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ORNL/TM-9512

**JET-ISX-B BERYLLIUM LIMITER
EXPERIMENT
SAFETY ANALYSIS REPORT
and
OPERATIONAL SAFETY
REQUIREMENTS**

P. H. Edmonds

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P. H. Edmonds

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JET-ISX-B Beryllium Limiter Experiment
Safety Analysis Report
and
Operational Safety Requirements

Prepared for

U.S. Department of Energy
Oak Ridge Operations

by

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ABSTRACT

An experiment to evaluate the suitability of beryllium as a limiter material has been completed on the ISX-B tokamak. The experiment consisted of two phases: (1) the initial operation and characterization in the ISX experiment, and a period of continued operation to the specified surface fluence (10^{22} atoms/cm²) of hydrogen ions; and (2) the disassembly, decontamination, or disposal of the ISX facility. During these two phases of the project, the possibility existed for beryllium and/or beryllium oxide powder to be produced inside the vacuum vessel. Beryllium dust is a highly toxic material, and extensive precautions are required to prevent the release of the beryllium into the experimental work area and to prevent the contamination of personnel working on the device. Details of the health hazards associated with beryllium and the appropriate precautions are presented. Also described in appendixes to this report are the various operational safety requirements for the project.

1. INTRODUCTION AND GENERAL OBJECTIVES

The Impurity Study Experiment (ISX-B) is an existing fusion experiment in Building 9201-2 at the Y-12 Plant and is operated by the Operations Group of the Fusion Energy Division. The experiment is described in the existing safety reports.¹⁻³ The main experimental program is scheduled to end on March 31, 1984. It is proposed to conduct a special experiment on the ISX-B device beginning in May 1984 and continuing for the next four or five months. This experiment is the subject of this safety analysis report. The purpose of this experiment is to generate operating experience and an experimental data base for beryllium as a limiter material in tokamaks. Based on the results of this experiment, a decision will be made as to the suitability of beryllium as a limiter material for the next generation of tokamaks and, in particular, for the Joint European Torus (JET) undertaking.

The project consists of three phases: (1) the design and fabrication of the beryllium limiter and assembly; (2) the initial operation and characterization in the ISX, and a period of continued operation to the specified surface fluence (10^{22} atoms/cm²) of hydrogen ions; and (3) the disassembly, decontamination, or disposal of the ISX facility. A detailed description of the project is given in the proposal.⁴ The first phase, the design and construction of the limiter, has been performed under Oak Ridge National Laboratory (ORNL) subcontract to Sandia National Laboratories (SNL). The limiter will be delivered ready for installation on the ISX. No safety problems are associated with this phase of the project. This safety analysis will address the second and third phases of the project when there is a possibility that beryllium and beryllium oxide powder may be produced inside the vacuum vessel. The resultant hazards and the measures used to protect against these risks will be discussed.

2. SUMMARY SAFETY ANALYSIS

The ISX-B is an existing facility that has operated for more than five years. The experiment is located on the second floor at the east end of Building 9201-2, Y-12. The final experiment to be done on this machine consists of a study of beryllium metal as a plasma limiter material. A possible result of this experiment is the coating of a significant portion of the inside of the ISX-B vacuum liner with a thin layer of beryllium or beryllium oxide. In addition, the possibility exists of the wall coating or the limiter itself generating quantities of powder containing beryllium. The total beryllium inventory in the machine will be about 1.5 kg. A quantity less than 3 g is expected to be distributed away from the limiter assembly. Primary protection against distribution of beryllium into the environment inside Building 9201-2 is supplied by a high-efficiency particulate air (HEPA)-filtered liner ventilation system. In addition, portable suction systems are available to supply dust extraction on isolated apparatus. Possible contamination will be monitored by both air and surface sampling. Existing experience on operation and cleanup of similar systems has not shown any significant problem; in particular, no dust containing beryllium was detected.

On completion of the experimental program, the device will be disassembled and the components either decontaminated or disposed of in a suitable toxic waste site, as costs

indicate. A small decontamination facility has been built next to the ISX-B for the evaluation of contamination levels and decontamination of small items. Large or heavily contaminated items will be transferred to the decontamination facility at Building 9201-4.

3. SITE

The beryllium limiter experiment will be performed in the already existing ISX-B facility. This experiment is located at the east end of the second floor of Building 9201-2 at the Y-12 Plant. The risks associated with the routine ISX-B operations are discussed in the ISX safety analysis reports.

Building 9201-2 contains other experimental facilities and office space. Sufficient precautions, as described in this document, have been taken to prevent the dispersion of beryllium-containing dust into these areas.

The ISX-B is located inside a walled and interlocked enclosure. This enclosure will be used as a controlled access area.

4. FACILITY AND PROCESS DESCRIPTION

The ISX-B is described in the appropriate safety analysis report.¹⁻³ Figure 1 shows the installation plan for the main toroidal vacuum system and associated components of the installation. The beryllium limiter experiment consists of the installation of a beryllium limiter into the ISX-B vacuum vessel and of the operation of the device using this limiter. A backup beryllium limiter has been constructed and is available for use in the event that the primary assembly experiences failure. A description of the experiment is given in Appendix A.

The additional hazard, described by this report, is due to the addition of a beryllium limiter to this existing facility. The total beryllium inventory associated with the limiter is about 1.5 kg. The beryllium will be sputtered from the limiter tiles by the plasma. The best estimate of the quantity of beryllium that will be sputtered is 3 g or less. This beryllium will be initially plated onto the vessel walls. Secondary processes may then redistribute this plating around the interior of the vacuum vessel in the form of dust containing beryllium.

The safety hazard associated with beryllium and beryllium oxide powder is inhalation; a description of the material properties and health hazards associated with beryllium is given in Appendix B. Protection against the spread of the dust is by the use of ventilation systems with efficient filtration. Surface cleanup is done by simple wet washing. Personnel protection is through adequate ventilation and the use of oral-nasal masks where required. Monitoring of contamination is made with vacuum filtration monitors for air monitoring and with swab wipes for surface monitoring. Subsequent analysis is by atomic absorption spectral analysis (performed on site at the Y-12 Plant); typical analysis turnaround times are about one-half day. The techniques described here are those routinely used in the beryllium fabrication and machining industry, which maintains a high safety record.

A preliminary experiment to test beryllium has been performed on the Utor tokamak in Dusseldorf, Germany. A brief account of the experiment and cleanup technique and experience is attached (Appendix C). In addition, a description of the cleanup of

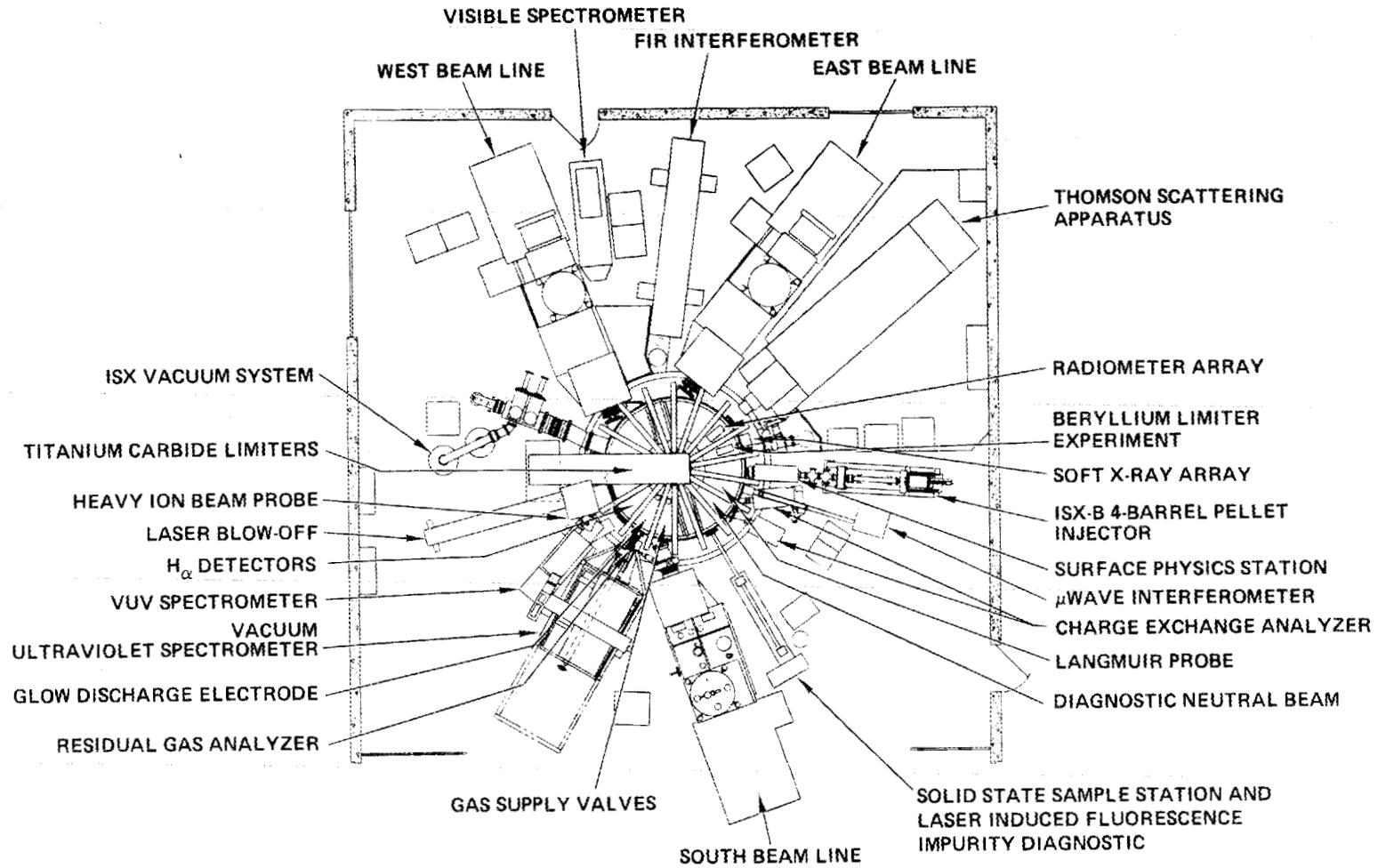


Fig. 1. Installation plan for the main toroidal vacuum system and associated components.

the Electron Beam Test Facility (EBTF) at SNL (Albuquerque) is attached (Appendix D). One conclusion that should be noted is the total absence of beryllium dust associated with both these experiments. Also included is a copy of a preliminary report by the JET undertaking on the health and safety implications of using beryllium on the JET experiment, which is located at Abingdon, England (Appendix E).

At the completion of the operational cycle, the experiment will be carefully dismantled; the various components will be checked for contamination using the apparatus and techniques previously described and will then be either disposed of in a suitable toxic waste facility or decontaminated for use on the next experimental device. The decontamination will either be done on site in an adjacent area using a large hood equipped with adequate ventilation and filtration or will be sent to existing decontamination facilities in the Y-12 Plant. The end product of the normal decontamination procedure is water containing beryllium and beryllium oxide; standard procedure is to handle this in mobile tanker trailers.

It is planned to use a considerable number of the components, such as the neutral beam systems and diagnostics from the ISX-B, on the next device, the Advanced Toroidal Facility (ATF) experiment. These components and diagnostics will be most stringently decontaminated and monitored to ensure that they will not transfer any significant quantity of beryllium to this next facility. The remaining contaminated components of the ISX-B machine will be disposed of in a toxic waste facility.

4.1 CONFINEMENT SYSTEM

During the experiment the beryllium limiter segments will be located inside the ISX vacuum vessel. There are three possible routes by which the beryllium could escape into the atmosphere. One is through the vacuum pumping system. Except for the air-driven aspirator, all pumping systems terminate in an oil-filled roughing pump. Any dust which may enter the pumps will be trapped by the oil. Oil samples will be taken on a monthly basis after startup of the experiment to monitor any possible migration. The various pumps will be sampled on a staggered schedule so that at least one oil sample will be tested each week. If any beryllium in excess of $0.1 \mu\text{g}/\text{sample}$ is detected, the oil will be changed and the contaminated oil disposed of. After initial pumpdown and leak-check cycles and before commencing plasma operation, the air aspirator will be permanently disconnected and the cryoabsorption pumps used for initial pumpdown. On completion of the experiment, the vacuum components will be tested for contamination and will be either decontaminated or disposed of, as costs would indicate.

The second possible route of dispersal into the environment is through a vacuum vent, either accidental or deliberate. A suction apparatus with a HEPA filter has been attached to the experiment and, with the appropriate control system, will maintain a reduced pressure inside the vacuum system in the event of a vacuum failure. The system has been designed so that the face flow velocity for a 12-in. aperture exceeds 100 fpm; this is adequate to prevent the escape of dust into the surrounding area.⁵ Two separate systems have been installed with redundant control systems. In the event of a failure of one suction apparatus, the other will automatically turn on and be valved into the tokamak. (A description of the control system is given in Appendix F. This apparatus will be referred to as the liner ventilation system.)

The third possible route is through the removal of a contaminated component from the device, either as a part of a routine surface study experiment or for repair or modification. A portable HEPA-filtered industrial dust collection system has been acquired that will be used on location to prevent the dispersal of any beryllium dust while the component is tested for contamination and then double bagged in plastic for handling.

4.2 VENTILATION SYSTEM

The liner ventilation system will be relied upon to prevent the dispersion of any beryllium-containing dust into the building. Because of this, no additional ventilation systems are required.

4.3 MONITORING AND PROTECTION SYSTEM

Routine monitoring for beryllium will be performed using standard air-monitoring systems located inside the enclosure. These monitoring systems will be powered by an uninterruptible power supply (UPS). In addition, a number of surface areas have been identified, and surface wipes will be taken from these surfaces. The monitoring and surface wipes will be evaluated on a weekly basis and after any vacuum opening or other event likely to have caused a possible contamination. The monitoring and analysis will be conducted by the Y-12 Health, Safety and Environmental Affairs (HSEA) Division. Sensitivity for the detection of beryllium is defined as $0.1 \mu\text{g}/\text{sample}$.

There are three air-handling systems: the liner ventilation system, the portable vacuum cleaner, and the fixed maintenance hood. Each of these systems includes two-stage filtering so that in the event of a simple filter failure, no beryllium dust will be blown into the work area. The liner ventilation system and portable vacuum cleaner both consist of Nilfisk vacuum cleaners with a primary Teflon-based filter that exceeds the HEPA specification. In addition, each contains a HEPA filter on the exhaust. The fixed maintenance hood contains a "bag in—bag out" dual filter box situated on the low-pressure side of the air blower.

The entire experiment is located within a walled enclosure. Access to this enclosure is through two doors and four roll-up fire doors. These doorways are interlocked into the experiment to prevent operation of the device with the doors open. As an additional security to reduce the possibility of inadvertent exposure to beryllium dust, this enclosure will be used as a controlled access area, and a record of entrance will be maintained. Entrance will be restricted to those approved by the project manager or his delegate and the Fusion Energy Division safety officer or his delegate. A list of these persons will be displayed at the enclosure east door; the other entrances will be used only when necessary.

Protective clothing, footwear, and breathing masks will be issued to all authorized personnel. The Y-12 personnel who wear issued clothing will not be required to wear the additional protective clothing. This equipment will be stored adjacent to the entrance. All personnel entering the area will be required to wear the protective clothing and to carry the breathing masks with them. In the event of a vacuum failure, all personnel will be required to don breathing equipment, and all except operations personnel will be required to evacuate the area until it is ascertained that the liner ventilation system is operational.

4.4 PROCESS WASTE DISPOSAL SYSTEMS

On completion of the experiment, the various contaminated components will be either decontaminated or disposed of in the Y-12 beryllium waste disposal facility, depending on decontamination cost. Decontamination consists of cleaning the surface with wipes and water rinse. Mild acid cleaning may assist in separating the beryllium from the surface. A freestanding hood with a HEPA-filtered ventilation system has been acquired for the decontamination of the smaller precision components. The larger components will be transferred to the Y-12 beryllium decontamination facility.

4.5 CRITICALITY CONTROL SYSTEMS

There is no criticality problem associated with this experiment.

4.6 FIRE PROTECTION SYSTEM

There is no additional fire hazard associated with this experiment. The ISX-B fire safety system is discussed in the ISX-B safety analysis report.

5. ACCIDENT ANALYSIS

The main elements of the experimental program subject to this safety analysis are identical to the ISX-B program, which has investigated a number of various limiter materials. These include stainless steel, graphite, titanium carbide-coated graphite, and boron. In addition, the beryllium limiter assembly is similar to the titanium carbide rail limiters. Because of these similarities, the likelihood of an unanticipated failure occurring is very low. There are two classes of accidents that will be described. These consist of a failure of the limiter segments or limiter assembly inside the vacuum vessel and a beryllium release into the enclosure or building.

5.1 LIMITER FAILURE

Figure 2 shows an assembly drawing of the limiter installed in the vacuum vessel. The D-shaped beryllium limiter segments are attached to a temperature-controlled base plate by a spring-loaded hold-down mechanism. The remainder of the assembly is made from stainless steel except for the aluminum guide plates and the ceramic breaks. The entire assembly can be positioned with the pneumatic cylinder. During operation, the beryllium segments will be exposed to the plasma edge thermal power. The plasma operating conditions are designed so that the limiter surface will not reach melting point. A spot infrared thermometer has been installed to monitor the surface temperature. If the temperature exceeds the preset value of 800°C, the temperature control system will terminate the tokamak shot. In addition, a videotape recorder (VTR) with a camera and monitor has been installed to view the limiter segments with the monitor in the control room so that any limiter damage will be immediately apparent to the operator. On a regular basis and initially daily, high-resolution still photographs will be taken of the limiter surface to identify any possible deterioration.

RAIL LIMITER ASSEMBLY

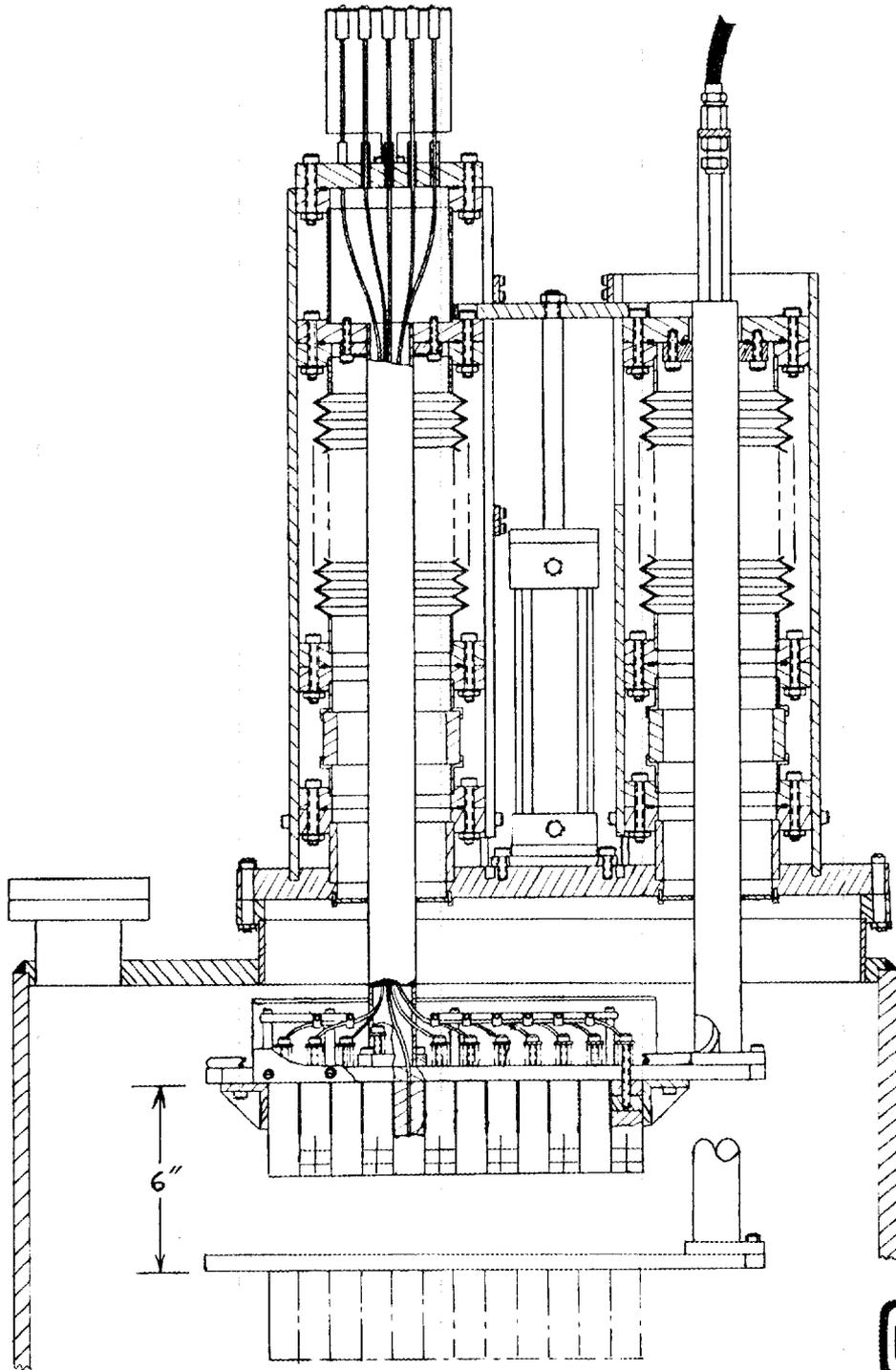


Fig. 2. Assembly drawing of the rail limiter installed in the vacuum vessel (courtesy Sandia National Laboratories, Albuquerque).

In the event of limiter failure, the machine will be vented to air, and a negative liner pressure will be maintained by the liner ventilation system. The limiter assembly will then be lifted from the machine and all loose material and dust vacuumed using the HEPA-filtered vacuum cleaner. The limiter assembly will then be bagged in plastic and transferred to the portable maintenance hood for disassembly, decontamination, and repair.

The limiter base plate temperature is maintained between 200 and 250°C throughout the experiment by a constant temperature control apparatus that circulates a heat exchange fluid through tubing welded to the base plate. In the event of a failure in the temperature control apparatus, the heating will be turned off by thermocouples mounted in the limiter tiles. If a leak into the liner should occur, a vacuum fault will occur. The heat exchange fluid will be tested at monthly intervals and replaced if any beryllium is detected.

5.2 POTENTIAL BERYLLIUM RELEASE

5.2.1 Normal Operation

When the main toroidal chamber is under vacuum, the only route by which beryllium can escape to the environment is through the roughing pumps. The assignment of rough pumps is shown in Table 1.

Table 1. Assignment of rough pumps

Function	Number	Location
Main tank roughdown	2	Enclosure
Main vacuum system	2	Mezzanine
Thomson scattering system	2	Enclosure
Beam line systems	2	Selrex enclosure
Charge exchange analyzer	1	First floor aisle
Spectrometers	2	Enclosure
Limiter isolation box	1	Enclosure

The beryllium content in the oil will be sampled on a monthly basis on a staggered schedule; oil changes will be made whenever beryllium is detected in the oil.

5.2.2 Loss of Vacuum

The following causes of vacuum failure have been identified:

- deliberate controlled vent to air,
- accidental vent caused by leak due to component failure (e.g., window seal failure),
- pumping system failure (turbo pump crash, rough pump belt loss, etc.), and
- loss of electrical power to apparatus.

In the event of a failure in the groups (a) to (c), the pumping system will be isolated from the main vacuum system when the liner pressure exceeds the liner vacuum trip level, set at 10 μ . At the same time, all diagnostic and beam line gate valves are closed, and an

alarm at the ISX control area is sounded. If the high-vacuum gate valves malfunction, the rough group interlock system will close the roughing valve; this also isolates the vacuum system. At times when the area is unattended, an alarm is sounded at the office of the Plant Shift Superintendent (PSS), who then telephones the duty operator at home.

As the pressure continues to rise, the automatic ventilation system described in Appendix F will turn on and maintain the liner at below atmospheric pressure. In the event of a power failure, the liner is automatically isolated. The only cause for concern in this fault condition is if the machine is vented or experiences a leak at the same time as the power outage occurs. The likelihood of this simultaneous fault is very low. Building 9201-2 experiences about four outages per year that last about an hour on average. Thus, the probability of an outage occurring during any one hour is 1:2200. During the period of the experiment, no vents will be scheduled. The typical duration of an unscheduled vent is about 4 hours, and the probability of a power outage occurring during a vent is then 1:500. This probability is sufficiently low so that no precaution has been made. However, in the event of a power outage occurring during an opening, the enclosure area will be evacuated, and entry will be prohibited until the air samplers (which are powered by an UPS) have been analyzed and the area declared contamination-free.

The experience to date in the Unitor tokamak and the EBTF indicates that there is, in fact, no beryllium dust associated with plasma operation. If beryllium contamination is observed the affected areas will be vacuumed and wiped clean before reentry.

5.2.3 Disassembly and Decontamination

At the completion of the experiment, the various parts of the machine will be tested for beryllium contamination and then either decontaminated or disposed of in a suitable toxic waste facility. The period of disassembly and decontamination is probably the most critical phase of the project and will be described in detail. Suitable protective equipment such as oral-nasal masks and disposable clothing will be worn where required. In addition, during the start of the critical decontamination phase of the project, a representative from the Culham Laboratory and JET Joint Environmental Services Division will be assigned to the project.

A large number of sample plates have been distributed around the inside of the device, in both the main vacuum vessel and the diagnostics, beam lines, and pumping systems. These will be analyzed both by atomic absorption spectroscopy and by nuclear activation to describe the distribution and level of beryllium contamination. The beryllium levels described here for contaminated and uncontaminated surfaces are consistent with those described by SNL (Appendix D).

On completion of the experimental cycle, the limiter assembly will be removed, bagged, transferred to the adjacent hood, and washed down with water to remove any loose beryllium dust. The limiter tiles will then be removed from the assembly. These will be double bagged in plastic and distributed for postexperiment analysis. The entire assembly will then be cleaned using an abrasive cleaning pad and cleaning solutions and detergents. The assembly will then be rinsed off and allowed to dry. All accessible surfaces will then be sample-wiped with test papers and analyzed for contamination. If the contamination exceeds $0.01 \mu\text{g}/\text{cm}^2$ or $1 \mu\text{g}/\text{sample wipe}$, the cleaning treatment will be repeated.

If on completion of a second treatment the contamination level exceeds the criteria, the assembly will be condemned. Otherwise, it will be declared contamination-free. The treatment of the diagnostic systems will be similar. If no contamination is observed on the sample plates, the diagnostic will be carefully disassembled and sample wipes taken to monitor any possible contamination. In the event that the contamination exceeds $0.05 \mu\text{g}/\text{cm}^2$, the affected components will be transferred to the hood and cleaned by washing and physically cleaning with abrasive materials as previously described.

Any diagnostics too large to be disassembled in the hood and too contaminated to be partially disassembled outside the hood will be sealed in plastic and transferred to Building 9201-4 decontamination facility for cleaning.

A special case exists for the beam lines. These will be carefully tested for beryllium using both sample plates and sample wipe analysis. If the front end and calorimeter show more than $0.05 \mu\text{g}/\text{cm}^2$, they will be resealed and shipped to the decontamination facility for surface cleanup and disassembly. The calorimeter and drive system will be retained, and the remaining components will be disposed of. If the main chamber is contaminated, it will be rinsed out with water on location, and the water will be drained into trailers. When the surface is dust-free the major components will be removed, transferred to the decontamination facility and decontaminated. The empty chamber will then be surface-cleaned in situ. After all the peripherals have been removed, the main vacuum vessel will be sealed, using plates and plastic covers, and removed to either a waste disposal site or to the decontamination facility, depending on the level of contamination. At the decontamination facility, the torus will be split in half, and the remaining diagnostic systems (such as the tubes containing the magnetohydrodynamic coils, TiC limiters, etc.) will be removed and the entire collection decontaminated. (The ORNL reporting limits and water quality criteria for beryllium are given in Table 2.)

Table 2. ORNL reporting limits and water quality criteria for analyses of Y-12 wastewater

Analysis	ORNL reporting limit	EPA priority pollution criteria ¹	EPA quality criteria for water ²	Units
Beryllium	0.001	8.7×10^{-5}	0.011	$\mu\text{g}/\text{mL}$

¹Sittig, Marshall, ed. 1980. Priority Toxic Pollutants: Health Impacts and Allowable Limits. Noyes Data Corporation. Park Ridge, NJ. 370 pp.

²U.S. Environmental Protection Agency. 1976. Quality Criteria for Water. Washington, D.C. 256 pp.

5.2.4 Other Accidents

In the event that a water leak should occur in the operating beam line, the supply system will be closed and the water drained into the beryllium trailer. (If a large quantity of water leaks into the beam line, the water will be tested for beryllium. If none is detected, the water will be drained into the conventional water drain.) The beam line vessel surfaces

will then be tested for beryllium; if none is detected, repairs will be executed. If contamination is detected, the beam line will be resealed and the backup beam line brought into service.

6. QUALITY ASSURANCE

The quality assurance program for this project only applies to the following components of the ISX-B:

- a. beryllium limiter assembly,
- b. liner ventilation system,
- c. fixed maintenance hood,
- d. portable suction cleaner, and
- e. sampling and monitoring systems.

A quality assurance assessment/plan has been drawn up for the preceding phases of the project.⁶

7. CONDUCT OF OPERATIONS

7.1 ORGANIZATION

The ISX-B is operated by the ISX-B operations group, which is a part of the Confinement Section in the Fusion Energy Division (FED) of ORNL. The ISX-B tokamak is the major device operated by the Confinement Section. The device is operated on a single shift basis. Figure 3 shows an organizational chart for the ISX-B program. The operations structure consists of the group leader, two engineers, and four technicians. Each of the technicians has a primary responsibility, but all are trained to operate the tokamak and to direct basic maintenance operations and pumpdown. In addition, the engineering department at Martin Marietta Energy Systems, Inc., supplies mechanical and electrical support on request for design and development. Maintenance support is supplied by Y-12 maintenance. The Y-12 facility also supplies the industrial hygiene and environmental services.

7.2 TRAINING

The operation of the ISX-B facility is by technicians under the direction of the group leader and the responsible physicist appointed for the day. The technicians have operated the tokamak for more than five years; the only additional feature associated with the experiment is in beryllium handling. Training will consist of a series of lectures on the hazards associated with beryllium and on proper procedures for handling and for sampling. These lectures will be presented by the group leader, the FED safety officer, and representatives from the HSEA Division of Y-12. All handling of beryllium-containing objects will be done under the direct supervision of HSEA Division personnel.

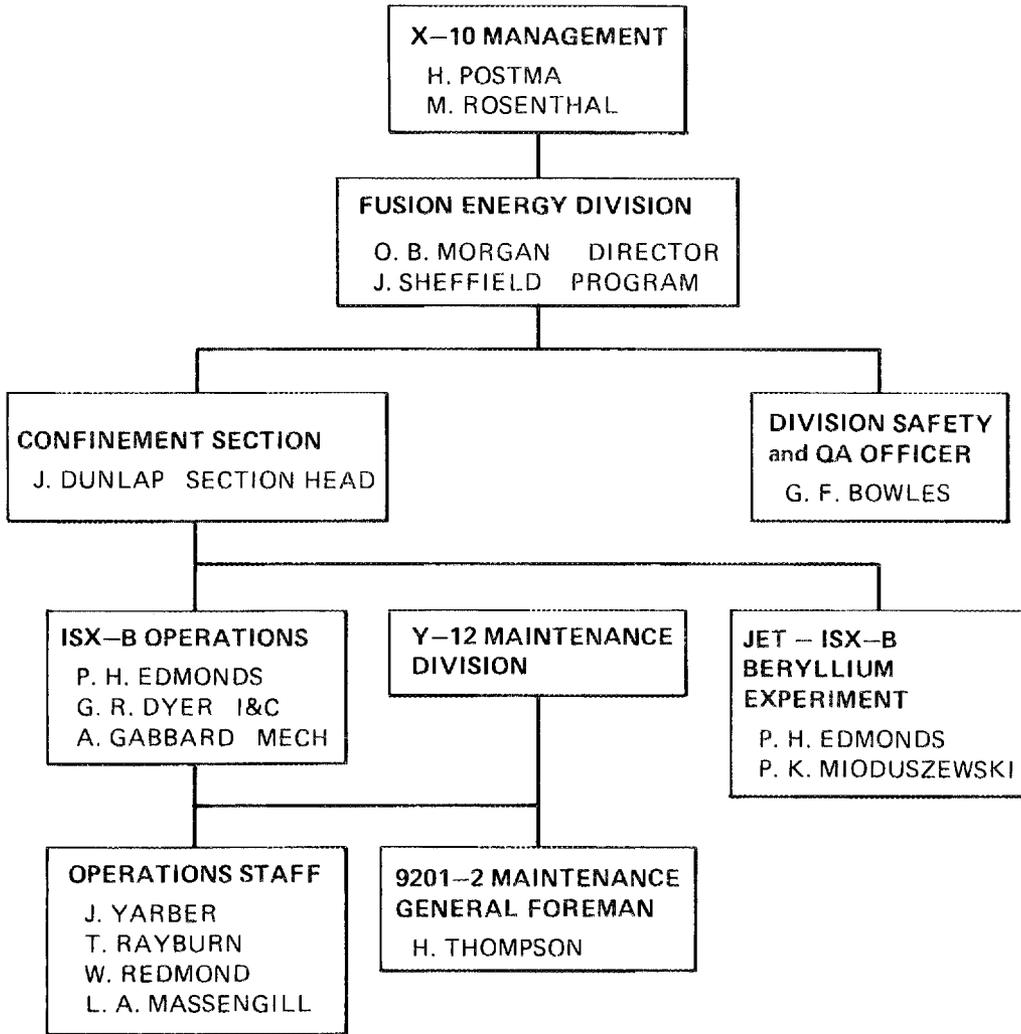


Fig. 3. Organizational chart for the ISX-B program.

7.3 INSPECTION AND TESTING PROGRAM

The initial inspection and approval of the experimental configuration will be carried out by the ISX-B operations group leader and the FED quality assurance and safety officer. The initial installation of the environmental systems will be approved by the HSEA Division; in addition, all operations involving possible exposure to beryllium will be monitored by HSEA Division personnel. Automatic protection systems will be tested monthly and the results of the test noted in a logbook that will be maintained for the experiment.

7.4 CONFIGURATION CONTROL

Before commencement of the experiment, a completed test of all safety systems associated with the experiment will be conducted. This test will be witnessed by the division safety officer. The conformance of the as-built system to specification will be verified. The safety systems include the liner ventilation system, the ISX-B vacuum system, and the electrical and interlock systems as described in Ref. 2. This operational safety check will be repeated quarterly for the duration of the experiment. Any configurational changes to any part of the safety system will be presented to the safety officer in writing by the operations group leader. No configurational changes will be implemented until this change request is approved by the safety officer. The approved request will be attached to the operations logbook.

7.5 PROCEDURES

Any changes in operating procedures will be approved by the group leader before implementation. A description of the changes will be appended to the logbook and distributed to the operations group and the safety officer by the group leader. If in the opinion of the group leader the changes have safety or environmental impact, then prior approval will be obtained from the safety officer and HSEA Division personnel.

7.6 SAFETY REVIEW SYSTEM

This Safety Analysis Report has been reviewed by an independent safety panel that was established by the U.S. Department of Energy-Oak Ridge Operations (DOE-ORO). The review panel included representatives from DOE-ORO, outside contractors with beryllium handling experience, X-10 and Y-12 environmental control, and FED. Because of the short duration of the experiment and the direct objective, no formal procedure to review changes has been made. Any possible changes will be made in consultation with the division safety officer and representatives from the HSEA Division. Substantive changes will be approved by the DOE Office of Fusion Energy and by DOE-ORO.

7.7 EMERGENCY PLANNING

Martin Marietta Energy Systems, Inc., and the Y-12 Plant have an existing emergency planning program.^{7,8} Emergency and evacuation procedures are well established, and

alarm buttons are located adjacent to the experimental area. The 9201-2 building emergency squad and the Y-12 emergency response team will be briefed on the specifics of the ISX-B beryllium limiter experiment.

7.8 RECORD KEEPING AND RECORDING

The existing record keeping procedures for the ISX-B experiment will be continued. These procedures consist of the following:

- a. A facility logbook is kept in which all events associated with the facility are recorded. In addition, operation procedure changes, safety system checks, and maintenance procedures are recorded in this logbook.
- b. An operations logsheet is maintained during tokamak operation in which all machine parameters are recorded.
- c. A data logsheet is maintained by the responsible physicist during operation in which a description of each tokamak shot is recorded.
- d. A weekly summary of operations is maintained by the group leader.
- e. A weekly summary of the physics program is maintained by the beryllium limiter experiment physics coordinator, P. K. Mioduszewski.
- f. A monthly report is written by the JET-~~ISX~~-B beryllium limiter experiment co-investigators, P. H. Edmonds and P. K. Mioduszewski. This report is distributed to both the JET undertaking and DOE.

The following additional records will be maintained for the duration of the beryllium limiter experiment:

- a. A diary of daily operation will be maintained by the duty technician.
- b. A detailed report of the project will be written on completion of the experimental program and submitted to the JET undertaking.
- c. The results of all sampling tests will be filed. Any positive tests will also be recorded in the operations logbook.

On completion of the experimental program all of the records associated with the beryllium limiter project and experiment will be collected and stored by ORNL records for a minimum of three years if there is no record of personnel exposure to beryllium. Otherwise, they will be stored indefinitely.

On completion of the experimental program a detailed report of the project will be written and submitted to the JET undertaking.

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Appendix A
PROPOSED EXPERIMENTAL PROGRAM FOR
JET-ISX BERYLLIUM LIMITER TEST

P. K. Mioduszewski
P. H. Edmonds
J. B. Roberto

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1. INTRODUCTION

The primary reason for performing a Be limiter test in ISX is to establish the data base and operating experience necessary to utilize a Be limiter in JET.

Although single properties like thermal shock resistance or tritium retention can be investigated in laboratory experiments, synergistic effects cannot be predicted and can only be studied in the proper plasma environment. Therefore, the ultimate test prior to application in a large device like JET has to be a tokamak test.

Among all limiter materials tested and used so far, there is no candidate compatible with all requirements: good thermo-mechanical properties, favorable plasma materials interaction characteristics, stable materials properties under neutron irradiation, and adequate technology basis (fabrication, bonding, etc). Beryllium is a metal that combines low-Z with good thermal properties. The melting point is 1283°C, which is rather low compared with graphite, but the good thermal conductivity makes Be a candidate for an actively cooled limiter. Beryllium can be operated in a temperature range around 500°C where hydrogen retention is low. The corresponding temperatures for graphite are in the temperature regime where chemical erosion is high. This gives beryllium an advantage over graphite in DT-burning devices, where the tritium inventory has to be kept at a minimum.

In fully nuclear machines, problems must be anticipated with beryllium as well as with graphite. Helium generation largely from (n,2n) reactions with high-energy neutrons has substantial effects on mechanical properties and swelling of beryllium. It is estimated that 3720 at. ppm He per MW year/m² would be generated in a fusion spectrum (17 cm³ of He at STP per cm³ of He).¹ Graphite, on the other hand, has the problem that its relatively good thermal conductivity is rapidly reduced at fairly low irradiation levels (<1 dpa).² Whether either one of these two materials will qualify for application in power-producing reactors cannot be decided on the basis of the present data base.

Except for some coatings—which have their own set of problems—beryllium seems to be the only viable alternative to graphite for high-heat-flux components in fusion machines. The primary reason beryllium has not yet been tested as limiter material—although it has some very favorable properties—is the health hazards associated with its use. Detailed discussions of relevant experience and practice in industry led to the conclusion that the beryllium toxicity problem is serious but that the material may be handled safely by taking proper precautions.³

2. SCOPE OF EXPERIMENTS

The task, as specified by JET, is divided into three parts:

1. designing, procuring, and fabricating a beryllium limiter assembly and testing the material before and after plasma operation;
2. setting up and characterizing a test plasma; and
3. operating the machine until the limiter has accumulated a total dose of 10²² hydrogen atoms per cm².

3. LIMITER CONCEPTUAL DESIGN

The limiter system to be used for the beryllium limiter test consists of top and bottom rail limiters: one Be limiter and one TiC-coated graphite limiter for reference. The limiters can be moved in and out with a stroke of approximately 15 cm. The limiter surface is shaped in the direction of the toroidal field (which is roughly the direction of plasma flow) to give uniform power deposition for exponential fall-off with $\lambda = 2$ cm decay length. Because the limiter is a straight rail scraping off a circular plasma, the test load on the rail varies in the direction of the major radius, and the limiter shape can be matched to the decay length of the power flow at one position only. This is ideally at the symmetry point at $R = R_0$ if the e-folding of the power flux turns out to be 2 cm, as assumed.

The Be limiter, consisting of 12 equal segments, is laminated in the direction of the major radius. Each segment is castellated on the plasma-facing surface for stress relief. The segmentation allows for a number of different pre- and post-experimental tests without cutting the limiter into pieces. All of the segments are equipped with thermocouples.

An important part of the limiter assembly is a temperature control system serving a twofold purpose: (a) adjusting the initial bulk temperature to any desired value between room temperature and approximately 200°C, and (b) cooling the limiter between shots to prevent the temperature from ratcheting up during operation. The boundary conditions for temperature control are given by the minimum bulk temperature, the surface temperature rise during one shot, the maximum tolerable temperature, and the total energy to be cooled away between shots. The minimum bulk temperature should be about 100 to 200°C and is determined by the thermo-mechanical properties of beryllium, which is very brittle at room temperature but becomes increasingly ductile at elevated temperatures. The surface temperature rise per shot is a JET specification and should be $\Delta T = 600^\circ\text{C}$. The maximum tolerable temperature should be within about two-thirds of the melting point, which is at 1283°C. Beyond this temperature erosion rates have been observed to increase markedly. The maximum energy deposited on the limiter during one shot is estimated to be 100 kJ; correspondingly, the cooling capacity between shots ($\Delta t \approx 2$ min) has to be on the order of 1 kW.

4. PLASMA PARAMETERS AND DIAGNOSTICS

The test plasma will always be set up with the TiC/C limiter to ensure that the Be limiter is exposed to well characterized plasmas and to guarantee accountability of particle and heat fluxes. Plasma parameters will be approximately $\bar{n}_e = 4 \times 10^{13} \text{ cm}^{-3}$, $I_p = 180 \text{ kA}$, $B_T = 12 \text{ kG}$, and $P_{\text{NBI}} \leq 1 \text{ MW}$. The plasma will be characterized with the following set of diagnostics:

Parameter	Diagnostics
* I_p , B_T , V_L , β_p , position	Magnetics
* \bar{n}_e	FIR interferometer
$n_e(r)$, $T_e(r)$	Thomson scattering
T_i	Velocity filter analyzer
*Impurities	Spectrometer
*MHD activity	Mirnov coils
*Scrape-off layer	Langmuir probe
* H_α radiation	H_α monitors
* P_{rad}	Radiometer
Surface composition	Surface analysis station
Limiter	
*Surface temperature	IR thermography
*Bulk temperature	Thermocouples
*Surface phenomena	Optical observation
*Throughout experiment	
Average weekly	

Of particular importance are the diagnostics of the scrape-off layer to account for heat and particle loads to the limiter. The main diagnostic in the scrape-off layer is a set of Langmuir probes backed up by various particle collection probes that can be inserted and analyzed in the ISX surface analysis station.

5. LIMITER TEST PROGRAM

5.1 PRE-EXPERIMENTAL TESTS

A series of tests and measurements will be conducted on the Be limiter before installation in ISX. These tests include measurements of thermal conductivity, yield strength, tensile strength, and surface hardness (as well as studies on structure and topology by micrography and scanning electron microscopy). All tests will be carried out at three temperatures: room temperature, 300°C, and 600°C. This set of data will establish a reference for the materials properties to which the limiter can be compared after exposure to tokamak discharges.

In addition to the materials characterization, several segments of the Be limiter will be doped with specific marker elements that will allow for studies on erosion, redeposition, and migration of the limiter material.

5.2 PLASMA-MATERIALS INTERACTION STUDIES

Plasma-materials interaction (PMI) studies will be conducted on the beryllium limiter itself, on collection probes exchangeable through the surface analysis station, and on permanent probes to be installed at various locations of the tokamak and to be analyzed after completion of the experiment.

The PMI studies consist of wall conditioning; material transport (i.e., erosion, redeposition, migration); and hydrogen recycling, implantation, and retention.

Wall conditioning includes initial characterization of samples prototypical of the stainless steel wall, the beryllium limiter, and the TiC/C limiter as well as discharge cleaning of the vacuum vessel and monitoring the surface state of prototypical samples and of the composition of the residual gas. It is of particular interest to monitor the thickness of the oxide layer that is always present on beryllium surfaces and relate it to possible changes of the surface properties of the limiter. Furthermore, the surface state of the in-vessel components should be correlated to the plasma impurities measured spectroscopically.

The main goal of the material transport studies is to determine the total amount of beryllium eroded off the limiter surface during plasma operation. In addition, attempts will be made to study redeposition and migration of the material around the tokamak. For this purpose, one or more of the beryllium limiter segments will be doped to a specified depth with characteristic markers. After completion of the plasma operation, the doped (as well as the undoped) limiter segments will be analyzed with surface analysis techniques to measure the net erosion on the doped segments on the one hand and the net redeposition on the undoped segments on the other hand. In addition, sputter-cleaned samples of a different material (for example, silicon) can be introduced through the surface analysis station to collect beryllium deposits over a specified number of shots and then be analyzed immediately. Finally, a number of permanent samples will be distributed around the tokamak, the vacuum system, the neutral beam injector, and other components that have vacuum connection to the main vessel. These samples could be silicon or graphite and will be analyzed with secondary ion mass spectrometry (SIMS), Auger electron spectroscopy (AES), and Rutherford ion backscattering (RBS) after completion of the plasma operation.

An important parameter for a DT-burning tokamak is the hydrogen retention in first wall and limiters. On the limiter itself the totally retained hydrogen will be measured by depth profiling with SIMS and nuclear reaction analysis (NRA) as postmortem analyses. Modeling of the hydrogen retention will include the particle flux measured with Langmuir probes, the temperature history of the limiter surface, and the total number of shots. Furthermore, beryllium samples can be introduced through the surface station, exposed for a given number of shots, and then analyzed for hydrogen retention as a function of particle flux and sample temperature.

By exposing samples with known properties like silicon or graphite, average ion fluxes will be measured with surface techniques for comparison with Langmuir probe data.

5.3 POWER DEPOSITION STUDIES

To study the thermal response of the Be limiter, the following diagnostics will be employed:

- IR-camera — Measure surface temperature rise as a function of time and space, and with known thermal properties infer heat flux as a function of time and space.
- Thermocouples — From the bulk temperature rise, the total energy deposited on the limiter during one shot can be inferred.
- Langmuir probes — Measure parallel particle flux Γ and temperature T . Comparison with heat flux q allows one to determine the heat transfer coefficient γ in $q = \gamma\Gamma T$.
- Calorimeter probe — A negatively biased, small calorimeter probe allows one to measure the ion saturation current and the total energy deposited during a shot. This yields additional information on particle and power flux.

The IR-camera measures the thermal response of the Be-limiter in a very thin surface layer only. This layer could be affected by the adsorption of high doses of hydrogen. If, in particular, the thermal diffusivity changes, the thermal response of the limiter, as seen by the IR-camera, would change correspondingly, even at unchanged heat flow. A change in secondary electron emission of the limiter surface would also result in a change of the surface temperature at unchanged scrape-off layer parameters because the heat transfer coefficient γ is a function of secondary electron emission. To detect those changes of material properties, an independent small calorimeter probe will be used. This probe can be calibrated at the beginning of the experiment and then used at various times throughout the experiment.

5.4 POSTMORTEM ANALYSIS

After the Be-limiter has accumulated the required particle dose of 10^{22} hydrogen atoms per cm^2 , essentially all the materials tests described in Sect. 5.1 will be repeated. Because most of the measured material properties are bulk properties, changes due to plasma exposure that occur only on the surface might not be directly visible. In addition to the materials tests described in Sect. 5.1 various surface analysis techniques (AES, RBS, SIMS) will be employed for depth profiling of the implanted hydrogen as well as for erosion/redeposition studies.

6. PLASMA CHARACTERISTICS WITH Be LIMITER

6.1 IMPURITY CONTENT AND CONTRIBUTORS

With moderate neutral beam injection (~ 1 MW) and no gettering, the dominant plasma impurity in ISX is oxygen. Although the impurity source is not identified, it is likely to be the stainless steel walls. In this case, switching from a TiC/C limiter to a Be limiter should not affect the impurity content and, hence, the Z_{eff} of the plasma. Having both limiter types with identical geometries in the tokamak offers the unique opportunity of making a meaningful comparison of plasma impurity content with two different limiter materials under otherwise identical conditions. The plasma impurities measured spectroscopically will be correlated not only to the limiter material but also to the surface state of the wall and of samples of limiter material analyzed with AES.

6.2 BERYLLIUM-IMPURITY EVOLUTION AND TRANSPORT

The dominant processes for impurity evolution from the limiter are sputtering, arcing, and evaporation. If the surface temperature is monitored carefully and shown to be below 900°C, the evaporation rate of Be is negligible compared to sputtering. Arcing tends to be a transient phenomenon that disappears after some conditioning phase and then occurs only during the current rise phase and at the end of the discharge. So, in most cases, the beryllium impurities in the plasma will be due to sputtering at the limiter. With known particle flux and energy at the limiter, the impurity source term can be estimated and correlated to the impurity content in the plasma.

6.3 SCRAPE-OFF LAYER CHARACTERISTICS

The scrape-off layer is characterized by particle density and temperature, or by the composite parameters particle flux and power flux and the corresponding decay lengths. The main diagnostics for that is a set of Langmuir probes to ensure density and temperature profiles. From these data we can deduce particle flux profiles in the scrape-off layer. This particle flux will be compared to the particle fluence accumulated over several shots on collection probes and analyzed with surface techniques. A third measurement of the particle flux will be obtained with a biased calorimeter probe that measures the ion saturation current and the total energy deposited during one shot. The power flux to the limiter q , which is related to particle flux Γ and temperature T by the relation $q = \gamma\Gamma T$, will be deduced from space- and time-resolved temperature measurements of the limiter surface.

Because particle flux and temperature are known from Langmuir probe data, measuring q allows one to determine the heat transfer coefficient γ . For D₂ plasmas, γ is between 7 and 17, depending on the secondary electron emission. With the determination of γ , it becomes possible to estimate the secondary electron emission at the limiter surface. Knowing the secondary electron emission, the sheath potential, which is $3kT_e$ without secondary electron emission, can be corrected. Finally, a better knowledge of the sheath potential allows one to obtain a better estimate of ion sputtering at the limiter.

7. PLASMA EDGE MODIFICATION WITH MEDIUM-Z INJECTION

7.1 PLASMA EDGE COOLING/CONFINEMENT IMPROVEMENT

One of the salient problems of future long-pulse, high-duty-cycle machines will be the surface erosion on limiters and divertor plates. JET is likely to be the first device that has to face this problem. It is, therefore, highly desirable to come up with solutions for cooling the scrape-off plasma sufficiently to reduce sputtering rates substantially. Possible ways to do this are either increased gas puffing or puffing of medium-Z impurities. The basic idea is to operate on a low-Z limiter with a plasma as clean as possible, and then inject in a controlled fashion a gas such as neon that radiates sufficiently in the plasma edge to cool down the plasma temperature. This cooling effect should be accompanied by a decrease in power deposition at the limiter detected through the limiter surface temperature.

To ensure that the bulk plasma is not cooled down as well, the limiter measurements have to be combined with studies of the energy content of the bulk plasma. As recently demonstrated in ISX,⁴ plasma confinement of neutral-beam-heated discharges can be improved by injecting small amounts of neon. These studies are of particular interest for limiter tokamaks like JET and are a logical complement to the edge cooling studies.

8. FINAL REMARKS

The experimental program described here is much broader than that given by the JET specifications for the beryllium limiter test, which includes mainly the design and fabrication of the limiter, pre-experimental and postmortem materials tests, and operation of the limiter in a test plasma with specified limiter temperatures and a total accumulated particle fluence of 10^{22} atoms/cm². These specifications are regarded as the absolute minimum test program. Because, however, the beryllium limiter test is a unique opportunity to learn more about application of Be in fusion devices on the one hand, and to conduct a dedicated limiter program on the other hand, we will attempt to achieve as much as possible of the experimental program described here.

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Appendix B
MATERIAL SAFETY DATA SHEET

MATERIAL SAFETY DATA SHEET

1304-56-9

NAME Beryllium Oxide	HEALTH 4
	FIRE 0
	REACTIVITY 0

I. IDENTIFICATION

PRODUCT NAME Beryllium Oxide	RTECS NO. DS 4025000
CHEMICAL NAME Beryllium Oxide	MOLECULAR WEIGHT 25.01
FORMULA BeO	CAS NO. 1304-56-9
SYNONYMS Beryllia	

II. PHYSICAL DATA

BOILING POINT, 760 mmHG	3900°C	FREEZING POINT	2530°C
SPEC. GRAVITY (H ₂ O = 1)	3.01	VAPOR PRESSURE AT _____°C	
VAPOR DENSITY (AIR = 1)		SOLUBILITY IN WATER, PERCENT BY WEIGHT	0.00002
PERCENT VOLATILES BY VOLUME		EVAPORATION RATE (BUTYL ACETATE = 1)	

APPEARANCE AND ODOR

White amorphous powder

III. FIRE AND EXPLOSION HAZARD DATA

FLASH POINT (TEST METHOD) Not flammable	AUTOIGNITION TEMPERATURE Not flammable						
FLAMMABLE LIMITS IN AIR % BY VOLUME	<table style="width: 100%; border: none;"> <tr> <td style="width: 25%; border: none;">LOWER</td> <td style="width: 50%; border: none;">Not flammable</td> <td style="width: 25%; border: none;">UPPER</td> </tr> <tr> <td style="border: none;"></td> <td style="border: none;">Not flammable</td> <td style="border: none;"></td> </tr> </table>	LOWER	Not flammable	UPPER		Not flammable	
LOWER	Not flammable	UPPER					
	Not flammable						

EXTINGUISHING MEDIA

Water

SPECIAL FIRE FIGHTING PROCEDURES

Wear self-contained breathing apparatus.

UNUSUAL FIRE AND EXPLOSION HAZARDS

None currently known.

IV. REACTIVITY DATA

STABILITY Stable.	SHELF LIFE None Established.
----------------------	---------------------------------

CONDITIONS TO AVOID

None currently known.

MATERIALS AFFECTING STABILITY

Reacts explosively with heated magnesium.

HAZARDOUS COMBUSTION OR DECOMPOSITION PRODUCTS

None currently known.

V. SPILL OR LEAK PROCEDURE

IN EVENT OF SPILLS OR LEAKS CALL

Environmental Coordinator or Plant Shift Supervisor/Superintendent AND INDUSTRIAL HYGIENE.

FOR QUESTIONS ON STORAGE, TRANSPORTATION, OR DISPOSAL CALL

Environmental Management Group

WARNING

THE INFORMATION CONTAINED HEREON IS INTENDED SOLELY FOR THE USE OF EMPLOYEES OF UNION CARBIDE CORPORATION - NUCLEAR DIVISION. THE INFORMATION IS NOT INTENDED TO BE A DEFINITIVE STATEMENT OF ALL HAZARDS ASSOCIATED WITH SAID MATERIAL OR ALL METHODS OF COUNTERACTING HUMAN EXPOSURE TO SAME. USERS ARE CAUTIONED TO PROCEED WITH DUE CARE IN THE HANDLING, STORING AND DISPOSAL OF THIS MATERIAL AND TO SEEK FURTHER INFORMATION REGARDING PARTICULAR APPLICATIONS AS REQUIRED.

1304-56-9*

NAME		Beryllium Oxide	5/83
VI. HEALTH HAZARD DATA			
EXPOSURE LIMIT AND SOURCE			
0.002 mg/C.M. of Be A-2 Carcinogen ACGIH (1982)			
EFFECTS OF ACUTE OVER-EXPOSURE			
SWALLOWING	Exceedingly low order of toxicity (very poorly absorbed from the gastrointestinal tract) None currently known.		
SKIN ABSORPTION			
None currently known.			
INHALATION	Causes nonproductive cough, difficult breathing, tightness of chest, chest pain, weight and appetite loss, general weakness.		
SKIN CONTACT			
Causes some irritation			
EYE CONTACT			
Causes irritation.			
EFFECTS OF CHRONIC OVER-EXPOSURE			
Suspect human carcinogen; causes cough, chest pain, weight loss, fatigue, club fingers, granulomas in lungs, liver and lymph nodes, increased pulmonary resistance, heart failure.			
OTHER HEALTH HAZARDS			
Susceptible individuals may become sensitized, causing allergic contact dermatitis.			
EMERGENCY AND FIRST AID PROCEDURES			
SWALLOWING	Give 2 glasses of water and induce vomiting.		
SKIN	Remove contaminated clothing and wash skin with plenty of soap and water.		
INHALATION	Remove to fresh air. Give artificial respiration if not breathing. Call a physician.		
EYES	Wash eyes with plenty of water for at least 15 minutes. If irritation persists, call a physician.		
NOTES TO PHYSICIANS			
In case of a severe exposure, complete bed rest is recommended. If cyanotic, give 40 to 60% oxygen. Calcium edetate may be used to increase detoxification of beryllium oxide. Treatment of overexposure should be directed at the control of symptoms and the clinical condition.			
VII. SPECIAL PROTECTION INFORMATION AND PRECAUTIONS			
RESPIRATORY PROTECTION (<i>Specify Type</i>)			
Wear full face mask with high efficiency particulate filter.			
VENTILATION			
Local exhaust ventilation to keep BeO concentration low.			
PROTECTIVE GLOVES	Rubber	EYE PROTECTION	Safety goggles
OTHER PROTECTIVE EQUIPMENT AND/OR PROTECTION			
Full body protective clothing.			

Appendix C
SUMMARY OF RESULTS OF UNITOR
BERYLLIUM EXPERIMENT
P. H. Edmonds

CONTENTS

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2. CLEANUP	33

1. INTRODUCTION

Unitor is a Microtor-like tokamak located in Dusseldorf, West Germany. It is normally run without a limiter, and the plasma rests on the outside mid-plane. Normal impurity is dominated by metal. General parameters are $T_i \sim 50$ eV, $T_e \sim 2000$ eV, $n_e \sim 10^{13}$ cm⁻³. Because of the low temperatures it is assumed that the metal sputtering is by carbon and oxygen and self-sputtering. Hydrogen ion fluxes were estimated at 10^{18} /(s/cm²).

The experiment consisted of installing two beryllium plates on movable probes approximately 180° apart. Diagnostics were removed prior to the experiment. Results of the beryllium limiter experiment are as follows:

1. Resistivity falls by 15 to 20% (estimate 2% of 1500 shots duration 60 ms).
2. Spectroscopy showed a dramatic drop in metallic impurity (Cr, Ni) and no Be, which probably was unseen because the available Be lines are faint and obscured by adjacent strong lines.
3. Oxygen impurity content also fell by an order of magnitude, but this may have been caused by moving the plasma away from the wall.
4. A plot of pulse length (a measure of volt seconds and, hence, ease of breakdown and of low plasma resistance) versus limiter position showed an increase as the limiters were moved into the liner. This improvement persisted for some number of shots (about five) after the limiters were withdrawn.

The conclusion drawn from this experiment by Prof. Hackman was that the plasma was dramatically improved by operation in beryllium.

2. CLEANUP

The device cleanup was done very carefully by an English company, Effluent Disposals, and was observed by representatives from the Safety and Environmental Services of Culham and JET.

A plastic tent was raised over the device and initial entry made with personnel wearing masks and disposable outer clothing. Initially the two limiters were removed and wipes taken of the area accessible through these ports. A significant amount of material was detected. The entire device was then filled and flushed out with water (150 L). No contamination was observed after this cycle from which the conclusion was drawn that no beryllium-containing dust was generated during the experiment. The machine was then filled with 10% nitric acid solution and drained. This liquid was tested for beryllium. Approximately 5 mg of Be was detected in two acid washes. Wipe samples indicated no further contamination existed inside the machine, and the vacuum vessel was declared contamination free and released for reuse. The conclusions drawn from the experiment were (1) no dust was generated and (2) cleanup is a simple task. The results of the experiment will be presented at the Nagoya meeting on Plasma Materials Interactions.

Appendix D
SANDIA NATIONAL LABORATORIES MEMORANDUM ON
CLEANUP OF ELECTRON BEAM TEST FACILITY

D. R. Parker

Sandia National Laboratories

Albuquerque, New Mexico 87185

date: February 7, 1984

to: W. B. Gauster, 1837

from: 
D. R. Parker, 3311subject: Beryllium Contamination of the Electron Beam Test Facility (EBTF), Bldg. 805,
Room 324

Introduction: This memorandum documents the Industrial Hygiene Division, 3311, activities during the clean up of the EBTF after the melting of a beryllium sample inside the apparatus.

First Cleaning (1/17/84): The shroud, cooling stage, and assorted electrical leads were removed. The interior surfaces of the EBTF chamber were wiped with cloths soaked in distilled water. The operator wore disposable coveralls, gloves, and a half-mask respirator with high efficiency particulate filter cartridges. Rather than encumber the operator, a personal air sampler was placed so that the filter cassette hung in the vicinity of the chamber access port. The result of this sampling was negative ($<0.7 \mu\text{g Be}/\text{m}^3$). A second personal air sampler was placed on a desk in the laboratory. This air sampler was also negative ($<0.6 \mu\text{g Be}/\text{m}^3$). Swipe sampling results are shown in the attached table.

Second Cleaning (1/17/84):

The interior surfaces were wiped with cloths soaked in ethyl alcohol. The operator wore disposable coveralls, gloves, and a half-mask respirator equipped with organic vapor cartridges and a dust-mist prefilter. Fresh, uncontaminated air was also blown into the chamber at a rate of 6.5 cubic feet per minute. Swipe sampling results are shown in the attached table.

Third Cleaning (1/17/84): The interior surfaces were cleaned with a metal polish ("Pul metallputz") which was applied with cloths and "Q-tips." Then, the procedures used in the second cleaning were repeated.

W. B. Gauster, 1837

-2-

February 7, 1984

Surface Contamination Limits: Equipment which is being used for tests involving beryllium must be cleaned if the smearable surface contamination exceeds 0.05 micrograms per square centimeter. Equipment which has been used for such tests may be returned to unrestricted use if the surface contamination is less than or equal to $0.01 \mu\text{g}/\text{cm}^2$. These criteria are based on wiping an area greater than or equal to 100 cm^2 , with a Whatman 41, one-inch diameter filter circle. If it is difficult to swipe the desired area due to accessibility, shape or size, then the equipment must be cleaned to a level of ≤ 5 micrograms per swipe for the duration of the experiment(s). Similarly, equipment may be returned to normal use when the levels are $\leq 1 \mu\text{g}$ per swipe.

Swipe Sampling Results: The results of swipe sampling are shown in the attached table. In addition swipes were taken in a chemical fume hood, which was employed for cleaning the shroud and cooling stage. These results are as follows:

Room 320, Hood base prior to cleaning: $0.03 \mu\text{g}/\text{cm}^2$
Room 320, Hood base after cleaning: $< 0.0001 \mu\text{g}/\text{cm}^2$
Room 320, Floor at hood: $0.002 \mu\text{g}/\text{cm}^2$

Conclusions: The melting of a beryllium sample resulting in significant contamination of surfaces inside the EBTF. This contamination was successfully removed with a modest effort, which did not result in contamination of adjacent areas or the generation of detectable airborne beryllium.

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EBTF SWIPE SAMPLING RESULTS

Swipe Sample Location	$\mu\text{g Be per swipe}$				
	1/12/84 Before Meltdown ^a	1/16/84 Initial Test Before Cleaning	1/17/84 After 1st Cleaning	1/17/84 After 2nd Cleaning	1/18/84 After 3rd Cleaning
1. Inside shroud	ND	> 80	--	1.3 & 2.6 ^b	--
2. Top of cooling stage	ND	8.4	--	2.6	--
3. Bottom of chamber (west)	ND	0.8	0.5	--	--
4. Bottom of chamber (east)	--	--	1.2	ND	ND
5. South chamber wall	ND	2.5	1.2	0.8	ND
6. East chamber wall	--	--	0.6	ND	ND
7. Chamber access door (interior)	ND	1.3	ND	ND	ND
8. Between IF window & e-gun	--	--	78	18	1.9
9. Around IF window	--	--	27.2	--	--
10. Video camera port	--	--	3.0	4.2	ND
11. North 8" flange	--	--	1.8	0.4	ND
12. Chamber ceiling	--	--	1.9	ND	ND
13. Cooling stage support rods	--	--	ND	--	--
14. Step stool	--	--	ND	--	ND
15. Floor and hand tools	--	--	--	--	All ND
Detection Limit ND =	< 0.24	< 0.2	< 0.2	< 0.2	< 0.2

^aSample had been heated to 800°C previously.

^b2nd sample before cleaning: 97 $\mu\text{g Be}$

Appendix E
THE HEALTH AND SAFETY IMPLICATIONS OF USING
BERYLLIUM ON JET LIMITER FACES

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S. Booth

J. Dean

THE HEALTH AND SAFETY IMPLICATIONS OF USING
BERYLLIUM ON JET LIMITER FACES

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The Health and Safety Implications of using Beryllium on JET Limiter Faces

1 Introduction

Beryllium has a combination of properties which makes it very attractive as the facing material for the JET limiters compared with the only other contenders, nickel and graphite. See section 3.1 and table 4.

Handling beryllium in solid pieces presents no problem if elementary care is taken. However, if fine beryllium dust is inhaled it can cause an irreversible lung disease called berylliosis, as silica and asbestos cause silicosis and asbestosis. There is also evidence that beryllium in a wound can inhibit healing. Consequently airborne and surface contamination by beryllium dust must be carefully controlled in work areas.

Beryllium components exposed to the JET plasma, as the limiter faces will be, will in part be reduced to dust including fine particles. The dust will normally remain safely within the vacuum system, but when the system is opened measures must be taken to prevent spreading the dust outside, and to reduce the airborne and surface contaminations to acceptable levels wherever people work.

This note sets out the regulations and established precautions for working safely in areas where there may be beryllium dust. Usually this is in workshops making components by machining or powder metallurgy. The note then discusses the relevant circumstances in JET and the facilities and procedures necessary because beryllium dust will be present.

The material for this note is derived largely from discussions with staff of the Royal Ordnance Factory, Cardiff, the AWRE, Aldermaston, and the UKAEA, Harwell, for whose unreserved co-operation the JET Project is extremely grateful.

2 Handling beryllium

2.1 Regulations

Although there are no statutory British regulations specifically naming beryllium and its compounds, it is recognised as an injurious dust and as such comes under the general provisions of the Health and Safety at Work (etc) Act 1974 /1/, and sections 4 and 63 of the Factories Act 1961 which relate to the ventilation of workrooms and the measures to be taken to protect persons against inhalation of injurious dust or fumes¹.

Safeguards to be observed when working with beryllium and its compounds are embodied in advisory documents issued by:

- a) the Health and Safety Executive, "Guidance Note EH13, Beryllium - Health and Safety Precautions, 1978" /2/.
- b) the UKAEA /3,4/.
- c) the Ministry of Defence (MOD) /5/.

2.2 Air contamination limits

These documents define "controlled areas" as those where beryllium powder could be present but concentrations are kept below safe breathable levels. A workshop containing enclosed machines could be a controlled area. No precautions

¹ The Safety and Factories Acts referred to do specifically mention lead and asbestos.

are needed, and access is free to areas defined as "uncontrolled", eg outside demarcation barriers. The approved upper limits of airborne concentration in controlled areas are variously known as the "threshold limit values" (TLV), "maximum permissible concentrations" (mpc) and "derived limits" (DL), depending on which document is quoted. The long-term upper limit is recognised as the maximum which can be breathed for a 40 year working life with no harmful effect on a person in normal health. People at special risk because of particular health conditions must be identified by medical examination and not allowed to work with beryllium.

Approved upper limits for controlled and uncontrolled areas are given in Table 1.

Table 1 Approved upper limits for beryllium concentration in air, $\mu\text{g}/\text{m}^3$

		HSE(EH13)	MOD	AERE(R5106)
Controlled Area	1. Average over 8 hours	2	2	2
	2. Short term exposure, ≤ 30 min	25	Not permitted	25
	3. Long term on ALARA principle	Not stated	0.2	Not stated
Uncontrolled Area	Long term	Not stated	0.01, 3 months average	0.01, 1 month average

The American Conference of Government and Industrial Hygienists in 1982 recommended a TLV of $2 \mu\text{g}/\text{m}^3$ in the work environment with no short term increase, based on some experimental evidence that, at very high concentrations and short exposures, beryllium compounds have a "low potency" for producing lung tumours in rats.

2.3 Surface contamination limits

With the same definitions of controlled and uncontrolled areas, the documents /2 to 5/ approve upper limits of surface contamination as Table 2.

Table 2 Approved limits for surface contamination by beryllium, $\mu\text{g}/\text{m}^2$

	HSE(EH13)	MOD	AERE(R5106)
Controlled area	100 ¹	500 ²	1000
Buffer area	Not stated	Not stated	100
Uncontrolled area	Not stated	<100	<100

Notes: ¹ Not clear from the document whether 100 is for controlled or uncontrolled area

² <500 for controlled areas normally, but
<3000 with special precautions and decontamination as soon as possible and
>3000 requires immediate decontamination

2.4 Monitoring

The only satisfactory monitoring of airborne or surface contamination is by collecting samples on filters or swabs and measuring the quantity of beryllium collected by means of an atomic absorption spectrometer². Spectrometers that can reliably detect 0.1 μg of beryllium are available for about £10,000.

Airborne samples are collected on filters through which air is drawn at a known rate, so that the quantity of air sampled in a known time can be calculated. There are installed (fixed), portable (movable) and personal (wearable) versions of such monitors. The air intake of a personal monitor is worn on the shoulder, ie close to the nose and mouth. Typical air flow rates and the consequent time to collect a sample are given in Table 3.

Table 3 Airborne beryllium sampling times

Monitor type	Typical air flow rate, ℓ/min	Time to collect 0.1 μg at 2 $\mu\text{g}/\text{m}^3$ Minutes
Installed	30	17
Portable	30, 60, 100	17, 8, 5
Personal	2	250

Surface samples are collected on filter paper discs by wiping a known area, usually about 1000 cm^2 (0.1 m^2). MOD procedures assume that 10% of the beryllium is transferred to the smear paper whereas AERE R5106 recommends assuming 25%.

² The alternative of irradiating the sample with γ emission from an antimony - 124 source and counting the resulting neutrons has practically been abandoned.

There is at present no on-line method of detecting the presence of beryllium dust without delay, although a prototype instrument is under development at AWRE. The shortest time in which a reliable analysis of a sample can be expected is 20-30 minutes. To this must be added the time to collect the sample and take it to the laboratory. It seems that when exploring an unknown environment, such as the JET torus, it would be possible to take a new sample about every hour.

2.5 Ventilation and filtration systems

The basic principle of air-flow control is that a velocity of $\geq 1\text{m/s}$ (200 ft/min) should be maintained from clean to contaminated enclosures within a work area. This normally means between the workshop and a fume cupboard with leaking doors: air-tight glove boxes are not usually used for beryllium. In addition it is normal to fit a high velocity extractor near to a possible source of dust, such as a grinder or cutter.

All air discharged to atmosphere must pass through high-efficiency filters and it is preferable that extra filters should be fitted near to each source of contamination, eg in each cupboard, so that less pipework becomes contaminated.

The air in workshops and buffer areas must be changed 5 times per hour and it is usual to filter the fresh incoming air, largely to reduce the load on the discharge and monitor filters. Such intake filters would be useful in JET also to reduce torus surface contamination by incoming dust.

2.6 Protective clothing

All personnel entering a beryllium controlled area must wear special disposable or washable clothing, which they put on and discard in circumstances designed to prevent the spread of beryllium dust across barriers and into uncontrolled areas. For visitors this could be overalls, overshoes and hats and for workers it would be a full change of clothing including underwear. Laundering of non-disposable garments could probably be arranged for JET through the AERE, Harwell. Personal washing and showering facilities must be available in the clothing change area and used under the direction of a health and safety officer.

All personnel must wear personal air monitors in the controlled area.

Breathing apparatus of the following types:-

- Masks with filters, giving 1000 attenuation,
 - fitting only over the mouth and nose (ori-nasal type)
 - fitting over the whole face (full face type) and inside which spectacles can be worn.
- Hoods or full face masks with airlines maintaining an outward air flow $> 1\text{m/s}$, supplied with filtered air or air from bottles.
- Self contained breathing apparatus with air bottles. This is dangerous in the hands of unskilled people and is normally reserved for rescue or other special work.

3 Beryllium in JET

3.1 Properties of beryllium

There is evidence to indicate that elements from the limiter faces will be dispersed into the JET plasma, and that if the atoms are heavy they could lead

to serious radiation losses. The limiter surfaces must withstand considerable temperature increases arising from the deposition of plasma energy, and the energy must be conducted readily to the substrate and then the cooling system. The material must be strong enough to withstand the thermal shocks and be strongly attached to the substrate with a good thermally conducting bond. Chemical reactivity should be weak, particularly with hydrogen, and the material must be non-magnetic.

The relative merits of beryllium showing why it is attractive compared with the only other two contenders, nickel and graphite, are discussed in /6/. Table 4 reproduces some of the more significant properties from /6/.

Table 4 Comparison of properties of alternative facing materials for JET limiters

Property	Beryllium	Graphite	Nickel	
Atomic number, Z	4	6	28	Be will give lowest radiation losses
Thermal conductivity, $Wm^{-1}K^{-1}$	1.6×10^2	4×10^1	6.7×10^1	Be is best to transmit surface heat
Melting point, $^{\circ}K$	1560	>3000	1739	Be has one of the highest melting points for light metals
Tensile strength, N/m^2	5.9×10^8	5.5×10^7	4.6×10^8	Be is strong. It is brittle up to $200^{\circ}C$

3.2 Contaminated space, quantities and concentrations

The proposed 4 mm thick limiter facings with an area of $\sim 20 m^2$ means ~ 150 kg of beryllium in the torus. At least 50% of this could be pulverised by erosion, evaporation and sputtering in at most a 5 year limiter life. On average, ~ 3 kg of beryllium would be pulverised in 2 months of operation, which in the total vacuum system of $\sim 200 m^3$ would give an average concentration of $\sim 10^7 \mu g/m^3$.¹

Most of the powder would lie as dust at the bottom of the torus, perhaps with some adhering to the walls, and it would only be disturbed when a gas is admitted. However, if only a small part is fine enough to be airborne the concentration would be very much greater than the $2 \mu g/m^3$ (or less) acceptable in a controlled work area. If the torus is to be entered by people it is essential to decontaminate to levels as low as reasonably achievable. The agreed levels in Tables 1 and 2 must be achieved if the torus is to be declared a "controlled area".

The extent to which peripheral systems, such as the pumping lines, the neutral beam injectors and the diagnostics, could be contaminated has not yet been established, and nor has their accessibility for decontamination. The best

$$^1 \frac{150 \times 10^3}{2} \times \frac{2}{5 \times 12} \times \frac{1}{200} \approx 10^7 \mu g/m^3$$

feasible position for the HEPA filters (high efficiency, particulate, air) in the pump lines is just downstream of the turbomolecular pumps: although this does mean that the pumps and their oil will be contaminated, and abrasive beryllium dust is harmful to bearings. It would be possible, but not easy, to modify the existing TM pumps so that the chamber containing the bearings is continuously flushed with clean gas.

Cryogenic pumps would be much easier to decontaminate.

During the hydrogen plasma phase of JET, the beryllium of the limiters and the dust in the torus would not be radioactive. In the D-D and D-T phases the reactions of ${}^9\text{Be}(n,\alpha){}^6\text{He}$ and ${}^9\text{Be}(n,\gamma){}^{10}\text{Be}$ produce very short-lived and very long-lived β emitters respectively, probably at negligibly low levels.

3.3 Decontamination and waste disposal

The high pressure (80 bar) water scouring system, possibly with a detergent before final washing with demineralised water, would be well suited to decontaminate the torus from beryllium dust.

The water, containing beryllium dust, would be collected, probably by suction pipes, and taken away for safe disposal. Commercial companies are licensed to do this with non-active beryllium. When it is active it would have to be taken by the UKAEA/AERE through their normal radioactive waste disposal routes.

It would probably be worthwhile to concentrate the waste on site, by filtering.

3.4 Tasks and procedures

No special precautions are required for handling dust-free beryllium components. Nevertheless, it is wise to take reasonable care, such as wearing gloves, washing hands afterwards and avoiding cuts. Also a strict control must be exercised to prevent the creation of dust by scraping, machining or otherwise working beryllium components. If they need to be worked they should preferably be sent to the manufacturer.

The vacuum system will need to be opened for a variety of reasons, such as changing RF antennae and limiters, replacing filters in the pump lines and replacing the turbo-molecular pumps. A complete procedure for opening and entering the system has not been developed, but the following proposal for gaining access to the torus is probably a fairly accurate illustration.

First a buffer zone will be created, probably in the form of a strong portable chamber sealed onto the entry port. Air will be drawn from the torus hall into the buffer zone at its entrance and discharged near the working face through a blower and filters. Since at this stage the buffer zone could be classified as a "maintenance area to a primary containment or high risk process plant", the air flow must provide 30 changes/hour.

The first task in the buffer zone will be to remove the flange plate ($\sim\frac{1}{2}$ tonne) or other vacuum sealing component, by a bagging sequence which avoids spreading the dust. Such sequences are well established, even with heavy components for which the crane sling must be passed through the bag.

If it is intended to enter the torus, the next task is to wash the walls and take away the waste. The water scouring system will be carried into the torus on the remote handling articulated boom. The boom can also carry air monitors, perhaps with only the intake and exhaust inside the torus and the filter outside for easy removal.

After decontamination, an air flow from the hall, through the buffer zone, into the torus and out through HEPA filters will be introduced. If introduced earlier it would carry embarrassingly large quantities of beryllium dust into the filters and also possibly into the TM pumps.

The capacity of the existing backing pumps, 250 m³/h from each of four at atmospheric pressure, is far too small to provide the minimum air change rate of 5/hour. Consequently it will be necessary, again creating a buffer zone, to provide a second opening at the opposite port and attach a blower and filter system to the vessel opening. Before the second opening is made the extract fans of the first buffer system will be switched off and closed so that dust is not drawn from the torus. When the final torus ventilation system is ready the system in the second buffer zone will also be switched off and closed. Next the boom will be withdrawn. As it is withdrawn, surface contamination samples will be taken and analysed repeatedly. While the boom is being withdrawn, the air flow through the torus will be boosted to the equivalent of 1 m/s through the port aperture of 435 mm horizontal x 940 mm vertical. This flow is equivalent to 9 changes/hour in the torus.

With the boom clean and removed it will now be possible to enter the adequately ventilated torus with breathing apparatus, giving 100% protection, and take further, repeated air and surface samples until it is declared safe to start work. Even so, workers will always wear respiratory protection. Samples must be taken and analysed, and workers must leave the torus, whenever there is a possibility that trapped dust has been disturbed.

In theory it should eventually be possible to reduce the airborne and surface contamination to levels at which the torus can be declared a controlled working area where breathing apparatus is unnecessary. In reality it will probably never be worthwhile to achieve this condition.

3.5 Manpower and training

In estimating manpower it seems reasonable to assume that it may be necessary to work in the vacuum system between 2 and 6 times a year for periods of one or 2 weeks. A foreman and 5 craftsmen would appear to be a reasonable team, considering the restricted space and the needs of safety surveillance.

It seems unlikely that JET could hire people accustomed to working with beryllium, but practical familiarity with radioactive and other toxic substances should be sufficient. IN any case all personnel concerned must be properly trained. The training should include:-

- a) information on hazards
- b) work procedures and precautions
- c) clothing, changing, washing and other related practices
- d) use of breathing equipment, with self-contained apparatus limited to the Patrol Service, Health Physics Service, or other special categories
- e) emergency actions
- f) actions in case of injury

The necessary training can be arranged through the Culham/JET Safety Services Section.

4 Recommendations for JET

In addition to the requirement to comply with the appropriate regulations concerning the handling of beryllium it appears, from the information recounted in this note, that the following recommendations would be appropriate for JET.

4.1 Contamination levels

4.1.1 The JET vacuum system will automatically be declared a beryllium hazard area as soon as the machine has operated with beryllium limiters, and will remain so until, if ever before de-commissioning, it is declared uncontrolled by the JET/Culham Safety Services.

4.1.2 Areas should be classified on a 2-tier system, black controlled areas and white uncontrolled areas, ie with no intermediate shading, which might be confusing.

4.1.3 Controlled areas will always be within the vacuum system or close outside the entry point. Respiratory protection will always be used in these controlled areas.

Nevertheless, the airborne concentration in a controlled area ought not to exceed $2 \mu\text{g}/\text{m}^3$, with an overriding target of $0.2 \mu\text{g}/\text{m}^3$ on the ALARA principle.

4.1.4 "Short term" exposures to airborne levels $>2 \mu\text{g}/\text{m}^3$ will not be permitted.

4.1.5 If a controlled area is set up where respiratory protection is not needed, the same limits as 4.1.3 will apply.

4.1.6 The airborne contamination in uncontrolled areas should not exceed $0.01 \mu\text{g}/\text{m}^3$ averaged over 1 month.

4.1.7 The surface concentration in controlled areas should not exceed $100 \mu\text{g}/\text{m}^2$.

4.1.8 The surface concentration in uncontrolled areas must not exceed $10 \mu\text{g}/\text{m}^2$.

4.2 Ventilation

4.2.1 An air flow velocity of 1 m/s should be maintained from a cleaner space through any open aperture into a space where contamination is unknown, eg the torus, or where it is suspected that levels may be higher than those set for controlled areas.

4.2.2 Buffer zones must be established between beryllium hazard areas and uncontrolled areas.

4.2.3 Until conditions on the beryllium side of a buffer zone, ie at the working face and in the JET vacuum system, are fully controlled, an air change rate of 30/hour should be maintained in the buffer zone.

4.2.4 When conditions on the beryllium side are fully controlled, the air change rate in the buffer zone can be reduced to not less than 5/hour.

4.2.5 The air flow rate in any beryllium controlled area must not be less than 5/hour, even when respiratory protection is worn.

4.3 Medical support

Qualified medical support must be available on site to attend immediately to any injury, however slight, where there is any risk of beryllium contamination.

All personnel who might be exposed to beryllium dust will be medically examined and those who would run a health risk higher than normal will be excluded.

5 General observations

About 200 - 500 man-years have been spent on beryllium work at the establishments visited. During this time there has been only one case of very slight berylliosis and one case of a cut from a grinding wheel which would not heal and resulted in a lost thumb.

The general attitude is one of calm confidence based on precise and unremitting health physics control. The characters and personalities of the operators, particularly in cheerfully accepting exacting discipline, is clearly important.

6 References

- 1 Health and Safety at Work Act, 1974
- 2 Copy attached. Guidance Note EH13 from the Health and Safety Executive; October 1978, "Beryllium - health and safety precautions".
- 3 UKAEA Health and Safety Code No D 2.1, "Safe Handling of Beryllium and its Compounds".
- 4 J Pollock, I S Jones, "Health Physics Control of Beryllium at AERE Harwell", AERE-R5106, July 1966.
- 5 Private communications from Health Physics Staff AWRE and ROF Cardiff to R Clayton, 1983.
- 6 P H Rebut and K J Dietz, "The first wall in JET", 12th SOFT, 1982.

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5 May 1983



Guidance Note EH 13
from the
Health and Safety
Executive

Beryllium-health and safety precautions

Environmental Hygiene 13 (October 1978)

These Guidance Notes are published under five subject headings: Medical, Environmental Hygiene, Chemical Safety, Plant and Machinery and General.

DESCRIPTION

Beryllium, Be, is a hard silver-white metal of low specific gravity (1.85) and high melting point (around 1280°C). It is stable in air, but burns brilliantly in oxygen. The most important properties of the metal are its high strength-to-weight ratio and its alloying property which confers to metals special properties of resistance to corrosion, vibration and shock.

With the exception of the naturally occurring beryl ore (beryllium silicate), all beryllium compounds and beryllium metal are potentially highly toxic.

Threshold limit value

Beryllium and its compounds: 0.002 mg/m³ of air calculated as beryllium. A level of 0.025 mg/m³ has been suggested as an upper limit which should not be exceeded even for very brief exposures.

INDUSTRIAL USES

These include the following.

- (a) In copper alloys, commonly containing up to 2% beryllium. These alloys have high tensile strength and possess high electrical and thermal conductivity. They are used in the electrical industry and in high definition moulds used, for example, in plastic injection moulding machines.
- (b) As an alloy with nickel used for diamond drill-bit matrix and for watch balance wheels. Complex nickel-chromium alloys containing low percentages of beryllium are used for dental plates.
- (c) In atomic energy development and nuclear reactor research, although stainless steel has replaced beryllium as the 'canning' material for uranium fuel rods.
- (d) In space exploration vehicles and in missiles.

Uses of beryllium compounds include the following.

Beryllia (beryllium oxide) is used as a heat-resistant ceramic and finds particular use in high temperature nuclear reactors. The excellent heat conductivity and high dielectric value of the ceramic account for its wide use in the electronics industry.

POISONOUS EFFECTS

Beryllium poisoning is a prescribed industrial disease under the National Insurance (Industrial Injuries) Act 1965.

Two main types of beryllium intoxication are recognised, (1) *Acute* and (2) *Chronic*.

(1) *Acute intoxication* due to the inhalation of beryllium fume or dust on local contact with soluble salts may result in any of the following manifestations.

(a) Inflammation of the mucous membranes of the nose, throat and chest with discomfort, possibly pain, and difficulty with swallowing and breathing.

(b) Exposure to moderately high concentrations of beryllium in air may produce a very serious condition of the lungs. The injured person may become blue, feverish with rapid breathing and raised pulse rate. Recovery is usual but may take several months. There have been deaths in the acute stage.

(c) Dermatitis. The soluble acid salts of beryllium may cause dermatitis and sometimes ulceration which usually resolve on removal from exposure.

(d) Conjunctivitis. The soluble acid salts may cause inflammation of the mucous membranes of the eyes.

(2) *Chronic response*. This condition is more truly a general one although the lungs are mainly affected. There may be lesions in the kidneys and the skin. Certain features support the view that the condition is allergic. There is no relationship between the degree of exposure and the severity of response and there is usually a time lag of up to ten years between exposure and the onset of the illness. Both sexes are equally susceptible. The onset of the illness is insidious but only a small number of exposed persons develop this reaction.

The symptoms may include breathlessness on exertion, cough, chest pain, loss of appetite, tiredness, loss of weight and skin changes. Early diagnosis is of prime importance in the subsequent success of treatment with modern drugs.

CONTROL

Beryllium and its compounds should preferably be handled in enclosed plant. Where this is not possible, local exhaust ventilation of the highest standard should be provided for processes where dust or fume are likely to arise. All working surfaces and components should be kept virtually dust free. It is recommended that beryllium contamination

should not exceed 0.01 ug/cm³ (0.1 mg/m³). Air exhausted from local exhaust ventilation systems and cleaning equipment should be efficiently filtered before discharge to the outside atmosphere.

PERSONAL PROTECTION

- (a) Protective clothing including gloves should be provided to prevent skin contact.
- (b) A respirator of the approved type should be provided for emergency use and maintenance operations e.g. when emptying dust collection plant.
- (c) Washing facilities of a high standard and easily accessible should be provided for use of persons exposed to beryllium and its compounds. If the skin is contaminated with the dust, affected parts should be cleaned without delay.

MEDICAL SUPERVISION

There are no regulations requiring a statutory examination of beryllium workers. However it is recommended that medical supervision is provided for those who use beryllium and its compounds in processes that involve risk of inhaling dust or fume (beryllium oxide is particularly hazardous).

Pre-employment medical examinations

These should include a full chest X-ray and possibly lung function tests. It is advisable that personnel having a history of asthma or eczema should not undertake work involving exposure to beryllium compounds.

Periodic medical examinations.

These should be annual and include a chest X-ray and if appropriate, lung function tests.

Special medical re-assessments

These may be indicated in the following circumstances:

- (a) On return to work after a chest illness involving more than two weeks sickness and on return to work after any illness lasting more than four weeks.

Guidance Notes in the Environmental Hygiene Series

EH 1 Cadmium - health and safety precautions
 EH 2 Chromium - health and safety precautions
 EH 3 Prevention of industrial lead poisoning
 EH 4 Aniline - health and safety precautions
 EH 5 Trichloroethylene
 EH 6 Chromic acid concentrations in air
 EH 7 Petroleum based adhesives in building operations
 EH 8 Arsenic - health and safety precautions
 EH 9 Spraying of highly flammable liquids
 EH 10 Asbestos - hygiene standards and measurements of airborne dust concentrations

- (b) Any injury to the skin by beryllium ceramic material should be recorded. Such an injury should be followed up as in the event of failure to heal consultant opinion may be necessary.

Medical records should be kept to facilitate any future long term follow-up of beryllium workers.

First aid

In the case of acute poisoning, the victim should be removed immediately from exposure and contaminated clothing removed. If the victim is cyanosed, oxygen may be required. He should be kept at rest and warm until either medical aid or an ambulance arrives. It is advisable to send a written note explaining what has happened, or to send a responsible person able to give a coherent history, with the patient to hospital.

In a case of conjunctivitis, the eyes should be flushed copiously with water and medical advice sought.

STATUTORY REQUIREMENTS

No specific Regulations have been made under the Factories Act 1961 nor the HSW Act 1974 to deal with exposure to beryllium, but attention is drawn to the requirements of Section 6 of the HSW Act 1974 regarding the duties of manufacturers etc. and of Sections 4 and 63 of the Factories Act 1961 regarding the ventilation of workrooms and measures to be taken to protect persons employed against inhalation of injurious dust or fume.

Beryllium works are Scheduled under the Alkali, etc. Works Regulation Act 1906 and Alkali etc. Works Orders 1966 and 1971.

FURTHER INFORMATION

This Guidance Note is produced by the Health and Safety Executive. Further advice on this or any other publications produced by the Executive is obtainable from Baynards House, 1 Chepstow Place, London W2 4TF, or from Area Offices of the HSE.

Appendix F
VENTILATION INSTRUMENTATION AND CONTROL SYSTEM
FOR BERYLLIUM LIMITER EXPERIMENT

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1. INTRODUCTION

The principle is that in the event of a vacuum failure, the Nilfisk Industrial Suction Unit (GB 733) will turn on and develop a blank-off pressure of about -100 mm Hg gauge. When the liner pressure is between this blank-off pressure and atmospheric, the isolation gate valve will open maintaining the liner at a reduced pressure. A back-up system will automatically turn on if the primary system fails to operate. The automatic control system can be bypassed for liner pumpdown by an auto-reset bypass circuit.

2. DESCRIPTION

Starting point is under vacuum. Atmospheric pressure is a nominal 740 mm. A leak or deliberate vent occurs. At about 10μ (10^{-3} mm Hg) the tokamak vacuum system shuts down; this indicates on the alarm panel and at the Plant Shift Superintendent's Office. At 325 mm Hg abs the two absolute MKS barotrons will exceed the set point and PA1-1 and/or PA2-1 will close. This turns both GB 733 units on and energizes the intermediate voltage rail. For additional reliability the two GB 733 units will be supplied by separate 440 V bus lines. The GB 733 units will generate a blank-off pressure of about -100 mm Hg and the differential pressure will be about $+315$ mm. The indicator will read positive off scale. As the liner pressure continues to rise, this differential pressure will decrease, passing through zero when the liner pressure equals the GBA 733 blank-off pressure at about 640 mm. When the liner pressure reaches 660 mm the second set of contacts on the absolute manometer, PA1-2 or PA2-2, will close, enabling the differential manometer contacts. The liner pressure will continue to rise until the differential pressure equals -50 mm when the contacts PD1-1 or PD2-1 will close. This will energize the delay timer TR, which, after a ten-second delay to protect against noise transients, will operate, energizing CR3 or CR4. Which closes first will depend on the actual set points for PD1-1 and PD2-1. We will assume here that PD1-1 closes; however, system operation is the same if PD2-1 closes first. When CR3 is energized CR3-1 latches TR1 in and CR3-2 energizes EOVI, opening the isolation gate valve IGV1. In addition, the limit switch LS1 on EOVI opens, disabling TR2. Hence, EOVI2 remains closed, preventing one GB 733 from pumping the other. In the event that a failure occurs and IGV1 does not open, LS1 will remain closed. When PD2-1 passes its set point, EOVI2 will be closed and the limit switch LV2 will open, preventing EOVI1 from opening. As soon as the isolation gate valve opens the differential pressure falls to zero, opening PD. However, the latch contacts CR3-1 (or CR4-1) to keep TR1 (or TR2) energized.

For pumpdown, it is necessary to close the gate valve with the liner at atmospheric pressure. For this purpose an auto-resetting bypass is included. This consists of two parallel relays, CR5 and CR6, which are energized by the pushbutton latch combination bypass enable, and CR5-1 or CR6-1. Energizing CR5 opens the normally closed contact CR5-2, deenergizing the relay string and closing the gate valve. Relay CR5 is reset when the pressure falls below 325 mm, and PA1 and PA2 open. Relay CR6 is installed to provide redundancy in the event of a failure in CR5-2, such as a burnt contact. A "Bypass Defeat" pushbutton is included to allow resumed filter operation if pumpdown is delayed.

Test procedures will now be described. The absolute manometer will be disconnected from the indicator/power supply unit. A variable voltage source will be connected to the indicator unit to simulate a high pressure. The valve actuating relays CR3 and CR4 will be removed. The signal lead from the differential manometer to the Jewell indicator will be disconnected, and a variable voltage source will be connected across the Jewell meter.

The absolute manometer voltage supply will be increased until the first set point is exceeded, when the suction motor will turn on. This voltage will be compared with 1.63 V.

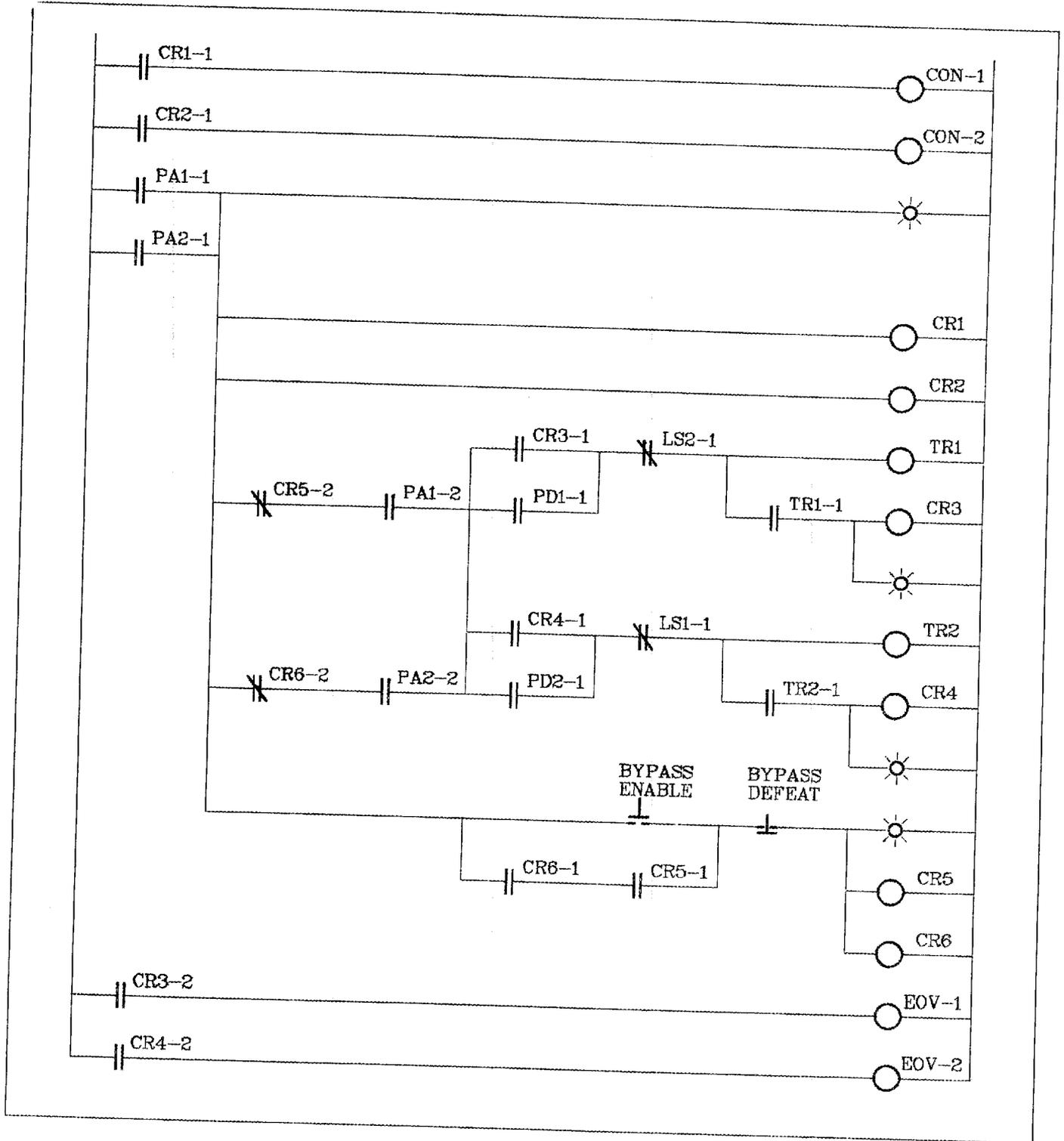
The voltage will then be further increased until the instrument reads about 700 mm. The voltage source to the differential manometer will then be increased until the trip light comes on. The voltage will be compared with the limit set valve of -0.5 V. The instrument should read -50 mm.

After 10 seconds, the gate valve indicator light should come on indicating correct function. The absolute manometer voltage source will then be reduced until the valve indicator light goes out. The voltage should be compared to 3.3 V. The voltage should then be increased to about 3.5 V, when after a 10-second delay the valve indicator light will come on again. The preceding test should be repeated for the second set of controls.

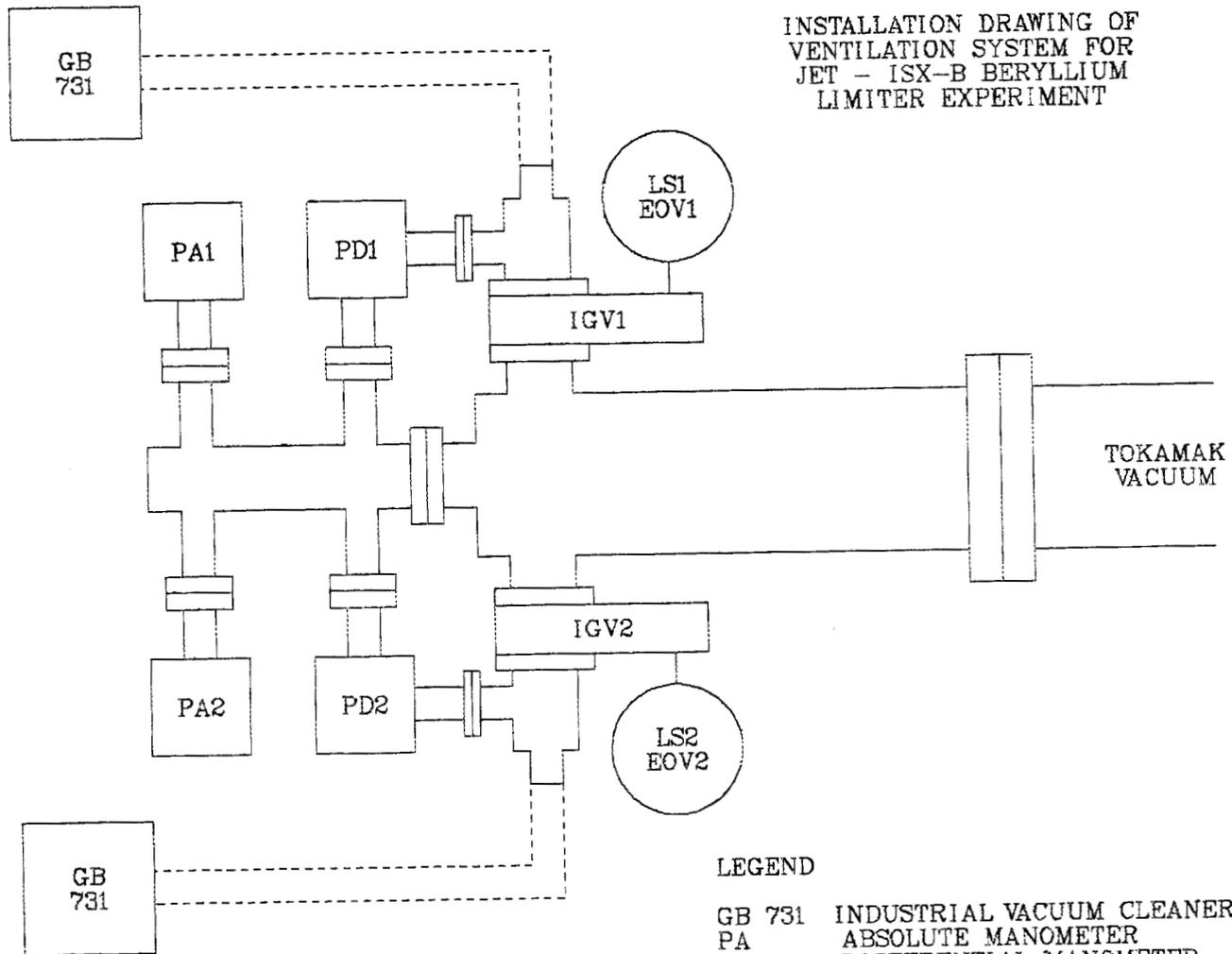
The bypass enable circuitry should then be tested. With the valve indicator light lit, push the bypass enable button. The bypass enable light should go on and the valve actuator light should go out. As CR5-2 is in series with PA1-2 and CR5-1 is in series with CR6-1 (and similarly for CR6 and PA2) no additional test is required to check these contacts.

Replace the leads to the indicator unit and Jewell meter, observing polarity. Check that the absolute gauge reads zero and the differential gauge reads positive off scale. Check that the valve indicator lights are off. Insert relays CR3 and CR4. This completes the control system test.

Interlock Schematic for Liner Ventilation System



INSTALLATION DRAWING OF
VENTILATION SYSTEM FOR
JET - ISX-B BERYLLIUM
LIMITER EXPERIMENT



LEGEND

- GB 731 INDUSTRIAL VACUUM CLEANER
- PA ABSOLUTE MANOMETER
- PD DIFFERENTIAL MANOMETER
- IGV ISOLATION GATE VALVE

Appendix G
JET-ISX-B BERYLLIUM LIMITER EXPERIMENT
OPERATIONAL SAFETY REQUIREMENTS

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1. INTRODUCTION

These Operational Safety Requirements (OSR) pertain to the JET-ISX-B beryllium limiter experiment. ISX-B is an already existing experiment that has operated for the past five years. The modification associated with these requirements consists of the installation of a beryllium metal limiter into the tokamak. This operating safety requirement is to support the necessary control and monitoring procedures associated with this beryllium experiment.

2. SAFETY LIMITS AND LIMITING SAFETY SYSTEM SETTINGS

The two items of equipment with safety limits are the flow meters that monitor the air flow rates in the air samplers and the controls for the liner ventilation apparatus.

The air sampler flow rate is monitored by a levitated ball flow meter. The normal air flow rate is 20 L/min. The consequences of excessive air flow are over-sensitivity, which is not serious. The consequences of insufficient flow are inadequate sensitivity, which has serious potential. The flow meters in use have an approximately 5% combined reading and instrument uncertainty. The maximum acceptable 8-h exposure level will be set at $1 \mu\text{g}/\text{m}^3$ indicated. (This is one-half of the established TLV.) The reliable detection level for beryllium is $0.1 \mu\text{g}$, and it takes 50 min to detect $1 \mu\text{g}/\text{m}^3$ at 20 L/min. The limiting safety setting will be established as $\pm 25\%$ of normal air flow, for example, 15 to 25 L/min. This provides a safety margin of 20% including instrumental accuracy before the TLV of $2 \mu\text{g}/\text{m}^3$ is exceeded. To maintain realistic operating ranges and to prevent false indications of overexposure, the high limit has been set to the same value, +20% of normal flow setting.

The control instruments for the liner ventilation system consist of a duplicated set of absolute and differential pressure manometers. The detailed system description is presented in the Final Safety Analysis Report (Appendix F). The absolute manometer, PA, detects a failure in the main vacuum system, starts the suction unit motor, and enables the remaining circuitry. The instrument and set point accuracy is $\pm 10 \text{ mm}$ ($\pm 1\%$). The operating requirement is that the unit actuates before the liner pressure reaches atmospheric and does not generate any false valve openings. The low-pressure safety limit is 10 mm. The variation in barometric pressure is less than $\pm 40 \text{ mm}$ (excluding freak weather); standard pressure at the 9201-2 site (elevation 800 ft MSL) is 740 mm. Including instrument accuracy, the upper safety limit is then 690 mm. The normal operating set point is 350 mm; the safety system setting has been made equal to the limiting safety systems at $\pm 100 \text{ mm}$ about the normal operating set point (250 to 450 mm), and the safety margin is 240 mm.

The differential manometer, PD, detects the rise of liner pressure above the blanked-off suction pressure. The suction unit specification is 110 mm. Instrument accuracy for the manometer is $\pm 3 \text{ mm}$. The normal set point is 50 mm. The limiting safety system setting is $\pm 20 \text{ mm}$. The safety margin is $\pm 27 \text{ mm}$. In addition to enabling the suction unit motor, the absolute manometer also enables the differential pressure circuitry to prevent accidental system operation during tests. The requirement is that this second trip must occur for all atmospheric conditions. The lowest realistic atmospheric pressure is 700 mm.

The instrument accuracy is 10 mm and the safety limit is 690 mm. The safety system setting will be set at 680 mm; the safety limit is 10 mm for this worst atmospheric pressure case. The summary of the set points and operating limits is shown in Table 1.

Table 1. Summary of set points and operating limits

Device	Normal operating value	Operating limit safety settings
Sampler air flow	20 L/min	15 L/min to 25 L/min
Absolute manometer		
Lower set point	350 mm	250 mm to 450 mm
Upper set point	680 mm	670 mm to 690 mm
Differential mamometer set point	50 mm	30 mm to 70 mm

Note: All pressures mm Hg.

3. LIMITING CONDITIONS FOR OPERATIONS

The limiting conditions for tokamak operations are not covered in the OSR and are addressed in the ISX Safety Analysis Report (SAR), as referenced in the Final Safety Analysis Report. Two limiting conditions exist for the operation of the safety systems.

a. *The liner ventilation system*

Prior to operation each day, the liner ventilation set points will be visually checked for proper setting. If any set points are outside the system settings as previously described they will be reset. In the event that a system failure is detected at any time, all further device operation will be delayed until the fault is repaired.

b. *Air monitoring system*

Four fixed head air sampling monitors will be maintained in continuous operation. Air flow rates will be checked prior to operation each day. If any air flow rate is outside the system setting, the defective unit will be repaired and replaced as soon as possible. In the event that two or more units are outside limits, the experimental run will be postponed until the units are repaired, and area access will be limited to personnel wearing protective clothing, footwear, and suitable breathing masks.

4. SURVEILLANCE REQUIREMENTS

Before operation each day, the fixed air samplers will be checked for proper operation, and the liner ventilation systems will be checked for available three-phase and control power and compressed air. Someone will also check that the bypass enabled light is off. Automatic startup of the liner ventilation system will be tested after completion of operations each week. The test procedure described in the SAR will be performed before initial

operation and quarterly thereafter until completion of the experiment. Surface wipes and air samples will be taken and tested on a regular basis (daily at the start of experiment; if no contamination is detected, then on a weekly basis). Following any vent, samples will be taken and analyzed. The roughing pump oil will be tested on a rotating schedule so that at least one sample is taken each week and so that each pump is tested at least every month. The heat exchange fluid will be tested on a monthly schedule.

5. DESIGN FEATURES

The design characteristics that are of particular concern to this OSR are those associated with the vacuum liner as a confinement vessel and the continued integrity of the limiter assembly. The existing vacuum system is expected to function as an adequate monitor of the confinement system. At the end of each operating week, a test of the vacuum protective system will be made by deliberately tripping the main vacuum ionization gauge. If any malfunction is observed, operation will be suspended until the defect is repaired. At the time of this test the Plant Shift Superintendent's (PSS) alarm will be enabled to test for proper operation of the PSS 131 alarm.

The integrity of the limiter will be monitored at all times by a closed circuit television camera. If the limiter should show signs of failure, the experiment will be terminated and the limiter will be removed for evaluation.

6. ADMINISTRATIVE REQUIREMENTS

All administrative controls will be in compliance with the Y-12 Health and Safety Procedures and the Fusion Energy Division procedures, as referenced in the Safety Analysis Report published by ORNL.

6.1 ADMINISTRATIVE CONTROLS

The ISX-B enclosure will be identified as a restricted access area. During operation of the ISX-B the interlock system will prevent entry into the enclosure. During maintenance, access will be administrative control. A list of authorized persons will be posted, and a record of all entrances and exits will be maintained.

6.2 STAFF REQUIREMENTS

The minimum staff required for operation of the ISX-B tokamak consists of a responsible physicist who is approved by the group leader and two technicians. In addition, if the beam lines are operating, a beam line operator is required. During maintenance periods all maintenance people working within the enclosure must be accompanied by a representative of the operations group.

6.3 TRAINING

Prior to initial operation of the experiment a series of talks will be given to the operating personnel to familiarize them with the special hazards and operating techniques necessary for the experiment. As additional experience is gained, particularly with regard to the

distribution of beryllium inside the vacuum vessel and to decontamination procedures, this information will be communicated to the operations personnel and maintenance supervisors through regular weekly meetings.

6.4 RECORD KEEPING

Adequate records will be kept of the operations of the experiment. These are described in the Safety Analysis Report in detail. Particular importance will be ascribed to the facility logbook and the regular diary that will be maintained by the duty operator.

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