JET–P(88)61

A.C. Bell, C. Caldwell-Nichols, J. Campbell, P. Chuilon, C. Gordon,
G. Newbert and M. Wykes

Preparation for D-T Operation at JET

Preparation for D-T Operation at JET

A.C. Bell, C. Caldwell-Nichols, J. Campbell, P. Chuilon, C. Gordon[1], G. Newbert and M. Wykes

JET-Joint Undertaking, Culham Science Centre, OX14 3DB, Abingdon, UK

[1]*on attachment from CFFTP*

Preprint of Invited Paper presented at the 15th Symposium on Fusion Technology, Utrecht, The Netherlands, 19th September – 23rd September 1988

ABSTRACT.

D-T operation of JET is currently programmed for mid-1991 onwards. An active gas handling plant to extract hydrogen isotopes from the torus exhausts and provide individual isotope feeds is being constructed. Although Torus Systems, additional heating systems and diagnostics have been designed for the tritium operation, their designs are presently subject to a detailed review. Some of the systems in direct contact with tritium will require modifications to improve their reliability and these modifications are being designed. Approval from safety and regulatory authorities is necessary to start operation with tritium, and to satisfy these requirements, analysis is being carried out of routine and accident conditions, waste arisings and compatibility of systems with tritium operation. It is concluded that in parallel with the continuing successful experimental programme of JET in the D-D phase, the review of all aspects of the JET design and operation for the D-T phase is proceeding satisfactorily and no insurmountable problems are foreseen, The complete JET cycle will have a negligible environmental impact and the measures taken will ensure that radiation doses to workers are low.

1. INTRODUCTION

The Joint European Torus (JET) situated at Abingdon UK is a major experiment to investigate the conditions for thermonuclear fusion in magnetically confined plasma. The main parameters of the JET machine and the recent plasma performance have already been described [1,2]. A major aim of the JET experiment is the study of alpha particle production, confinement and plasma heating. To achieve this a planned programme of enhancement of the JET machine and its ancillaries is being undertaken, leading to the capability of plasma operation with tritium from mid 1991 onwards. The major addition is the Active Gas Handling System (AGHS) whose main function is the extraction and separation of hydrogen isotopes from the torus exhaust so that tritium and deuterium can be recycled [3]. This is planned to be in operation in 1990 so that ample experience can be accumulated prior to operation of JET on a closed cycle with tritium. The major milestones in the programme, including the extensive work of modification for additional heating, disruption control and impurity control amongst other things are shown in Figure 1.

The main features implemented and preparations for D-T operation of JET have been discussed in previous papers [4,5]. This paper follows on in describing the progress being made towards D-T operation of JET, particularly those aspects related to safety approval.

2. TRITIUM COMPATIBILITY OF JET SYSTEM

As one of the ultimate objectives of the JET experiment was the study of alpha particle heating, the majority of JET systems were designed from the outset for D-T operations. These have been described previously [4,5] and include:

i. The massive biological shielding which is designed to reduce the radiation dose due to operation to staff in the control room to well within the JET radiation exposure target, and at the site boundary to less than normal fluctuation in the background dose levels.

ii. The facilities for carrying out remote maintenance on critical components in the torus hall where dose rates prohibit access to the vacuum vessel and make normal hands-on maintenance impossible [6].

iii. The double-walled vacuum vessel and the associated gas baking loop which permits operation at elevated temperature whilst minimising the permeation of tritium to the environment. The gas baking loop which circulates helium through to vacuum vessel interspace to maintain the temperature at $\sim$ 300°C will allow tritium permeating through the inner wall to be ultimately collected as oxide on a zeolite bed which can be regenerated periodically. Installation of the loop blower in a gas tight housing to minimise tritium losses through the shaft seals has been completed.

However as JET is an experimental device, progressive modifications have been made since commissioning and it is essential to carry out a review to confirm that safety, operability and maintainability are not prejudiced in the tritium phase.

A tritium compatibility analysis is therefore being carried out on all JET systems proposed to be used during the D-T phase. There are four issues to be addressed for each system:

i. Will it operate satisfactorily in the D-T phase?

ii. Can it be maintained or removed remotely?

iii. Are the routine tritium releases resulting from the operation of the system acceptable?

iv. In the event of failure of the system, are operator and public radiation doses acceptable?

In addition to completely new systems such as the AGHS and Lower Hybrid Current Drive, and systems requiring major modification, for example the ventilation system, cooling circuits and overpressure protection, systems basically unchanged need to be considered. In this latter category are the diagnostics of which there are about 55 on JET at present (Fig.2). About 15 non-active phase diagnostics which were not intended for use in the D-T phase will be removed, mainly because they would not survive the neutron dose. The remainder have been assessed for compatibility and a number have required modification such as:

i. Replacing turbopumps with regenerable getter pumps and, where appropriate, replacing rotary backing pumps with sealed ones.

ii. Interspaces evacuated and monitored.

iii. Additional containments.

Some modifications may not be cost effective and the relevant diagnostics will be removed. The KH2 X-ray Pulse Height Spectrometer design provides an example of aspects which require to to be considered. It is currently pumped on the torus side by a turbomolecular pump and one proposal is to replace this with an ion pump (Fig.3). An alternative scheme would be to pump the beamline via the torus. Tritium permeation through the bellows has been assessed and conservatively estimated to be acceptable at 0.06 Tbq/a. Other aspects examined include the method of control of the beryllium window bypass to minimise the tritium contamination of the components outside the torus hall. The In Vessel Inspection System (IVIS)[12] is an example of a system which has been reviewed and is now fully tritium compatible, incorporating ion getter pumps.

However from the availability point of view and from the need to lower the potential for release of activity to the environment, the main modification required to ensure that many of the diagnostics are compatible with tritium operation is to design the quartz windows, of which there are over fifty on the machine, against catastrophic failure. Experience of JET operation so far has shown that a window, which operates up to the vessel wall temperature, may crack as a result of thermal shock if cold water from a leak of one of the internal cooling circuits impinges on it. Although all of the window failures experienced have either been seal failures or, following water leaks [8], cracks, the possibility of complete disintegration of a window which has the potential for release of tritium to the torus hall [15] and would lead to extensive outage, cannot be ruled out. The use of double windows in vulnerable positions is now being considered as a way of minimising this possibility.

Economic factors and the environmental issues associated with discharge of large quantities of tritium have obliged JET to adopt a closed cycle system for extracting hydrogen isotopes from the torus exhaust gases and separating the tritium for re-injection into the JET machine. This plant is designed to the highest standards of tritium containment to minimise operator and public dose and will be housed in a building separate from the main torus building. The major components of the plant have been designed and procurement is underway. As it is designed specially to handle bulk quantities of tritium, tritium comptability is inherent in the design. This includes secondary containment with leak detection on all major systems and provision for reduction of maintenance release by baking and evacuation.

It is described in the accompanying paper [9].

The AGHS also includes a tritium clean-up system, referred to as the

Exhaust Detritiation System (EDS), to provide an air flow through the torus during maintenance intervention within the vessel and to detritiate the exhausted air [7].

Other examples of where tritium compatibility analysis has led to design modifications are :

a. The LHCD main double bellows [10]. The initial assessment showed unacceptable tritium permeation to the atmosphere of around 60 TBq/a. This figure was based on clean metal permeation through both bellows at 400°C, as the usual mitigating effect of oxidised surfaces could not be claimed for a bellows constantly cycled during plasma operation. The option of pumping the interspace was rejected due to the excessive pumping speed required to maintain the interspace at the 10^{-8} mbar required to reduce tritium permeation to the atmosphere to an acceptable level of 2 TBq/a. It is now proposed to maintain the outer bellows at ∿ 200°C.

b. Modifications are being made to the cooling water circuits and the protection circuits; particularly to the Neutral Injection System, to minimise the quantity of water entering the main tritium systems if there is an internal leak and thus reduce the quantity of tritiated water to be handled. Different physical methods of leak detection may need to be employed to provide diversity and to enable the conflicting requirements of rapid shut-down and avoidance of spurious trips can be met. For example, box pressure, N_2 boil-off rate and expansion tank level can each give an indication of a Neutral Injection leak. An important consideration is also the ability to separate the highly tritiated arisings during water leak incidents in which cryppumps defrost from the water containing low levels of tritium contamination in the poloidal and toroidal field cooling circuits.

c. The vessel overpressure protection currently consists of a 50 mbar differential rupture disc relieving into the torus hall. This means that a large cryospill or water leak could result in a release of tritium to the torus hall. Such a release of tritium to the environment is unacceptable for a single system failure and further protection is required. This can be achieved by making the first line of defence against over-pressurisation of the vacuum vessel pressure operated valves discharging into the AGHS manifold lines, the rupture disc being retained as the ultimate protection for the vacuum vessel in the remote event of the relief valves failing to operate. As the AGHS has facilities for collection of elemental tritium and tritiated water, releases to the environment are minimised. A variety of circumstances needed to be covered, including H_2 deflagration in the pellet injector box, variations in AGHS suction pressure, the operation of the isolation valve, and the current concept is shown in Figure 4.

d. Various planned enhancements will be made to the Torus Hall, Access/Hot Cell and basement ventilation plants, to allow air to be extracted from the torus hall at about 1 air change per day. A filtration system for radioactive particulates will be included and the recirculating system will maintain a constant humidity of 7°C dew point (Figure 5).

The system will also need to take into account pressure relief for the fire extinguishing system.

3. SAFETY APPROVAL

The use of radioactive materials in the UK is constrained by Government legislation which controls the licensing of plants, the exposure of employees, the disposal of waste and transport. The main statutes which JET is subject to are listed below:

3.1.1 Radioactive Substances Act 1960

The main impact of the Act on JET is that all routine discharges of tritium or activated substances to the environment for disposal as waste must be approved in advance by Her Majesty's Inspectorate of Pollution (HMIP). JET is required to make a submission to HMIP showing that "Best Practicable Means" have been used in minimising the environmental impact and showing that in all cases, radiation doses to the most exposed members of the public are within the targets recommended by the National Radiological Protection Board (NRPB) [11]. JET will have no difficulty in meeting these targets so the emphasis is on demonstrating that the various options have been considered and that where necessary any particular engineering solutions are justified using cost benefit analysis (CBA). For example the AGHS stack height is 25 m above ground level. CBA, based on a cost of £3000 per man-Sv, was used to show that from dose considerations, a higher stack was not required.

3.1.2 Ionising Radiation Reg's. 1985 (IRR's)

The legislation is concerned with limiting radiation doses to employees and the compliance is monitored by the Health and Safety Executive. JET occupational dose targets are considerably below the legislative limit of 50 mSv for annual committed dose to exposed workers. The legislation requires a contingency plan to be submitted to the HSE if quantities of radioactive material exceed certain limits. The quantity of tritium to be used at JET (90 g) is less than this limit (540 g) but a contingency plan will be produced nevertheless.

The accounting requirements of the IRR's will be met by the arrangements, using periodic PVT measurements which are needed for process monitoring.

3.1.3. Transport Regulations

UK legislation is based on the IAEA Code of Practice for safe transport of radioactive materials. It is not JET's intention to develop special transport containers for either tritium or waste as the timescale for approval, particularly in the case of type 'B' containers is of the order of two years.

3.1.4. Nuclear Installations Regulations

Under the 1965 Nuclear Installations Act, nuclear sites in the UK are required to be licensed by the Nuclear Installations Inspectorate (NII). At present, however, UKAEA sites are exempt from licensing and a semi-independent internal unit of the UKAEA, the Safety and Reliability Directorate (SRD) is responsible for ensuring that the same standards are applied to UKAEA sites as if they were licensed. Under the JET Host Agreement, the UKAEA ensures that JET applies similar standards and JET is required to satisfy SRD that the design of the plant, its construction and commissioning, and its operating procedures are acceptably safe. When satisfied, SRD will endorse the issue of an Authority to Operate (ATO) for the plant.

3.2. Design Targets

The overriding consideration for radioactive plants is that ALARP (As Low As Reasonably Practicable) principles should be followed to limit routine and accidental releases. Generally this means that the best up-to-date technology should be employed and that where several options are available, they should be examined to determine which gives the lowest public/ worker risk. In cases of doubt, cost benefit analysis should be used to eliminate solutions of disproportionate cost.

As part of the Quality Assurance (QA) procedures, JET Technical Control Documents require systems to be classified from the point of view of radiation, remote handling, quality and tritium. This allows design and analysis effort to be concentrated efficiently where it is required. For example the criteria for tritium classification listed below are used to determine which systems require detailed safety analysis or need to be taken into account in waste handling.

There are four classes defined as follows:

CLASS 1 - Systems with a high potential for accidental/routine release or exposure of personnel when the effects of the secondary containment or any other barriers are neglected.

CLASS 2 - Systems with a low potential for routine/accidental release and exposure of personnel, - or -

Systems necessary to prevent/limit release or exposure for Class 1 systems under fault conditions.

CLASS 3 - Systems which will generate tritiated operational or decommissioning wastes.

CLASS 4 - Systems with no potential for tritium release/exposure or generation of waste.

3.2.1 Routine Releases and Exposure

The UK NRPB considers that radiation doses of 50 μSv are "of no concern". This value has been chosen as the design target for routine releases. Assessments have been carried out of the annual public doses through various pathways which are as follows:

Direct radiation from torus: < 5 μSv (at site boundary)

Gaseous releases:

Activated air < 5 μSv (inhalation/direct radiation)

Tritium < 5 μSv (inhalation and ingestion)

Liquid Discharges (to Thames):

Tritium << 1 μSv (drinking water for hypothetical critical group)

The occupational dose limits set by JET policy are 5 mSv/a for radiation workers and 1 mSv/a for non-radiation workers. For routine releases and radiation from the torus, the annual dose to the most exposed person on-site would be:

Direct radiation < 50 μSv

Activated Air < 20 μSv

Tritium < 10 μSv

which is clearly well within the above targets. However, the majority of occupational exposure will arise during maintenance operations and the use of protective clothing, and other dose control measures will be used to limit exposure of individuals in accordance with these limits.

3.2.2. Accidental Releases

A basic JET design philosophy is that no single failure of any system should result in exposure of workers or members of the population to greater than the annual dose limit. To comply with this, the containment philosophy employed in the AGHS is that all the main tritium process lines are doubly contained apart from certain exceptions eg. those which are of thickwalled, all-welded construction and which operate at room temperature and sub-atmospheric pressure such that the permeation losses are low (<0.04 $TBqa^{-1}$) and the probability of a significant release is low [9]. Secondary containments are generally of stainless steel and, where possible evacuated or filled with helium. Leak detection is provided and overpressure protection (eg rupture discs) on systems with a high inventory discharges into evacuated buffer tanks, each capable of holding the complete AGHS inventory.

3.3. Safety Analysis

The above considerations, as well as those of conventional hazards, were analysed qualitatively in the AGHS Preliminary Safety Analysis Report (PSAR) and this was endorsed by SRD before the final plant design was started. A comparable PSAR is in the course of being produced for the torus systems.

For the second phase of the safety analysis, a Design Safety Review is carried out on each of the AGHS subsystems. This includes Failure Mode and Effects Analysis (FMEA) of all components or component groups. For those components which, in the event of failure of a protection system, have the potential for significant tritium release, a Probabilistic Safety Analysis (PSA) is carried out and an event tree produced quantifying the probability magnitude of releases for each initiating event (Figure 6). One major problem, of course, in the application of PSA to new systems is the paucity of reliability data relevant to fusion and cryogenic plant. Generic fission reactor data modified where necessary have been used in the Fault Tree Analysis used to derive the initiating event frequencies (Figure 7). For analysis of torus systems a study has been carried out of the failures during the D-D phase to provide more appropriate data.

Before proceeding to procurement, a Design Safety Review has been carried out in each subsystem of the AGHS and endorsement of SRD obtained.

The design target for each identifiable accident sequence is that the product of frequency and magnitude of release to the environment should be less than 10 Ci a^{-1}. This target is considerably more restrictive than the guidelines laid down for nuclear chemical plant by the UK NII. These are concerned with public dose/frequency for discrete fault sequences and when related to the JET site give the release limits shown in Figure 8 with JET design guidelines for comparison.

The analysis of one of these subsystems (Figure 9) shows that the design targets are met.

Specific torus systems identified through the PSAR as having a high risk of release will be subject to a Design Safety Review.

The final safety submissions before approval for operation is given takes two forms:

i. Final Safety Analysis Report (FSAR)

This takes account amongst other things, of system interactions, modifications following the reviews, procedure for control of operation and QA interfaces.

ii. Commissioning report

This is required to show that safety-related systems are performing as intended.

Approximately one year has been allowed for commissioning, initially with H/D and possibly small amounts of tritium in the AGHS before the D-T phase starts in 1991.

4. RADIOLOGICAL PROTECTION INSTRUMENTATION

Gamma and neutron monitoring instrumentation has been installed in the JET torus building from the start of operations. Enhancement for the D-T phase requires the addition of tritium working area monitoring and measurement of stack discharges of tritium and activated gases.

For the AGHS building and torus building working area, ionisation chambers with a sensitivity of better than 1/10 DAC HTO will be installed. In addition to local alarms, the instruments will be connected to a central CODAS computer to record data and enable trends in chronic levels to be monitored. Discriminating HT/HTO monitors have been ruled out because of the extra complexity, low probability of purely elemental releases and the risk to individuals if protection measures were based on a single instrument reading. During maintenance operations, sampling methods may be used to establish the true level of HTO.

For monitoring of the torus hall air, the instruments are to be installed in the ventilation ducts outside the biological shielding. Activated air measurement and compensation of tritium monitors will be provided.

To demonstrate compliance with discharge limits all discharge stacks will be equipped with a catalyst and silica gel samplers for HT and HTO. Consideration is being given to the need to collect tritiated methane.

A programme of environmental sampling is being carried out. Around 20 tritium sampling points will be installed around the JET site boundary before the D-T phase to establish baseline levels before D-T operation starts and provide data throughout the D-T phase.

5. WASTE HANDLING

Studies have been carried out on the waste arisings at JET and the options for transport, treatment and disposal. The options are constrained by four factors:

i. There is no intermediate level waste disposal facility at present in the UK.

ii. There is only one low level waste repository which, in addition to overall annual limits, imposes a limit of < 12GBq/te on the tritium content.

iii.Discharges of aqueous waste to the Thames may be severely restricted.

iv. When the JET experimental programme is complete, the UKAEA will take over the responsibility for JET and its decommissioning.

Anticipated waste arisings have been categorised as:

i. Process wastes (solid)

These will be mainly absorber beds (molecular sieve, uranium beds, zeolite) containing tritium and/or activated corrosion products. Tests are underway at present to determine if the number of uranium beds produced as waste from the AGHS can be reduced by using a regenerable iron bed for cracking of water in the impurity processing loop [9].

ii. Component waste (solid)

Components which are activated, contaminated and/or tritiated will be removed from the machine and AGHS during maintenance.

iii. Housekeeping wastes.

These will consist of clothing, swabs etc.

iv. Low level tritiated water

During D-T operation, the use of water in situations where it may become tritiated will be minimised; however minor leakages from cooling circuits, air conditioning condensate and tritiated water collected from the exhaust detritiation system cannot be avoided.

Higher concentrations of tritium may arise from accident situations. Comparable concentrations could also be collected in the EDS driers if they are operated following a major vacuum leak (Ref. 7).

A current strategy for dealing with JET waste taking account of these restrictions and the main types of arisings and wastes is currently being defined.

6. MAINTENANCE

The JET machine was designed from the outset in such a way that essential maintenance and replacement of components in the D-T phase could be carried out remotely. Components are classified according to the need for remote handling and this is periodically reviewed in the light of experience. Progress on development of remote handling is dealt with elsewhere (Ref. 6).

One important aspect of torus maintenance is reduction in tritium emission from in vessel components. Glow discharge cleaning will be carried out to reduce tritium emissions from an estimated 4 TBq/h to negligible levels. The AGHS has been designed to separate this evolved tritium.

In the AGHS, remote maintenance is not necessary but the systems have been designed to facilitate maintenance. For example, where possible, bake-out heaters have been provided so that tritium outgassing can be carried out before opening of containment; extra manual valves are provided to minimise the effects of tritium outgassing of long pipes; containment closures may be replaced by glove-port modules.

7. CONCLUSIONS

In parallel with the continuing successful experimental programme of JET in the D-D phase, the review of all aspects of JET design and operation for the D-T phase is proceeding satisfactorily and no insurmountable problems are foreseen.

In addition a design for the AGHS capable of satisfying the UK safety requirements has evolved and procurement has now started. The complete JET cycle will have a negligible environmental impact and the measures taken will ensure that worker doses are low.

ACKNOWLEDGMENTS

The author wishes to acknowledge the work carried out by the JET team and in particular members of Fusion Technology Division which is summarised in this paper.

REFERENCES

1. E. Bertolini et al., Proc. 12th Symposium in Fusion Engineering, Monterey 1987.
2. A. Gibson et al - Proc 15th European Conf. on Controlled Fusion and Plasma Heating, Dubrovnik 1988.
3. R. Haange et al., Proc. 3rd Topical Meeting on Tritium Technology in Fission, Fusion and Isotope Application - Toronto 1988
4. M. Huguet et al., Proc. 7th Topical Meeting on the Technology of Fusion Energy, Reno 1986
5. Dean et al., Proc. 14th Symposium on Fusion Technology, Avignon 1986
6. T. Raimondi, Proc. 15th Symposium in Fusion Technology - Utrecht 1988
7. A. Dombra et al., Proc. 15th Symposium in Fusion Technology - Utrecht 1988
8. B. Green et al., Proc. 15th Symposium on Fusion Technology - Utrecht 1988
9. J.L. Hemmerich et al., Proc 15th Symposium on Fusion Technology - Utrecht 1988
10. A. Kaye et al - Proc 15th Symposium on Fusion Technology - Utrecht 1988

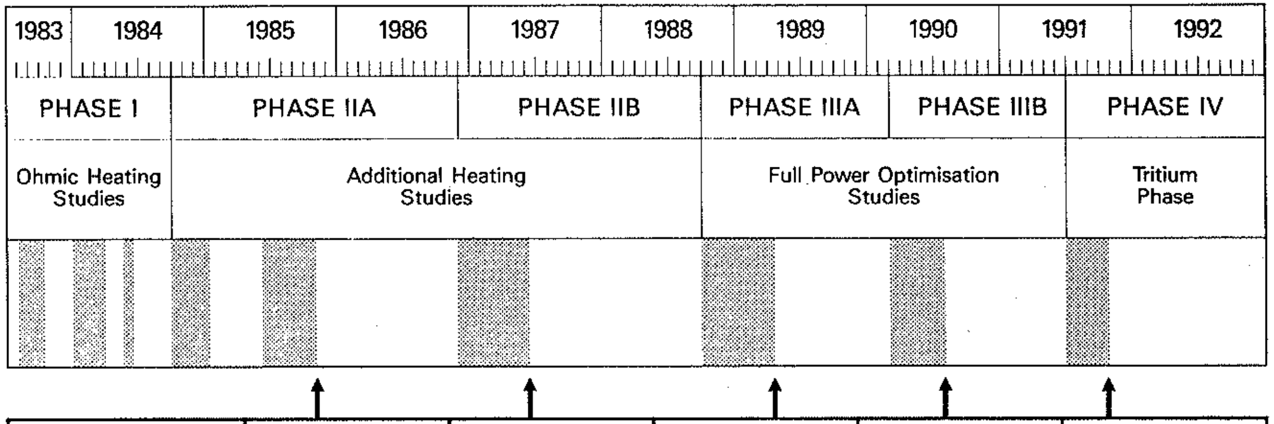
11. UK National Radiological Protection Board - GS9, November 1987.

12. T. Businaro, Proc. 15th Symposium in Fusion Technology, Utrecht 1988

13. M. Wykes, Safety Analysis of Torus Vacuum Breach, JET P(88)37, 1988.

FIG 1

JET PROGRAMME

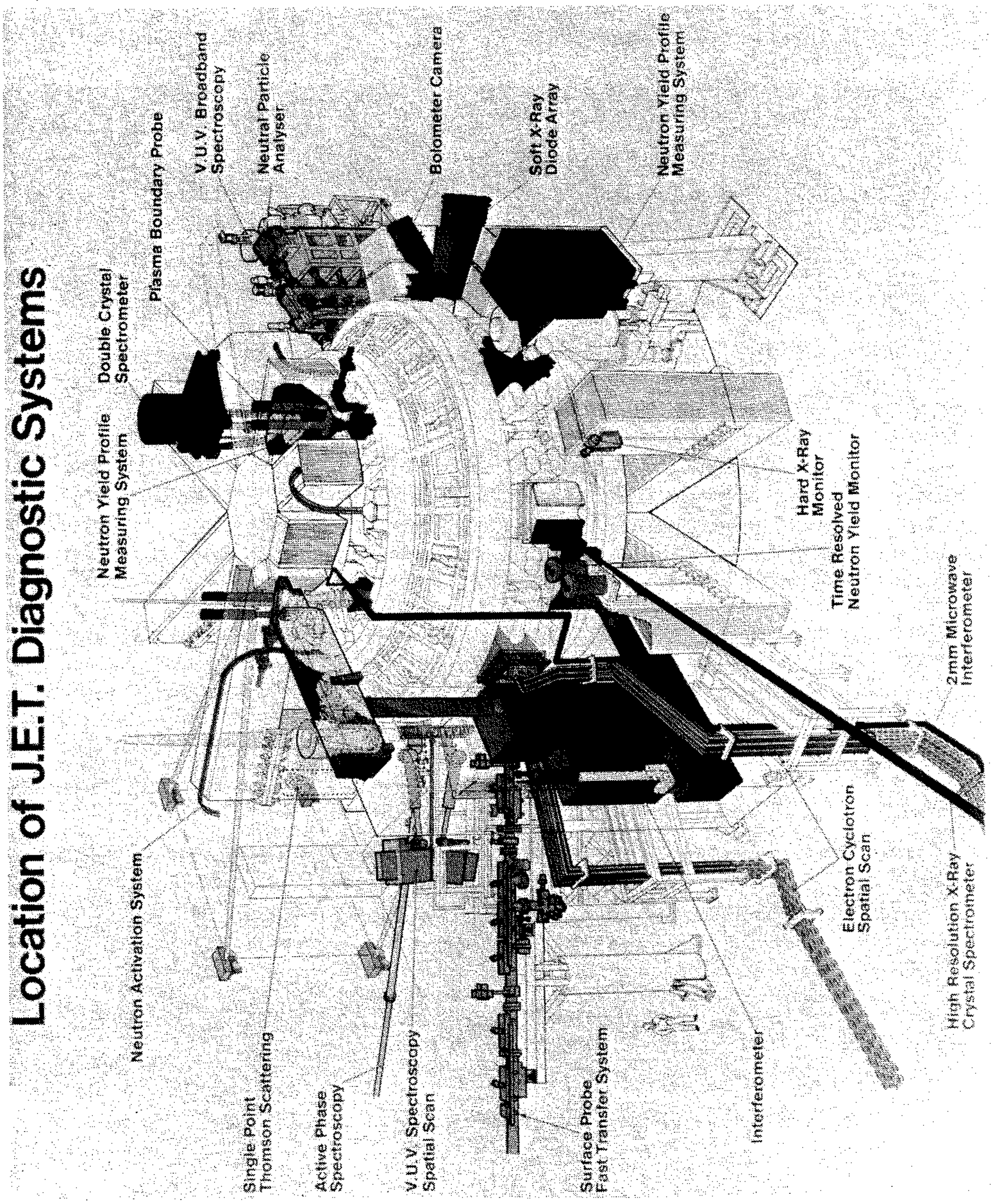


Ohmic Systems	5MA	Vessel restraints and improved volt-seconds for 7MA operation			
Separatrix		Additional P1 Coils	Cooled separatrix dump plates		
Limiters	Eight carbon mid-plane limiters	Carbon belt limiters	Beryllium belt limiters		
Pellets	Single pellet injector	ORNL multiple pellet injector ($1.5 km s^{-1}$)	Prototype high speed pellet injector ($>3 km s^{-1}$)	[Multiple high speed pellet injector]*	
Pump limiters				Adjustable pump limiter	
NBI	First NBI line (80kV)	Second NBI line (2×80kV)	One line modified to 140kV	Second line modified to 140kV	
ICRH	Three A_0 antennae	Eight A_1 antennae			
LHCD			Prototype system	Full system	
Disruption control			Saddle coils		
Tritium and Remote handling				Tritium plant and main RH modifications	Final modifications

**To proceed if successful development takes place outside JET*

CR86.2 (rev.24/2/88) - Ro1540, H1.P CR88.2

FIG 2



Location of J.E.T. Diagnostic Systems
Neutron Activation System
Single Point Thomson Scattering
Active Phase Spectroscopy
V.U.V. Spectroscopy Spatial Scan
Surface Probe Fast Transfer System
Interferometer
Electron Cyclotron Spatial Scan
High Resolution X-Ray Crystal Spectrometer
2mm Microwave Interferometer
Time Resolved Neutron Yield Monitor
Hard X-Ray Monitor
Neutron Yield Profile Measuring System
Double Crystal Spectrometer
Plasma Boundary Probe
V.U.V. Broadband Spectroscopy
Neutral Particle Analyser
Bolometer Camera
Soft X-Ray Diode Array
Neutron Yield Profile Measuring System

FIG 3 Diagnostic pumping

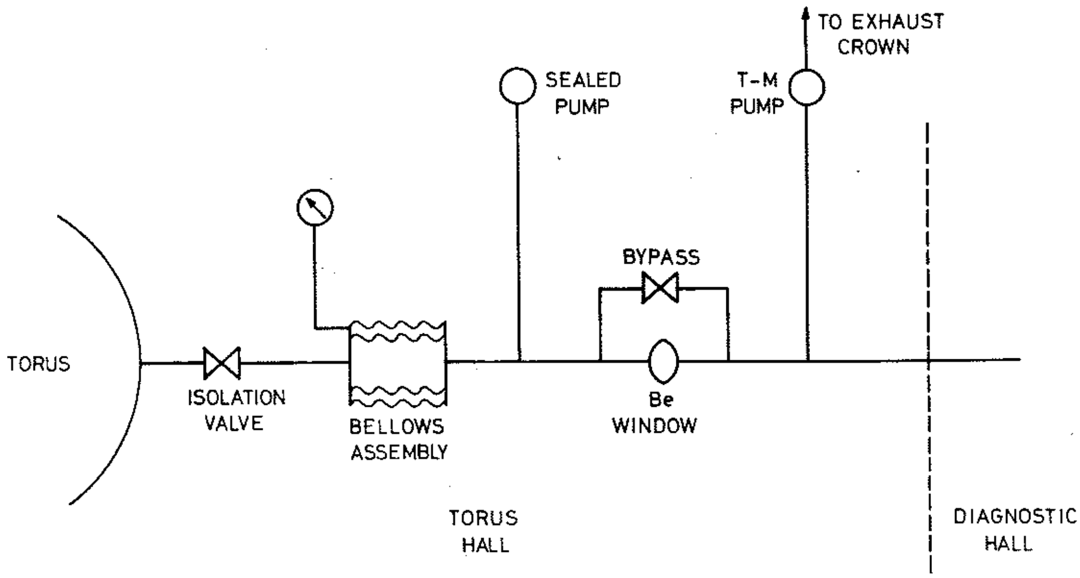


FIG 4 Torus overpressure relief through AGHS

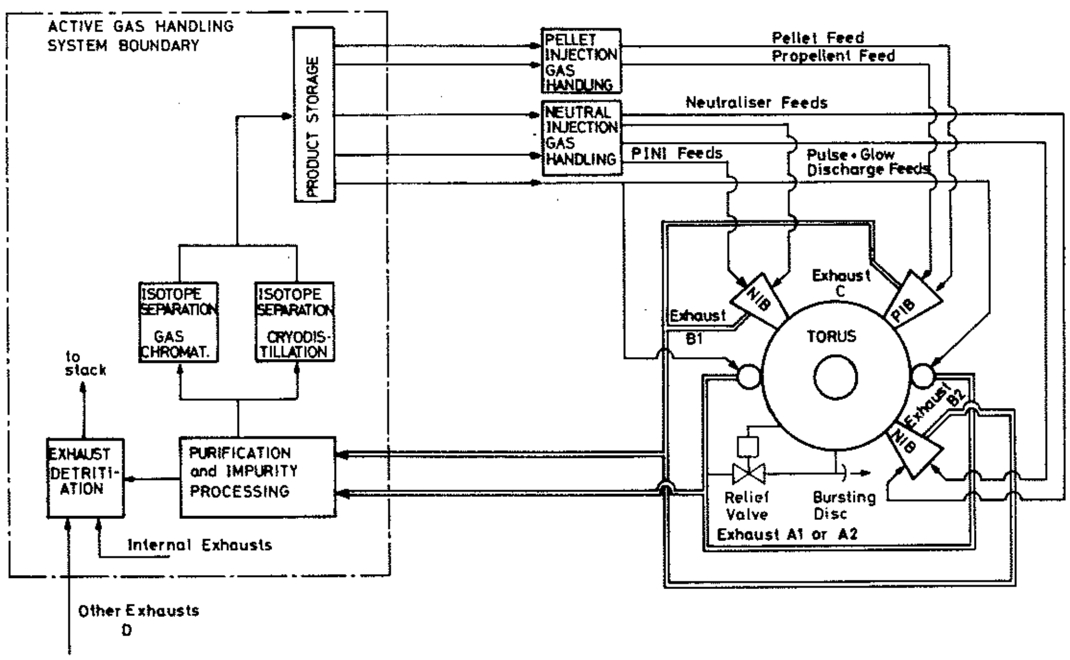


FIG 5 Proposed ventilation system

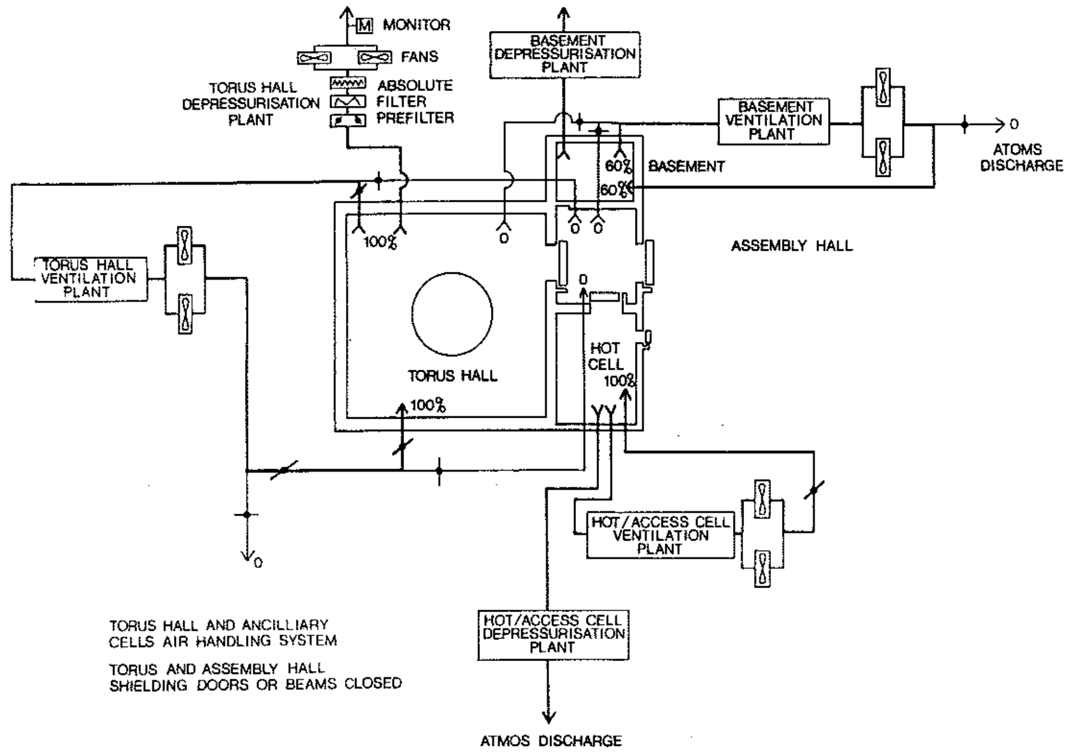


FIG 6 Typical event tree analysis

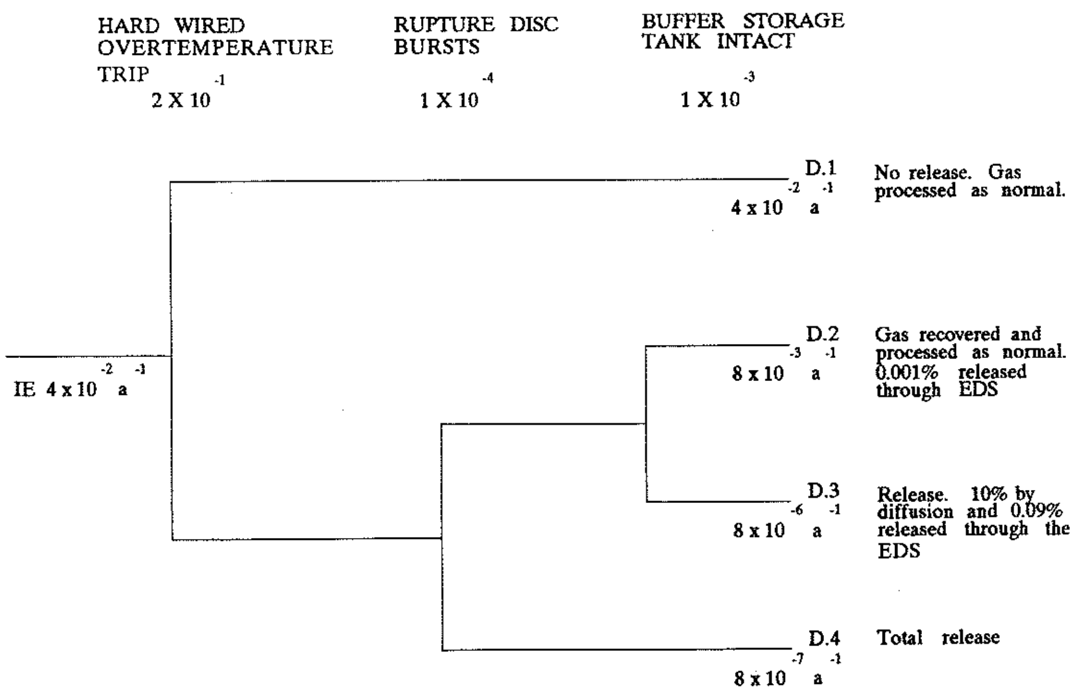


FIG 7 Typical fault tree used to derive initiating event frequency

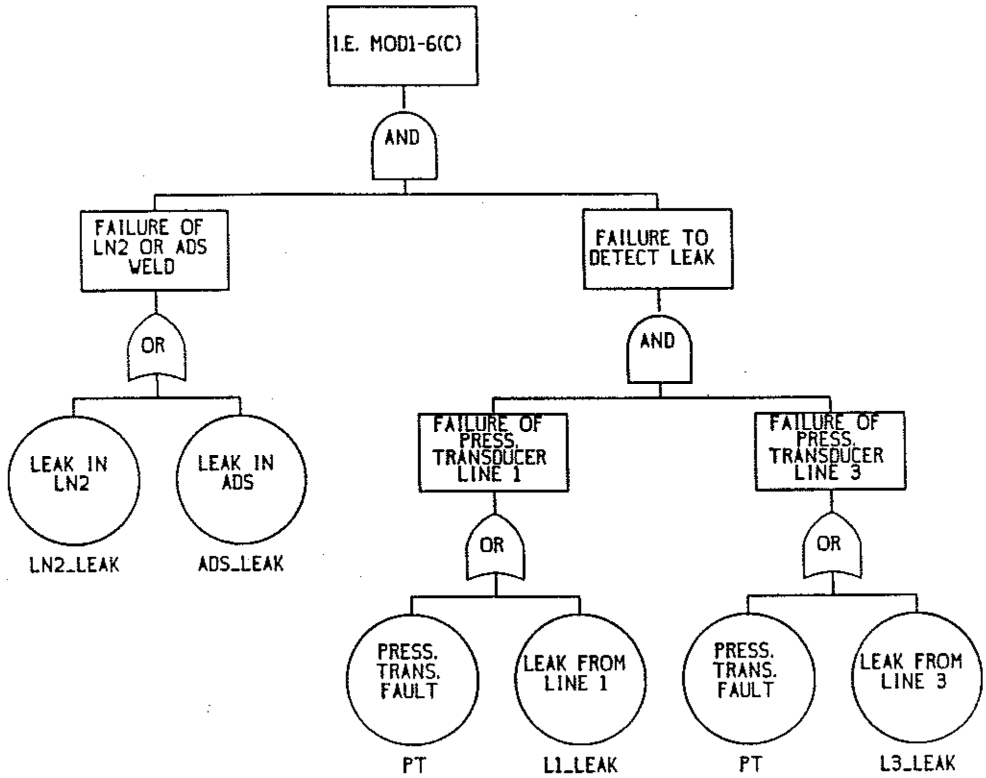


FIG 8 Tritium release target

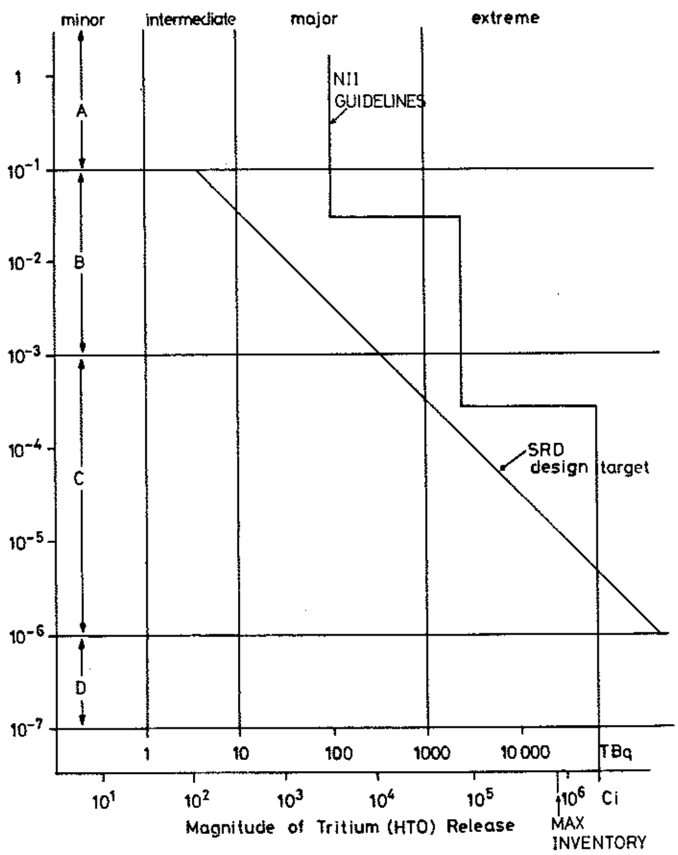
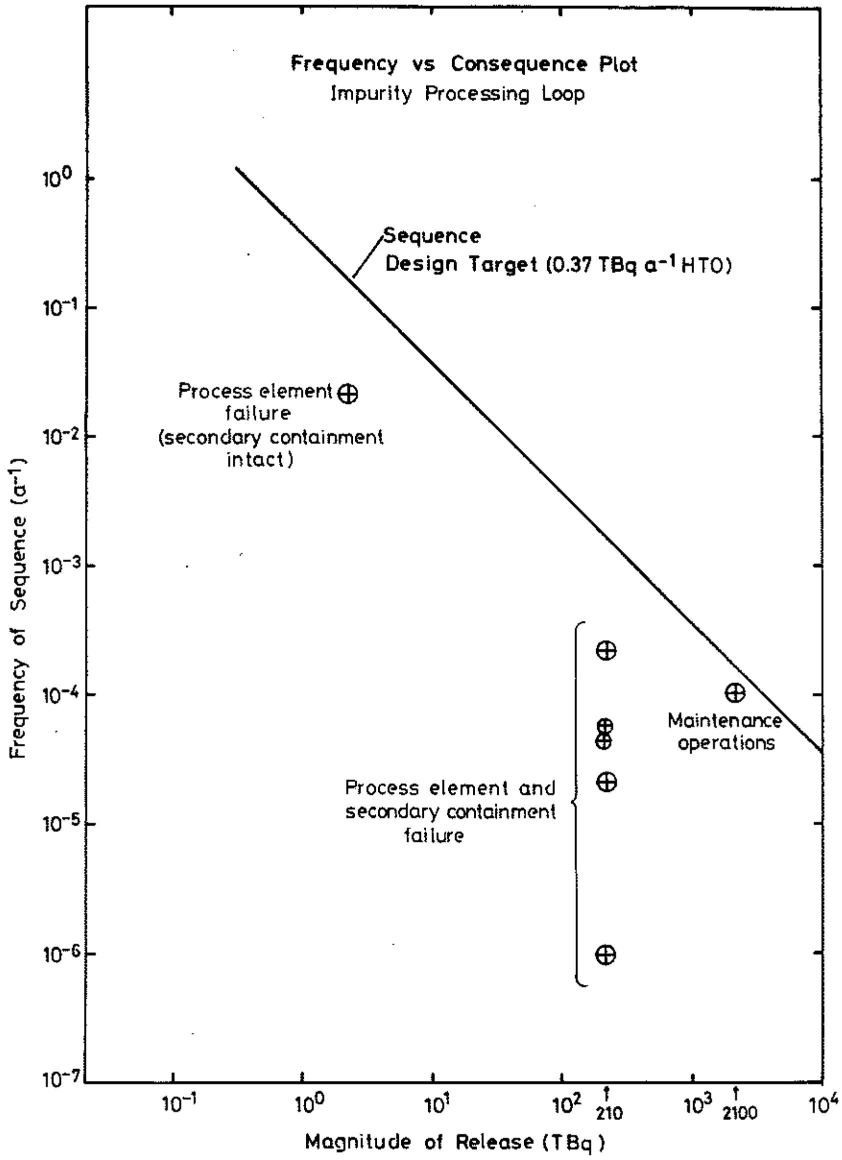


FIG 9



Frequency vs Consequence Plot
Impurity Processing Loop
Sequence
Design Target (0.37 TBq a-1 HTO)
Process element failure (secondary containment intact)
Process element and secondary containment failure
Maintenance operations
Frequency of Sequence (a-1)
10^0
10^-1
10^-2
10^-3
10^-4
10^-5
10^-6
10^-7
10^-1
10^0
10^1
10^2
210
10^3
2100
10^4
Magnitude of Release (TBq)