Cattenom sites.

c) Federal Republic of Germany (FRG)

Upon completion of the German Risk Study the FRG concluded that the dominant containment failure mode would be a relatively slow overpressurization that would take about 4 to 5 days before a failure pressure (estimated at about 180 psi) of a 1300 Mwe PWR inner steel containment shell (with a design pressure of 75 psi) would be reached. On this basis, it was decided that the longer time available would permit implementation of measures to avoid overpressure failure such as filtered venting.

The first filtered venting system (see Figure 4) has been constructed for the Brokdorf plant, a PWR, in October 1986. It makes use of existing containment penetrations. The mode of operation is manually controlled based on the conclusion that the exact mechanism of containment failure cannot be predetermined. The containment is to be manually vented upon reaching 1.1 times the design pressure. The filtration medium is stainless steel filter mats which are to remove both liquid and particulate material at a high efficiency. The filter plenum is equipped with drains and lines to allow water condensation to be returned to the containment. The operation is to be cyclic, with periods of isolation following venting, as needed.

Venting systems are also to be provided for the BWR plants. The BWR containment is to be manually vented from the wetwell air space when the pressure reaches its design valve. The filtration unit is to consist of a venturi scrubber section and a dry particulate post-filtration section that can be operated at various pressures. The DF is estimated to be at least 1000 for aerosols and 100 for elemental iodine.

6. U. S. Applications:

a) U. S. Experience

The only operational filtered vented containment systems on U. S. reactors that the staff is aware of are for the Zero-Power Plutonium Reactor (ZPPR) test facility located in Idaho, and for the Fast Flux Test Facility (FFTF) located in Washington. A filtered vent design was also proposed for the now abandoned construction of the Clinch River Breeder Reactor (CRBR).

The Zero-Power Plutonium Reactor (ZPPR) test facility utilizes (Ref. 10) a deep bed of graded sand and gravel as its roof to form a filtered path for plutonium and other aerosols in the event of a core-melt accident (see Figure 5). The sand and gravel filter is supplemented by a bank of high efficiency particulate air (HEPA) filters which serve as a secondary filter.

The FFTF system (see Figure 6) is intended to be part of the Containment Margins System (CMS) (Ref. 11), and is designed to deal with very low probability events involving the release of primary system sodium, fuel and core debris in the reactor cavity. A system for venting and controlling excessive FFTF reactor containment pressure consists of a 30 inch diameter containment penetration line with 2 isolation valves located outside of containment. The isolation valves can be remotely operated from the control room and are equipped with key lock switches to prevent unauthorized operation. Downstream of the isolation valves is a combination scrubber/filter system. The scrubber portion consists of a venturi scrubber utilizing water sprays (with a chemical additive to enhance removal of elemental iodine), to remove an estimated 90% of any particulate being released from containment. The scrubbed gas then enters a five stage cylindrical filter composed of polypropylene in a fibrous mat. The fibrous filter is estimated to remove about 99% of the remaining particles. Thus, the combined removal efficiency of the system is 99.9%. The effluent is then released to the stack, after being continuously monitored for gross radioactivity content. The system is designed as safety-related up to and including the outboard containment isolation valve, but is non-safety grade beyond this point.

The design for the Clinch River Breeder Reactor (CRBR) also proposed a system (Ref. 12) to accommodate core-melt and core disruptive accidents. The applicant proposed controlled venting of the reactor containment atmosphere through filters as a means of reducing the likelihood of a large uncontrolled release of radioactivity beyond 24 hours. This system, which was to consist of exhaust fans, an air washer, sodium scrubber and water separator, a heater prefilter, a HEPA filter, an iodine absorber bed and an after-filter reached a preliminary engineering design state.

All U. S. boiling water reactors (BWR's) have water suppression pools that can serve to scrub and retain radioactivity with a variable degree of effectiveness. Analyses of severe accident sequences have estimated a wide range of DF values for certain fission products exclusive of noble gases, from as little as 3 to over 1000, depending upon the accident sequence and pool temperatures. Several studies have examined the feasibility of using BWR suppression pools, together with existing equipment and possible modifications, to allow an effective filtered containment vented system. Emergency Procedure Guidelines (EPG's), the predecessor to plant specific Emergency Operating Procedures, have been developed by industry and approved by the staff for use of vents at U. S. BWR's. These EPG's were developed in direct response to operating problems identified as a result of the TMI accident. The venting EPG's are intended primarily for pressure relief during accidents more severe than design basis events before core damage would occur, but include provisions for post-core damage use. Both drywell and wetwell vents have been proposed by some licensees. Some licensees, however, have indicated their intent to use wetwell vents to prevent containment overpressurization after core damage. This post-core damage use would provide a filtered vent by scrubbing non-noble gas fission products through the suppression pool. One licensee has also proposed venting the wetwell through the spent fuel pool enhance fission product scrubbing after core damage.

PWR's containing ice condensers also contain a passive filtration device capable of scrubbing and retaining fission products. The effectiveness depends upon not being bypassed in an accident, but only so long as an ice-bed remains in place (does not fully melt). The feasibility of utilizing an ice condenser containment as a filtered vented system has not been extensively explored.

In other operating reactors, certain engineered systems, such as fan coolers, could also enhance the trapping and retention of fission products over and above the effects of natural deposition processes.

b) Proposed U. S. Applications

In July 1987 the Boston Edison Co. voluntarily proposed (Ref. 13) a series of Pilgrim plant modifications termed the "Safety Enhancement Program" (SEP). A goal was to identify and implement plant improvements responsive to a draft staff BWR MARK I initiative (Ref. 14) in a manner which would promote effective use of plant capabilities in the event of a severe accident. The proposed enhancements include 12 physical plant changes, including the installation of a Direct Torus Vent System (wetwell air space). In proposing the vent system, the licensee acknowledged that venting is one of the strategies used in the BWR Owners Group Emergency Procedures Guidelines. The design changes provided a direct unfiltered torus vent path from the torus to the main stack bypassing the Standby Gas Treatment System (SGTS) on the torus purge exhaust line. The bypass consists of an 8-inch line around the SGTS to a 20-inch main stack line. The new line would be designed to ASME III Class 2 standards, and would include DC operated solenoid valves instead of more common AC solenoid valves. This would allow for operation in the event of loss of the emergency diesel generators. To limit the likelihood of inadvertent operation, key lock switches would be used to control valve operation.

The Long Island Lighting Company (LILCO) has also addressed the issue of venting with the proposed installation (Ref. 15) of their Supplemental Containment System (SCC) on the Shoreham Nuclear Power Plant Station. One of the primary goals of the SCC is to provide a wetwell airspace vent. The mechanism proposed to achieve this is the "FILTRA" design installed at the Barsebeck Nuclear Plant in October 1985. DC battery power would be provided for 48 hours to facilitate isolation valve operation post-accident. The system is seismically designed as a non-safety related system beyond the containment isolation boundary. The operation of the system would act to promote SRV operation, and to maintain the drywell floor seal integrity, by prohibiting containment pressure from rising above 60 psig.

The licensee for Vermont Yankee, a BWR with a MARK I containment, also examined several containment enhancements in a report (Ref. 16) to the staff in September, 1986. Included was an assessment of the feasibility and benefits of venting through the suppression pool wet well for a number of severe accidents. Although concluding that containment venting was not practical with the present plant configuration, the licensee recommended that further study, including several relatively low-cost modifications, was warranted.

10. Areas of Incomplete Information

There are a number of areas associated with venting for which the staff presently has incomplete technical information. These include the following:

a) A good quantification of the net reduction in core-melt probability, if any, and its associated uncertainty, and how this might be expected to vary for different designs and operating characteristics. As examples, does venting result in an increase in core-melt probability for some accident sequences and, if so, which and how much? What reduction in core-melt probability can be expected for the Swedish FILTRA design at a U. S. reactor?

b) A good quantification of any benefits to be gained from venting (including any risks to be avoided) for each important accident sequence in a plant, and at various times within a sequence. This would include quantification of the reduction in accident consequences and net reduction in risk from venting based, in part, on a quantification of the reliability of important components such as rupture disks, and uncertainties in filtration performance.

c) A quantification of the risks of inadvertent venting. For example, what are the consequences of inadvertent venting and how would these vary for different meteorological conditions?

d) A quantification of any negative impacts of venting and design changes on existing safety systems. For example, could venting followed by containment re-isolation and spray actuation result in containment buckling by excessive negative pressure?

e) How well can existing designs survive accident conditions such as hydrogen combustion, and external challenges such as seismic events and tornados?

f) How should vent systems be actuated (actively, passively) for optimum safety and reliability? As examples, how should vent valves be powered during station blackout conditions? Is there adequate assurance that containment could be re-isolated once vent valves are opened?

g) What are the costs and benefits of mitigation strategies other than venting? For example, can the formation of non-condensible gases that could lead to containment overpressurization be reduced by use of different materials within containment?

11. Regulatory Issues

There are also a number of important regulatory issues related to filtered vents which the staff believes are important for use in the U. S. These are as follows:

a) Is there a net safety benefit to venting? If so, under what conditions?

b) What are the accident conditions and off-site environmental conditions where venting is justified? When is venting not justified?

c) What design, testing and quality assurance standards should be applied to vent systems?

d) How should vent systems be operated (passively or actively)? If actively operated, who should make the decision to vent and under what conditions ?

e) What performance standards (degree of mitigation) should be applied to vent systems?

f) Should filtered venting be required in order to provide an adequate level of safety, or is it a safety improvement that is to be judged by cost-benefit analyses?

g) If the latter, how should the effects of land contamination be factored into any cost-benefit study?

h) If not required, what safety credit should the NRC allow in licensing and operational assessments if a licensee proposes a filtered vent design?

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15. Viewgraphs, "Shoreham Supplemental Containment System", April 1987

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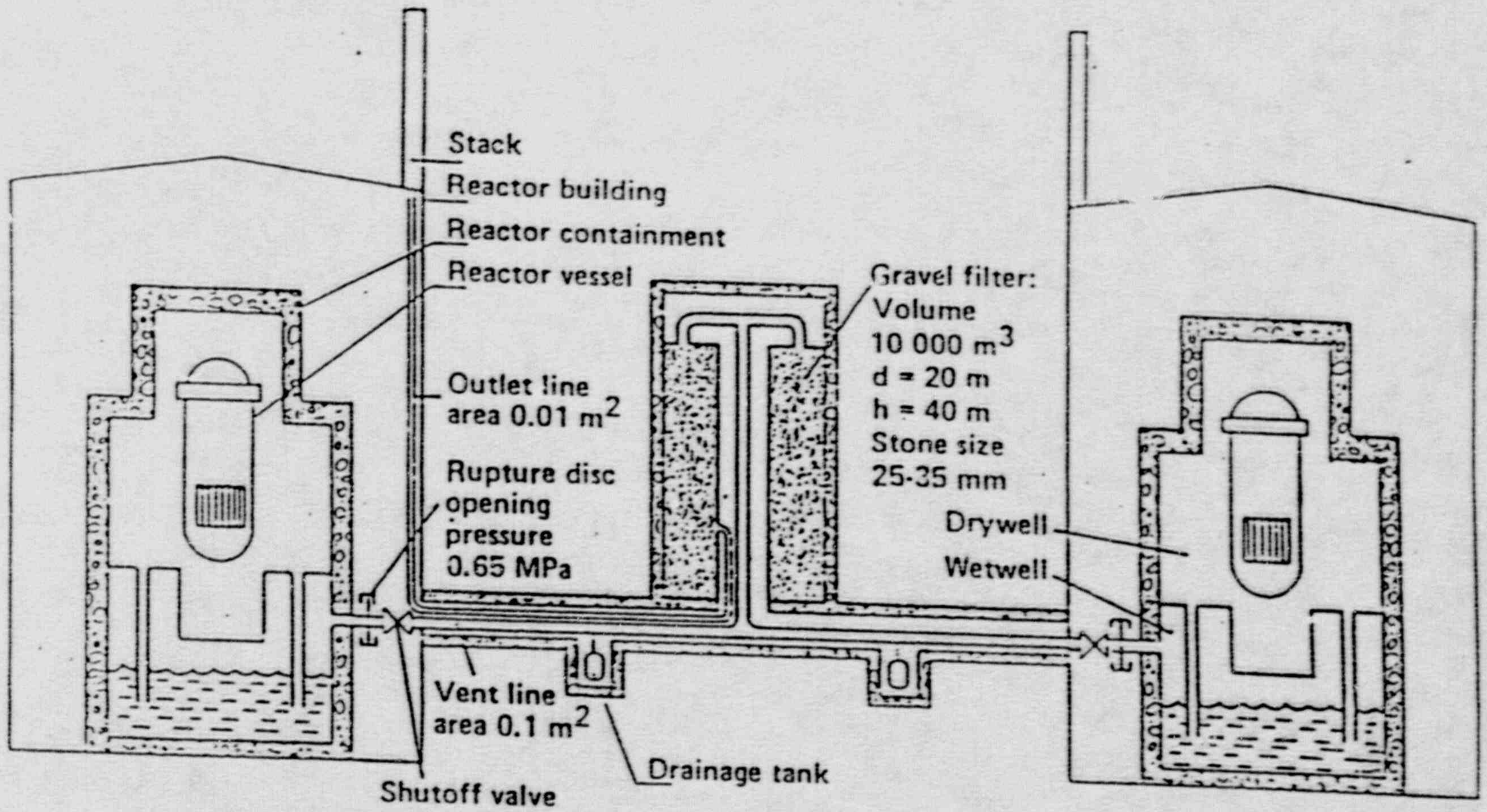

Figure. 1 Schematic drawing – filtered venting of reactor containment. (FILTRA)
(from Ref. 9)

ASEA-ATOM

FILTRA - MVSS

FILTERED CONTAINMENT VENTING WITH MULTI VENTURI SCRUBBER SYSTEM

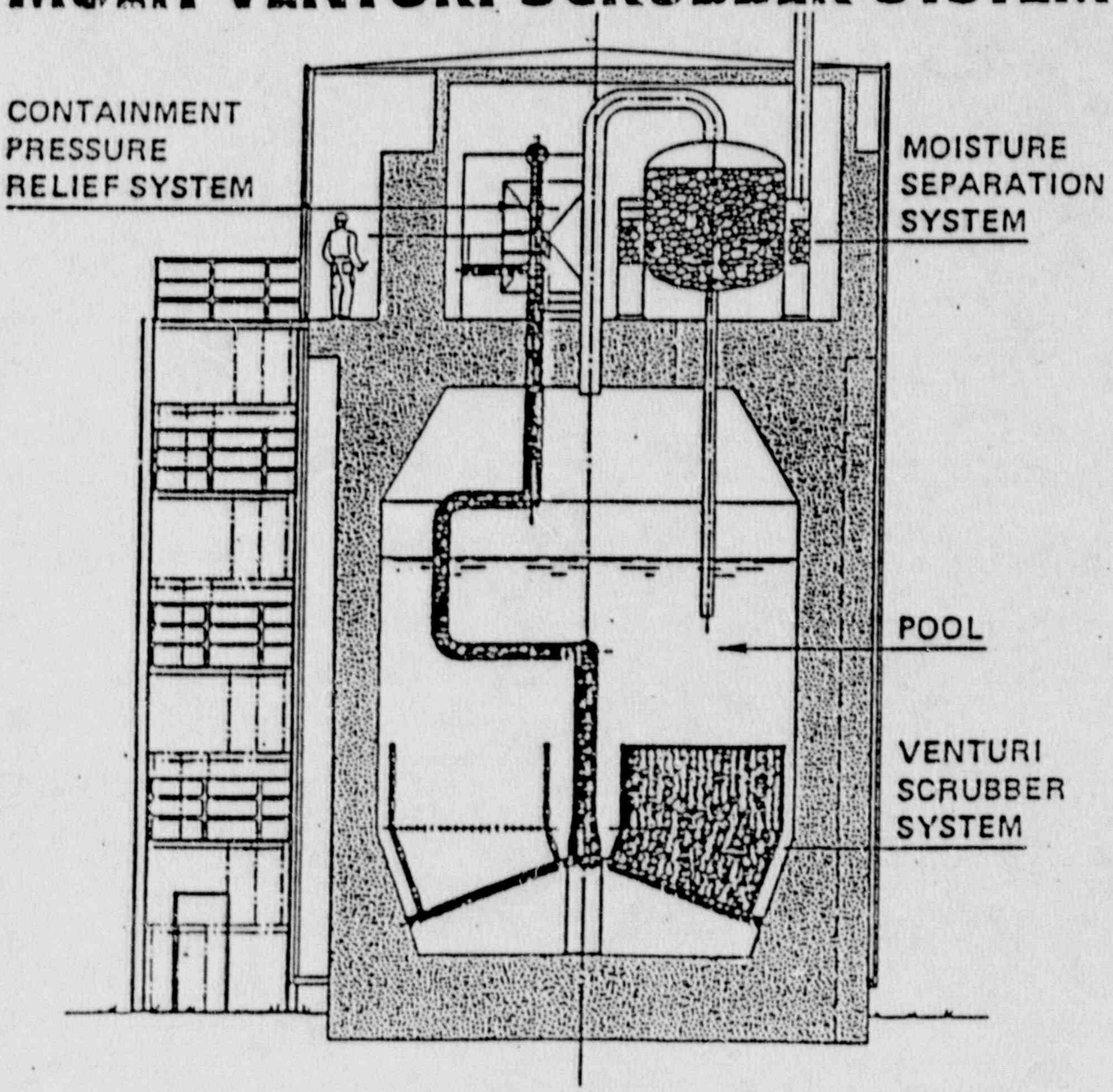

FIGURE 2 THE SWEEDISH MVSS CONCEPT
(from Ref. 9)

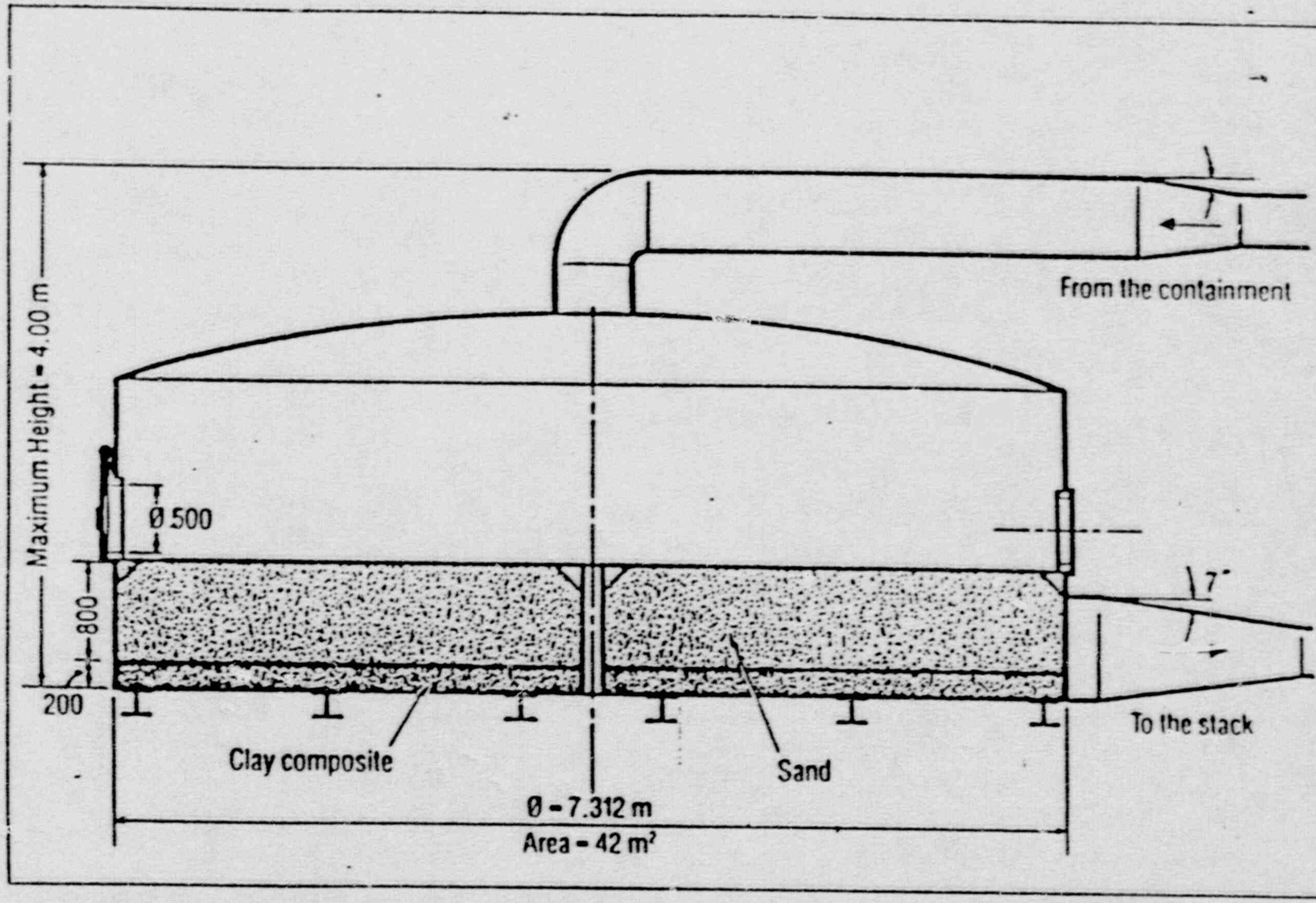

Figure 3 Sand filter for venting of French PWR containments (from Ref. 9)

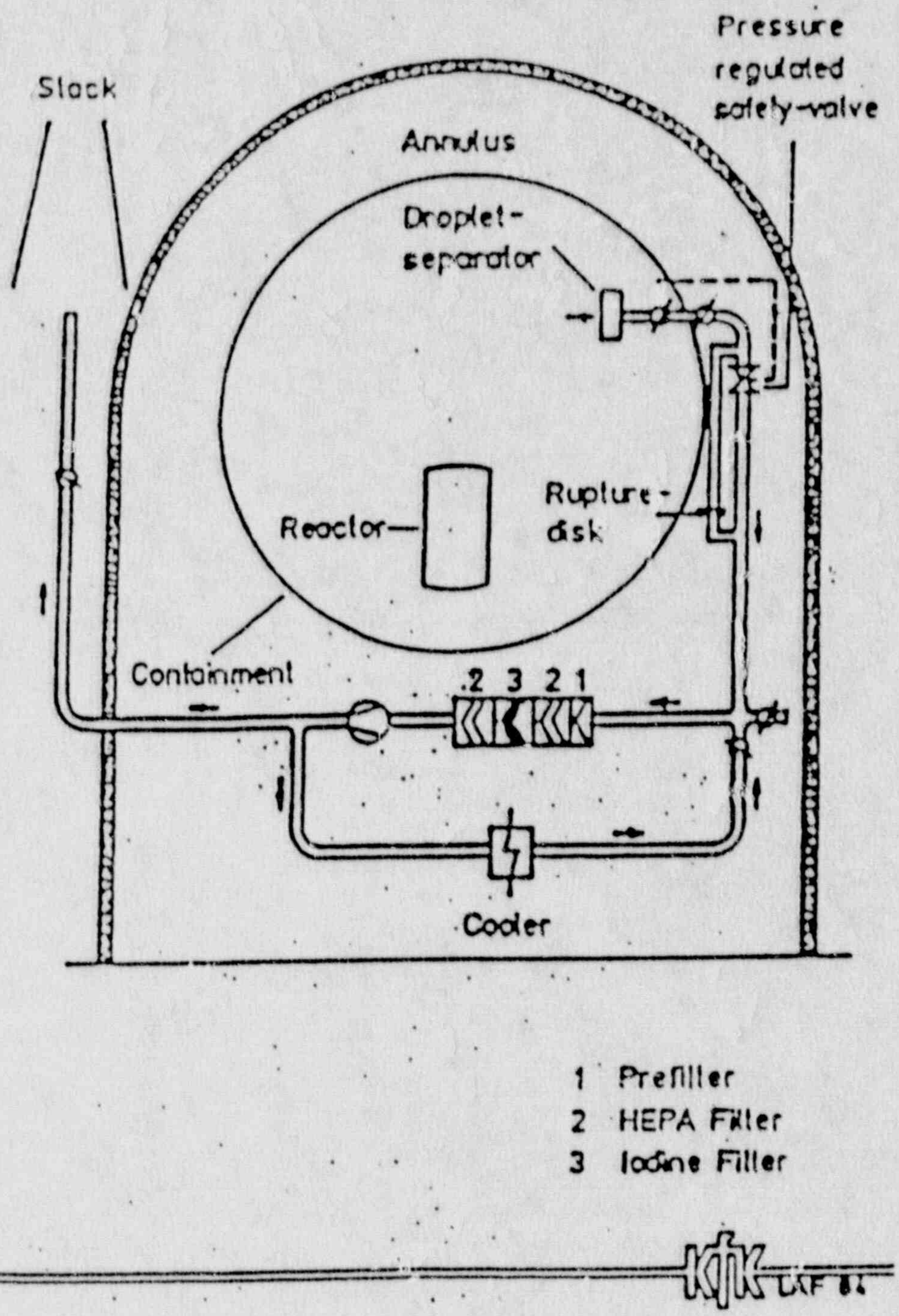

FIGURE 4 THE GERMAN POST ACCIDENT VENTING CONCEPT
(from Ref. 7)

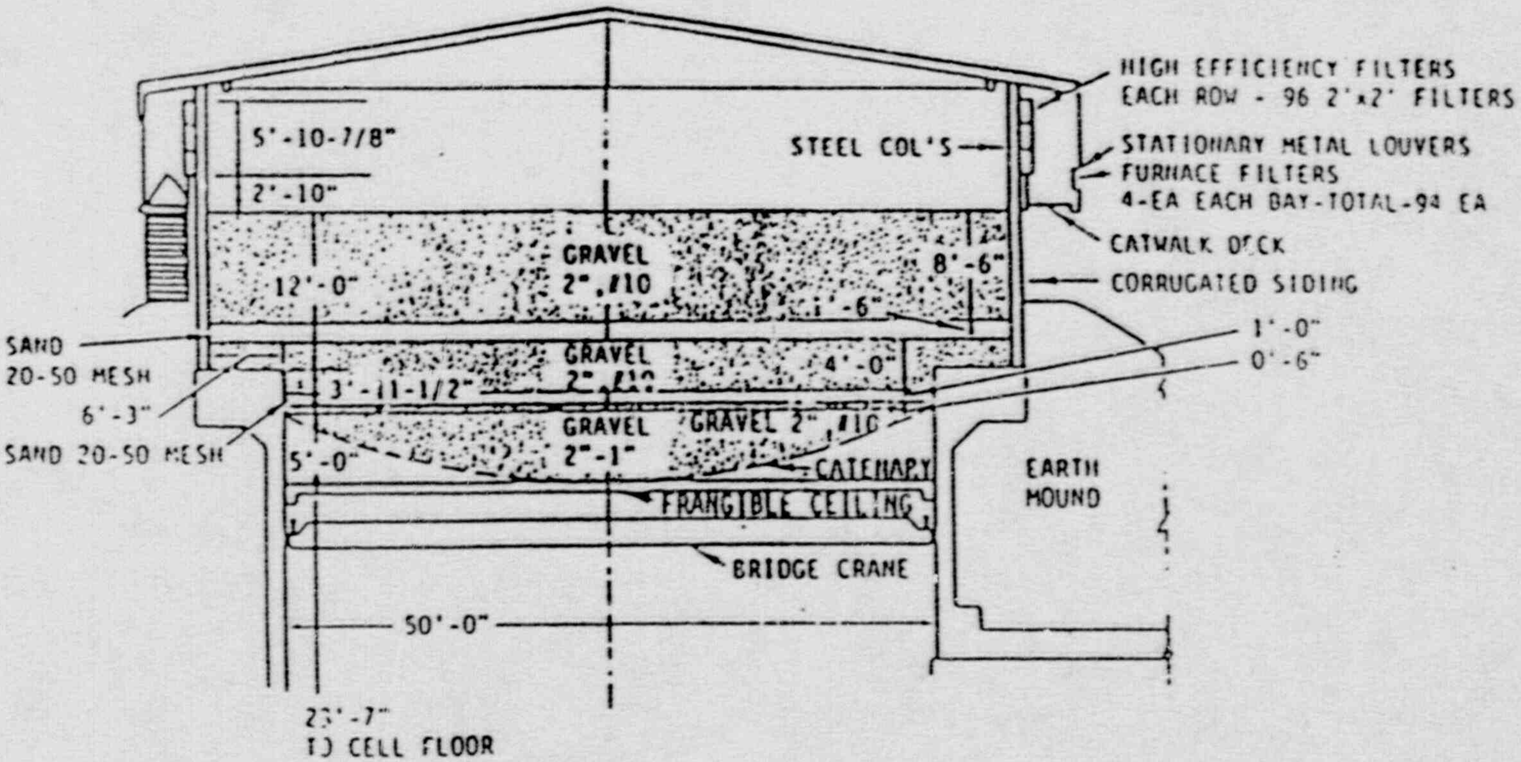

Figure 5 Roof Cross Section of the Zero Power Plutonium Reactor (from Reference 2)

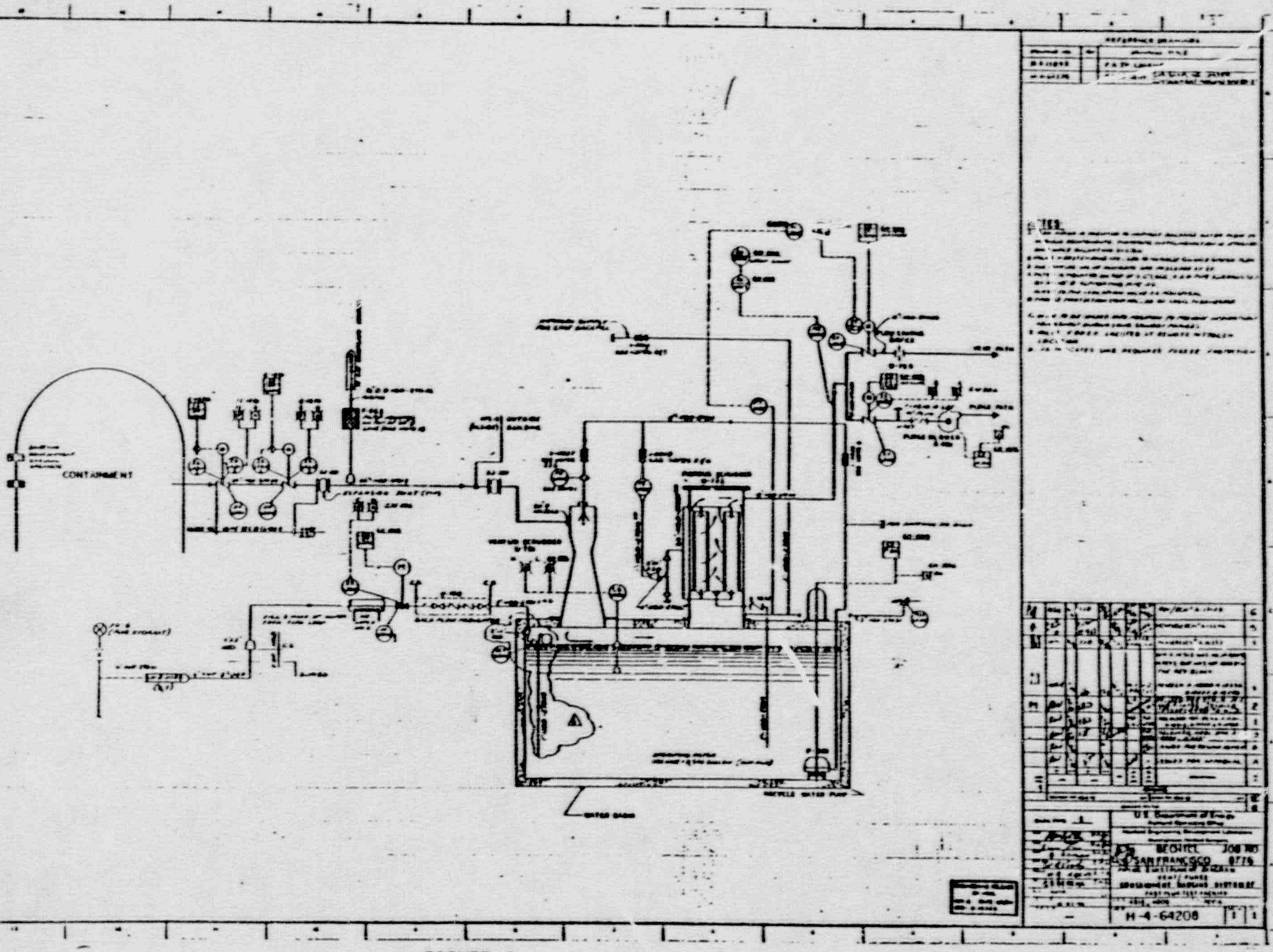

FIGURE 6
(from Ref. 11)