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ABSTRACT

The first tritium experiment in the JET machine was carried out in November 1991. A number of different regulatory approvals were required in order to proceed with the experiment. These included radioactive discharge authorisation, approval of the safety justification and endorsement of the arrangements for accounting for tritium. Preparation for the full D-T phase of JET planned for 1996 was underway prior to the experiment and has continued subsequently. Up to 90g of tritium will be used in the full D-T phase and JET has obtained authorisation for holding this amount on site and for related radioactive discharges. Safety submissions for tritium operation of the JET machine and tritium plant have been made.

The paper highlights the regulatory issues involved in determining the appropriate site inventory limit. It emphasises the importance of establishing a well-founded justification in the case for radioactive discharge authorisations and the necessity of matching the form of the compliance monitoring employed to the predicted mix of nuclides discharged. The accident analysis criteria and routine dose limits used at JET are discussed in relation to the tightening of regulatory requirements, together with QA and design standards.

1 INTRODUCTION

The JET Joint Undertaking was established in 1978 and the first plasma was achieved in 1983. It is situated on a United Kingdom Atomic Energy Authority (UKAEA) site at Abingdon, England. Although the majority of the operation has been with hydrogen or deuterium plasma, in November 1991 a series of experiments was carried out with D-T fuelling with up to 14% tritium. The quantity of tritium used (0.1g) and hence the neutron activation of the JET machine, was restricted in order to limit the radiation dose to in-vessel workers during the early part of the shutdown which started in March 1992. The current JET programme makes provision for a further experiment involving a limited quantity of tritium (~1g) prior to a full D-T phase presently foreseen for 1996 using up to 30g per day of tritium. As this will result in significant activation of the machine which will effectively preclude hands-on maintenance, remote handling facilities have been developed for key maintenance tasks.

The Active Gas Handling System (AGHS) [1] has been constructed to extract tritium and deuterium from the torus exhaust and isotopically separate it for re-injection. By this means, the total inventory of tritium on site can be limited to 90g.

The AGHS is currently being commissioned with H/D mixtures and tritium commissioning with 0.1g of tritium will start in early 1994. Full tritium commissioning of the AGHS with up to 3g of tritium is planned in the second half of 1994 increasing to ~36g when the cryodistillation system is fully commissioned.

JET is governed by statutes which require that, amongst other things, JET obtains the approval of the UKAEA for radioactive operation, and complies with the safety standards of the UKAEA. The Safety and Reliability Directorate (SRD) of UKAEA monitor that this requirement is fulfilled.

2 TRITIUM INVENTORY

The tritium inventory limit for a site is determined by the opposing requirements of maximising it to increase operational flexibility and minimising it to limit the potential accident consequences. It is one of the prime methods by which the regulator will seek to minimise the risk from a plant. It is therefore essential that arbitrary low limits are not set before the viability of any design is fully established. It is extremely difficult to raise any established numerical limit which has safety connotations and if not impossible, very time consuming if the limit has been subject to public consultation or enquiry.

The JET inventory limit approved by Her Majestys Inspectorate of Pollution (HMIP) is 90g. This limit was formally notified to the local authorities (including elected members) before coming into force. Prior to the formal HMIP submission it had been accepted by the Fusion Safety Committee and SRD. The agreement of SRD was for 90g of which 60g was free gas. This would allow for say 30g "fixed" in torus walls or in storage, 30g in the AGHS cryodistillation plant and around 30g of working inventory in the AGHS and torus cryopumps. SRD had not been prepared to accept that these values were necessary until several questions related to the ALARA principle had been satisfactorily answered in particular:

i) As the system posing the greatest risk from tritium releases, a justification for the use neutral beam injection in the D-T programme was sought by SRD. This was resisted by JET as it would lead to the need for the whole of the D-T programme being re-examined. Alternative fuelling options may pose differing risks but it would not be acceptable for an experimental programme to be driven by the lowest risk option when the overall risk was already low.

ii) A similar argument was applied with the high speed pellet injector and the requirement for a cryodistillation plant with a significant inventory (30g). This need was eventually accepted and a proven design of plant was selected. However, if the decisions were being made now in 1993, there would have been intense regulatory pressure to select a version of the low inventory cryodistillation plant designed by CFFTP for TFTR which has not yet been proven. It is therefore important to ensure at the outset that any limits established can encompass a "minimum technological risk" scenario where this would not lead to unacceptable accidental or routine doses.

The other main factor which determines a site tritium inventory limit is the off-site exposure of members of the public in the event of an accident. Early in the project, the Nuclear Installation Inspectorate (NII) had specified that doses in excess of 100mSv should be "as remote as reasonably practicable". If a range of pessimistic assumptions about meteorological conditions, release height, HT/HTO conversion and inventory distribution are made, this "limit" would not permit 90g to be held on site if hypothetical severe accidents are considered. This worst case approach is not required by the NII and the recent Safety Assessment Principles [2] state that design basis accidents meeting the 100mSv limit need not include faults of frequency lower than 10^{-5}/year. Emergency planning, however, is required to consider more severe accidents.

The JET approach has been to determine a Design Basis Accident (DBA), analogous to that of nuclear power plants, to determine the extent of normal emergency planning required.

The DBA is the catastrophic failure of a torus double vacuum window, co-incidentally with the failure of the exhaust detritiation and mechanical forevacuum pumps. This is conservatively assumed to lead to the release of around 50% of the inventory of the NIB cryopumps within about 4 minutes into the torus hall followed by the remainder by diffusion over a longer period. It is assumed that all this inventory is released at a height of 35m into the building wake over a period of 30min. The release of the 20g, and the conversion of the majority of it to HTO under class F conditions, may lead to an early dose of ~5mSv thus satisfying the 100mSv limit. For future plants, it is important that realistic Design Basis Accidents, rather than hypothetical severe accidents are used to determine the inventory limit of any part of the system. This is in accordance with the NII principles [2].

3 RADIOACTIVE DISCHARGE LIMITS

The discharge authorisations for most UK nuclear facilities have been in place for a number of years and historically have been based on some notional fraction of the ICRP recommended ALI for a specific critical group. Regulatory pressure has usually been applied to have management or reporting limits based on previous discharges, so that there was a trend downwards in the effective limits. HMIP in the UK now require a more rigorous justification for discharge limits for new plant and except for trivial discharges require it to be shown that:

i) Discharges are necessary

ii) All reasonably practicable steps have been taken to minimise the discharges and the environmental impact

iii) The doses to members of the public are acceptable.

In JET's case as it was recognised that difficulties could arise with further upward revision of authorisation, the first application was for discharges relevant to the full D-T phase [3]. To comply with the first HMIP criterion, the potential discharges had to be estimated. Whereas this was fairly straightforward for activated air which was related to neutron production, it was more difficult for tritium and activation products. Using design values for tritium permeation, cryodistillation plant efficiency and EDS detritiation factor would have resulted in extremely low discharges of tritium. These values did not give sufficient margin for uncertainty for operation of an experimental plant and in particular for maintenance, minor leakage and unavailability of some plant. The values used in the submissions to

HMIP were therefore based on the worst case where possible and considered a pessimistic number of maintenance interventions.

HMIP sets an absolute limit for exposure of a member of the public of 0.5mSv/year. This, and the limit agreed by the JET Council at the start of the project (50μSv/year) was complied with as shown in Table 1 which gives the authorised limits and relevant critical group doses. Doses were calculated separately for HT and HTO using ETMOD [4], supplemented by a model for ingestion.

4 DISCHARGE MONITORING

The use of HT/HTO samplers [5] enabled compliance with the separate authorisations to be demonstrated and enabled the critical group notional doses to be effectively halved, compared with the case if total tritium monitoring had been employed.

The discharge authorisations for activated air, and activation products are based on total $\beta\gamma$ as analysis for individual nuclides would be too costly. This has the disadvantage that the limit is determined by the most radiotoxic nuclide as, at this stage it is not possible to predict the mix of nuclides in typical activation dust during D-T operation to an accuracy likely to be acceptable to the regulators.

For example the limit for $\beta\gamma$ discharges to the Thames is determined by the dose from Co_{60} deposited in the outfall channel which would be experienced by hypothetical persons paddling infrequently in the water. In D-D operation, $\beta\gamma$ activity is dominated by Be7 from carbon tiles which is of lower radiotoxicity but results in discharges which are a numerically high fraction of the limit.

A further area of concern is the dosimetry and monitoring of tritiated species other than HT/HTO. Organics in tokamak exhaust gas may be a few percent by volume and depending on the efficiency of impurity processing may be higher than this in the discharge streams. In the absence of dosimetric models for methane and similar hydrocarbons the assumption is usually made that the dose conversion factor (DCF) is (pessimistically) the same as that of HTO. For tritiated formaldehyde, which has been measured in the discharges from tritium plants [6], this may not be the case, and compliance monitoring based on total tritium measurement may underestimate this dose from this source.

5 REDUCTION IN DOSE LIMIT

It was decided at the beginning of the JET project that management dose limits should be set which were comparable or below the best practice in the nuclear industry (Table 2). This has had two effects: firstly the neutron production both in D-D and the first D-T experiment had to be restricted to limit the dose which would be accumulated by in-vessel workers during the shutdown; and secondly, JET limits have remained within the regulatory limits despite their reduction.

Emergency planning reference levels have also been revised downwards (see Table 3) which has required the JET Emergency Plan and related facilities to be extended to deal with events having off-site consequences. Although the requirement to avoid planning for off-site sheltering is desirable, it has not been a regulatory requirement and therefore there has been no need to change the design basis accident as the NRPB limits for sheltering were reduced from 5mSv to 3mSv [7]. Of particular concern is the Ministry of Agriculture, Fisheries and Food (MAFF) requirement for foodstuffs intervention when a critical group dose would exceed 1mSv over one year [8] [9]. Depending on the model used this dose could conceivably be exceeded for releases of HTO of the order of a few grams. The most pessimistic case would be using the UFOTRI [10] code which gives chronic ingestion doses about 40 times greater than the plume passage early dose from inhalation and skin absorption. The TRIDOS [11] code would give peak ingestion doses of about 3 times the early dose from plume passage. The difference arises from the assumptions which are made on harvesting and consumption patterns.

6 CHANGES IN PROBABILISTIC SAFETY LIMITS

During the period of JET operation, the regulatory standards for assessing the results of Probabilistic Safety Analysis have not changed significantly, primarily because they are risk based and not affected by ICRP60 and other recommendations. The current AEA standards are shown in Table 4.

In addition to the above standards, there is an assessment standard for the JET AGHS which requires that any accident sequence should not result in a product of frequency and quantity of tritium released of >0.37TBq/yr. This is an appropriate limit for assessment of a plant with a large number of accident sequences such as the AGHS. The use of this standard has enabled the AGHS design and safety analysis to proceed in parallel with a reasonable assurance that the overall risk targets could be met.

7 TRITIUM ACCOUNTANCY

The Ionising Radiations Regulations (IRRs) require radioactive materials to be accounted for and specifies limits for "losses" which must be reported. The aim of these requirements is to minimise the risk of undetected loss and the consequent radiological hazard. It is not related to safeguards accountancy which does not apply in the UK for tritium. The reporting level is 2×10^{13}Bq. In view of the difficulty of accounting for tritium, the Health & Safety Executive agreed that the IRR accountancy requirements would be met by measurement of all physical transfers of tritium in and out of the JET buildings, including waste streams and that was no requirement for accountancy methods to be applied to the processing of tritium or use in the JET machine. Additional requirements may be enforced on JET through contractual arrangements of tritium supply but these are not regulatory requirements.

During the first tritium experiment at JET, the measurements made of tritium injection and recovery [12] showed that 14 ± 14% of the tritium which was injected into the vacuum vessel was not recovered. Subsequent destructive analysis of first wall tiles gave a best estimate of the hold-up of 6%. This, and the result of deuterium and tritium hold-up in D-D operation of JET and other tokamaks, shows that it would be impossible to apply safeguards accountancy to these machines although it may be possible to apply some form of accountancy to laboratories and tritium processing plants.

8 DESIGN CODES FOR JET TRITIUM PLANT

The advantages of employing appropriate design codes were recognised at an early stage in the design of the AGHS. In particular, this would avoid the need for detailed structural assessment by SRD, of all components in the system and would enable the design appraisal to be carried out by a third party agency (such as TÜV) to a consistent industry-recognised standard. It would also facilitate demonstrating that a requirement of the JET statutes "to comply with the safety standards of the host organisation (UKAEA)" could be met.

The hazard was considered comparable with that of a typical non-nuclear chemical plant to which codes such as ASME VIII or BS 5500 were applicable. This judgement was supported by the UKAEA standards applicable to radioactive plant of comparable hazard potential, specifying BS 5500, and the codes employed in cryodistillation plants installed at Darlington and Chalk River.

ASME III was ruled out because of the additional complexity of stress analysis, restriction to qualified contractors and additional QA requirements. In addition the requirement for 'nuclear' qualified components would not have been practicable for the vacuum/cryogenic technology used in the AGHS.

In accordance with the UKAEA codes of practice, the requirement for 'U' stamping by qualified contractors was waived and plant was constructed in accordance with the content of the code. JET QA requirements were equal to or exceeded the requirements of the code. Alternative national codes such as the German AD-M series were permitted. Although the code permitted certain components such as ceramic feedthroughs to be subject to a special case qualification, there were a number of areas where difficulty of application and interpretation arose:

i) Use of proprietary (eg CF) vacuum flanges with socket welds. Special flanges made to 'code' requirements with butt welds had inferior leak rates. Special case tests and stress analyses were necessary to justify the use of standard flanges.

ii) Incompatibility between thin walls for good cryogenic performance and code requirements for allowable stresses under external pressure loadings.

iii) Interpretation of code requirements for leak testing leading to a requirement for additional pressure tests despite the performance of vacuum leak tests to extremely stringent specifications.

iv) Compatibility of material specifications.

9 CONCLUSIONS

1) Inventory limits should be set sufficiently high to permit conservative design and minimum technological risk.

2) A Design Basis Accident rather than worst case approach should be taken to determine the upper limit for inventory.

3) Limits, once accepted by regulators are difficult to increase.

4) Limits should be set as a compromise between anticipating changes to regulatory standards and setting margins to cover unexpected events.

5) Matching the compliance monitoring equipment to the mix of nuclides and species discharged should be considered to avoid unrealistically high hypothetical critical group doses.

6) A common standard for modelling of ingestion doses and crop intervention following a tritium release accident is required.

7) Further work is required on the dosimetry of organic tritium compounds.

8) Probabilistic risk targets used in fission plants are applicable to fusion plants.

9) The imposition of tritium safeguards should be resisted by the fusion community.

10) The use of 'Nuclear' grade components should be avoided in experimental fusion system designs, if necessary by claming safety credit for additional barriers.

Table 1 Waste Disposal Authorisations

Discharge Route	Activity	Annual Discharge Limit	Critical Group Dose	Collective Dose
Atmosphere	Tritium as oxide	90TBq (2430Ci)	6.3μSv[1]	0.9manSv
	Tritium (excl oxide)	110TBq (2970Ci)	0.05μSv[1]	
	Activated air and coolant	24TBq total βγ (27mCi)	7μSv[1]	8manSV (C14)
	Activated dust	1GBq total βγ (27mCi)	0.8μSv (typ)[1] 12μSv[2]	
River Thames	Tritium	10TBq (270Ci)	0.12μSv[2]	0.23manSv
	Activation products	100MBq total βγ (2.7mCi)	0.02μSv[2] 8μSv[4]	0.002manSv
Organic liquid to Harwell	Tritium	12GBq (0.3Ci)		
	Other βγ	144MBq (4mCi)		
Solid waste to Harwell	All	Unlimited		

Critical Group Individuals

1 Lives continuously at Culham site boundary and eats locally grown foodstuffs.

2 Takes all drinking water from Thames and foodstuffs grown with irrigation water from Thames.

3 Exposure to river bank sediment and fish consumption.

4 Outfall channel exposure.

Table 2 Dose Limits

		IRRs 1985	NRPB1991 (ICRP60)	1992 NII Principles	JET Limits
Radn Workers	limit	50	20	20	5
	objective	<15	<15	2	
Others	limit	5		5	1
	objective			0.5	
Public	limit	5	1	1	0.05 (off-site)
	objective	1	0.3	0.1	

Table 3 Emergency Reference Levels 1991
(1986 Figures in Brackets)

Countermeasure	Whole Body Dose Equivalent (MSv)	
	Lower	Upper
Sheltering	3 (5)	30 (25)
Evacuation	30 (100)	300 (500)
Foodstuffs Intervention	1 (5)	-

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