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THE EFFECTS OF TRITIUM CONTAMINATION IN THE FED/INTOR REACTOR HALL*

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ABSTRACT

The purpose of this study was to determine the constraints imposed on the FED/INTOR fusion plants by tritium contamination in the reactor hall. Limitations imposed by gamma-radiation levels and the maintenance philosophy adopted were included. The cost (capital and operating) required to maintain 5, 50, and 500 $\mu\text{Ci}/\text{m}^3$ was evaluated. Three different maintenance strategies (unsuited worker, suited worker and robotics) were studied to determine if tritium contamination placed a constraint on reactor availability.

I. INTRODUCTION

In a deuterium-tritium fueled fusion reactor, the control of tritium is an important issue since tritium contamination in the reactor hall is a potential problem. Several areas are affected by the tritium levels maintained in the hall atmosphere during different scenarios - reactor operation, maintenance, accident. The environmental impact and the perceived public risk are important in the public domain. For the plant worker, the dose received and the associated worker efficiency can be significant. A major economic issue is the capital and operating costs associated with the atmospheric detritiation systems needed to maintain a given level. The delay time needed to achieve tritium and/or gamma radiation levels associated with a given maintenance philosophy is a major constraint in achieving a desired reactor availability.

In this study, the effects of tritium contamination in the reactor were evaluated for the FED/INTOR designs (Fusion Engineering Devices/International Tokamak Reactor) including all the above considerations. The magnitude of the tritium leak rate or release possible from tritium systems in the reactor hall was evaluated for the different operating conditions considered - normal, accident, maintenance. Since FED/INTOR are preconceptual reactor designs, detailed specifications were not available. Therefore ranges were

used in evaluating the tritium sources. Capital and operating costs involved in maintaining a given tritium atmospheric level (5, 50 and 500 $\mu\text{Ci}/\text{m}^3$) were evaluated for a continuous tritium leak rate and for a release. Correlations were made between a given tritium atmospheric level and the environmental release, the worker dose, the worker efficiency, and the reactor availability for a given maintenance philosophy. When the gamma radiation level was a limitation, this was factored into reactor availability considerations.

II. TRITIUM SOURCE TERMS

The approach used to assess the magnitude of the tritium source terms was to assume that all tritium systems were fabricated and operated according to established tritium handling practices.² The additional assumption was made that individual components had minimal leaks, i.e., that they were well designed and had been leak tested under stringent conditions. With these constraints, systems which could serve as models for various components within the reactor were analyzed and then sized to approximate the FED/INTOR configuration. In all cases, a range of values resulted because of the uncertainties in the data base. Strategies which could result in lower tritium source terms were incorporated when possible.

The tritium source terms considered in the reactor hall were the following: water coolant system, torus including first wall, limiter/divertor and blanket sections, diagnostic system, sputtered carbon particles, fuelers, blanket tritium recovery lines, test modules, vacuum pumps, and wall surfaces. It was assumed that both the ventilation system and atmosphere detritiation system were in a separate building and thus the waste products (filters, molecular sieve beds) were not source terms. If this were not true, then these systems would also be source terms.

Of the source terms considered, the one

which could contribute the greatest tritium load during normal operation was the water coolant system. The coolant system in the CANDU reactors in Canada was considered to approximate the water coolant system in a fusion reactor. Acute spillage cited for CANDU plants was assumed to correspond to major coolant accident releases in the fusion reactor hall. Remaining spillage was considered to be representative of maintenance operations. All leakage was considered to be representative of state-of-the-art leakage rates because the Canadians have instituted comprehensive leakage prevention programs from cost (D_2O) and worker safety (DTO) considerations. In addition, the fusion coolant system (especially for INTOR) might be operated at higher temperatures and pressures than the CANDU systems. This could result in higher losses even with the use of well-designed equipment. Because the total volume of coolant in the CANDU plants ($580 - 850 \text{ m}^3$)³ was greater than that in FED or INTOR, the leakage rates cited for CANDU plants were reduced proportionally for the fusion plants. However, a smaller plant could have a larger leakage rate than a large plant. A reduction in the leakage rate requires a major design effort to eliminate flanged joints and other known leakage sources. The likelihood of a significant reduction is unknown; therefore, the values calculated should only be considered as most likely values.

Two separate coolant systems - one for areas of high tritium contamination and the other for those of low tritium contamination - were recommended to minimize the volume of coolant with a potentially high tritium concentration. These systems also reduced the size and cost of the water detritiation system required.

The average tritium leak rate from the water coolant was estimated to be $< 12 \text{ Ci/d}$ during reactor operation, $< 70 \text{ Ci/d}$ during maintenance and $< 4000 \text{ Ci/d}$ for accident conditions. A summary of all leak sources is shown in Table 1. During reactor operation, tritium leaking from the coolant system ($< 12 \text{ Ci/d}$) is half of the total. During maintenance, several systems could release $> 50 \text{ Ci/d}$. If several systems were being serviced simultaneously, the tritium release rate could be 10^3 Ci/d . Releases up to 10^5 Ci could occur as a result of an accident.

The walls of the reactor hall can be a major contribution to atmospheric tritium levels during reactor operation. Experience

at Ontario Hydro³ indicates that concrete walls serve as a sink for any tritium released during maintenance or accident conditions. This is then released when atmospheric tritium levels are reduced. (Four days at $\sim 0.7 \text{ Vol\%}$ /min are required to reduce levels.) The recommendation is made that a non-permeable metal liner (stainless steel or aluminum) be used in the reactor hall.

III. ATMOSPHERIC DETRITIATION SYSTEMS

Large volume air detritiation systems were evaluated on the basis of conceptual design, capital cost, operating cost, and system requirements for both operating and accident conditions.

An air detritiation system consists of the following main pieces of equipment: blower, air preheater, catalytic reactor aftercooler, and water removal system. The system design is based on make-up air and exhaust being equal to one volume percent per day to maintain negative pressure in the reactor hall. There would also be an emergency detritiation system that would be employed when accident conditions arose to increase the total capacity of the system and thereby reduce the time required to cleanup a release.

The proposed conceptual design took into consideration three existing detritiation systems. Mound's system has a capacity of $\sim 28 \text{ m}^3/\text{min}$ and uses activated alumina beds for water removal. Both the TFTR system at Princeton and the system at LASL use molecular sieve dryer beds to remove water. A designed, but not yet built, system at LLL with a $\sim 140 \text{ m}^3/\text{min}$ capacity was also considered.

Total cost for reactor building detritiation is divided into two categories: total capital cost and annual operating expenses.

Total capital cost is the sum of the detritiation system cost, the cost of the building to contain the system, and the cost of a tritiated water recovery unit capable of handling 100 L/d . The detritiation system costs were obtained by scaling the cost of the TFTR Vault Cleanup System. Building costs were estimated at $\$230/\text{m}^3$, with the building volume required to contain the detritiation system scaled from the present system at Mound. The cost for the water recovery unit was estimated to be $\$5\text{M}$. The total cost for an $\sim 140 \text{ m}^3/\text{min}$ unit is $9.9 \text{ M\$}$.

The size of the detritiation system is an

Table 1. ESTIMATED RANGES^a OF TRITIUM SOURCE TERMS RELEASED TO THE ATMOSPHERE IN T E REACTOR BUILDING FOR NORMAL, MAINTENANCE, AND ACCIDENT CONDITIONS

System	Normal (Ci/d)	Maintenance (Ci/d)	Accident (Ci)
Water, Coolant^{b,c}			
Limiter/divertor/first wall	0.1-12	0.3-70	10-4000
Shield	0.2	~1	30-60
Blanket	0.2	~1	30-60
Torus	<1	---	<10 ³
Limiter/divertor	---	<10 ³	---
First Wall	---	<50	---
Blanket	---	<50	---
Diagnostics	0.01-0.1	<50	<10 ³
C-particles	---	10-10 ³	(?)
Fuelers	0.01-0.1	10-10 ²	~10 ⁵
Blanket Recovery Lines^b	0.01-0.1	<10	~10 ⁴
Test Modules	(?)	(?)	(?)
Vacuum Pumps			
Turbomolecular	0.01-0.1	10	<10 ²
Cryopumps	0.01-0.1	10	10 ⁴ -10 ⁵
Building Surfaces	1-10	1-10	1-10
TOTAL	2.6-24	0.3-10 ³	10-10 ⁵

^a No system had been completely defined (FED or INTOR).

^b HTO ~ 2-3 x 10⁴ more hazardous than HT.

^c Availability and processing considered when appropriate (100 vol-%/d).

important consideration. Scaling up beyond existing technology (140 m³/min system) presents some uncertainties. Availability of some of the required equipment in the larger sizes may be a problem. The handling and installation of such large-sized equipment may also be difficult. With scaling up of the process, there is a greater possibility of experiencing inefficient flow behavior through the larger-diameter reactor and dryer beds. If the system were comprised of 140 m³/min units as opposed to larger unit(s), this would provide the advantage of having redundant capabilities in the event that one of the units failed.

The total capital cost of the Atmospheric Detritiation System is shown as a function of the average operational release rate in the reactor building in Table 2. Total capital costs rise rapidly with increasing leak rates. For an accident case, the total capital cost is shown in Table 3. Operating costs are shown in Table 4. All electricity costs were based on 0.05/kwh. It was assumed that the equipment would operate 24 h/d under normal conditions with an additional load from emergencies 2 d/month. Manpower was estimated at \$25/h.

Table 2. ATMOSPHERIC DETRITIATION SYSTEM CAPITAL COST VS. LEAK RATE AND REACTOR BUILDING CONCENTRATIONS

Leak Rate Ci/day	Total Capital Cost for Various Room Concentrations, M\$		
	5 $\mu\text{Ci}/\text{m}^3$	50 $\mu\text{Ci}/\text{m}^3$	500 $\mu\text{Ci}/\text{m}^3$
1	9.9	6.0	5.5
10	35.6	9.9	6.0
130	210.0	35.6	9.9
1000	1390.0	210.0	35.6

Table 3. ATMOSPHERIC DETRITIATION SYSTEM CAPITAL COST VS. VOLUME AND CLEANUP TIME

Reactor Volume, m^3	Capital Cost, M\$					
	1 g release			25 g release		
	24 h	48 h	72 h	24 h	48 h	72 h
50,000	25.5	21.0	21.0	30.0	25.5	21.0
100,000	46.0	37.0	37.0	50.5	41.5	37.0
150,000	66.5	53.0	48.5	75.5	57.5	53.0
200,000	87.0	69.0	64.5	96.0	73.5	69.0

Table 4. ATMOSPHERIC DETRITIATION SYSTEM ANNUAL OPERATING COSTS VS. FLOWRATE

Flowrate m^3/min	Manpower	Annual Operating Costs, K\$		
		Utilities	Water Cleanup	Total
140	62.0	470	300	830
1,400	135	4,210	300	4,650
14,000	885	41,650	300	43,000

IV. WORKER EFFICIENCY

The tritium concentration in the radioactive areas determines the exposure time and the types of protective clothing required for personnel who work in the areas. The following worker efficiencies are based on MRC-Mound records. The efficiencies include: time required to change into and out of the protective clothing, loss of dexterity (in cases where gloves and bubble suits are worn), and the time required for showering, when necessary. They do not include requirements of Health Physics personnel.

A worker in an uncontrolled area is assumed to have an efficiency of 100%. For comparison, in controlled areas where the room concentration is $5 \mu\text{Ci}/\text{m}^3$ or less and surface contamination is less than 50 counts/min workers wear smocks and shoe covers and the average efficiency is 71%. When surface contamination is between 50 and 10,000 counts/min, all workers wear two-piece blues and gloves. The efficiency for workers in this type of protection is 56%. It is Mound's policy to require all personnel doing maintenance, operational or repair type work to wear the two-piece blues. When room concentrations exceed $5 \mu\text{Ci}/\text{m}^3$ but not $500 \mu\text{Ci}/\text{m}^3$, and for any water handled with a concentration of 1 Ci/liter or less, bubble suits and supplied air must be worn. Bubble suits provide a safety factor of about 100 against tritium, which means that a worker in a bubble suit can be allowed to work in a $500 \mu\text{Ci}/\text{m}^3$ environment for the same length of time as an unprotected worker in a $5 \mu\text{Ci}/\text{m}^3$ environment. Workers in bubble suits with supplied air have an efficiency of 50%.

V. MAINTENANCE STRATEGY

The following three approaches to the maintenance/repair task are considered. (1) A series of unsuited work crews are cycled through the building until the task is completed. The building atmosphere contains $< 5 \mu\text{Ci}/\text{m}^3$ of HTO; otherwise, it is assumed (for the purposes of this treatment) to be unacceptable to allow unsuited workers to enter the building for extended periods. The amount of time a single crew spends in the building is determined by worker dose limits. (2) A series of crews of workers in bubble suits are cycled through the building until the task is completed. The bubble suits are designed to permit a worker to enter the building when the atmosphere contains $< 500 \mu\text{Ci}/\text{m}^3$ of HTO. The estimated efficiency, E ,

of the suited worker is taken to be 50% of that of the unsuited worker. This value may be too low since the "unsuited" workers may have to put on, work in, and take off other special apparel. In this case the value of E could approach the 80-90% range for suited workers. (3) A robotics unit (e.g., robot, remote manipulator) is used to perform the task. Here it is assumed that the robotics unit performs the task with an efficiency equal to 20% of that of an unsuited worker.

A final stipulation is that, in cases where workers (suited or unsuited) are performing the task, it is necessary to delay their entry into the reactor building a full 24 h following reactor shutdown in order to allow the induced gamma background to decay to an acceptable level for personnel access.

The three access approaches were compared in terms of the total time required to complete a maintenance/repair task. The parameter employed as the discriminator in this analysis was the actual work time required by an unsuited work crew following initial entry into the building. The results of this analysis are shown in Fig. 1. In this figure two cases are considered for the unsuited work crew. Each involves a different assumed cleanup time required to reduce the HTO activity in the building atmosphere to $< 5 \mu\text{Ci}/\text{m}^3$. The strategies suggested by the figure are: (1) a robotics unit is preferred for repairs that would take an unsuited work crew < 6 h to perform; (2) an unsuited work crew ($E = 100\%$) is preferred for repairs that would take > 6 h to perform, provided the crew can enter right after the 24-h delay period; and (3) a crew in bubble suits is preferred in circumstances where the task would require < 8 h of unsuited work crew time but the permissible entry time of the unsuited crew is extended beyond the 24-h delay period because of a need for additional air decontamination or a condition where the reactor building atmosphere cannot be decontaminated to $< 5 \mu\text{Ci}/\text{m}^3$ of HTO. Also, the value of the efficiency factors E assumed has a lot to do with selecting approaches (1) and (2).

A summary of the worker dose, capital and operating costs, environmental releases for each of these cases is shown in Table 5.

For the environmental impact, two sources of tritium loss to the environment were considered. The first was the leakage possible from building penetrations ($\sim 1 \text{ Vol.}\%/\text{d}$ for

Fig. 1. Strategies for maintenance/repair access as a function of building atmosphere cleanup conditions.

the FED/INTOR design).⁴ The second was the loss from the stack due to building ventilation. An assessment of this source was that one building volume was released each day. As a comparison the routine stack release found at CANDU reactors, Canada was 70-100 Ci/d.

The 20% availability estimate used in the FED design assumed unlimited manpower.⁶ However, with limited manpower, the availability expected would be lower. To determine the range of this value the assumptions made were that 10, 15, 20, and 30% of the total maintenance time per year was dedicated to operations which required ~ 24 hours to complete with unlimited manpower. Since, with limited manpower, twice the time was required for each one day job requiring contact maintenance/repair, the availability possible was 0% (if 30% of the maintenance/repair tasks were one day jobs), 4% (if 20% were one day jobs), 8% (if 15% were one day jobs) and 12% (if 10% were one day jobs). The availability shown in Table 5 for limited manpower was for the 15% option which corresponded to once a week.

VI. CONCLUSIONS

Since the water coolant system was a major source of tritium leakage to the reactor hall, separate coolant systems were recommended for the first wall/limiter, for the blanket and for the shield systems to minimize the volume of coolant with potentially high tritium concentration. Maintenance operation required the largest atmospheric detritiation

TOTAL TIME AFTER SHUTDOWN FOR COMPLETION
OF MAINTENANCE / REPAIR TASK IN HOURS

Table 5. CONSEQUENCES OF A GIVEN DETRITIATION STRATEGY WITH LIMITED MANPOWER AND A TRITIUM LEAK RATE OF 100 Ci/d

Maintenance Force ^b	Concen. ³ ($\mu\text{Ci}/\text{m}^3$)	Detritiation System Cost ^a		Environ. Release ^c (Ci/d)	Occupational Dose ^d (mrem/d)	Maintenance Time Required ^a (h)	Avail. ^e (%)
		Capital (M\$)	Operating (M\$/a)				
5 Men	5	> 210	> 15	0.1 - 1	125	48	8
10 Men	50	> 30	> 3	0.1 - 10	140	48	8
10 Men	500	> 10	> 0.8	0.5 - 100	250	48	8
5 Robotic Units	50	> 30	> 3	0.1 - 10	---	24	20

^a Effect of tritium soaking not considered; metallic liner assumed.

^b At an efficiency of one, the assumption made is one man per shift; 5 shifts per day. With 50% efficiency, two men per shift. For robotic units, the efficiency is 20% but only one 24h shift per day.

^c From the stack release from the ventilation system and building leakage.

^d This includes a gamma dose of 2.5 mrem/h for each worker.

^e Limited manpower would be a more realistic assumption.

system with average tritium losses of 100 Ci/d. The total cost at this leak rate for ten years of operation of a system to maintain levels of 5, 50 and 500 $\mu\text{Ci}/\text{m}^3$ was 360, 60, and 18 million dollars. Maintenance of levels < 50 $\mu\text{Ci}/\text{m}^3$ did not appear justified from cost.³ The use of bubble suits at 50 $\mu\text{Ci}/\text{m}^3$ did not adversely affect reactor availability. The environmental release at 50 $\mu\text{Ci}/\text{m}^3$ was expected to be < 50 Ci/d. With limited manpower, robotic maintenance achieved the 20% design availability; manned maintenance did not.

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