Idaho National Engineering and Environmental Laboratory

INEEL/CON-04-01902
PREPRINT

Comparison Of Tritium Component Failure Rate Data

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September 14-16, 2004

Sixteenth Topical Meeting on the Technology of Fusion Energy

COMPARISON OF TRITIUM COMPONENT FAILURE RATE DATA

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Published failure rate values from the US Tritium Systems Test Assembly, the Japanese Tritium Process Laboratory, the German Tritium Laboratory Karlsruhe, and the Joint European Torus Active Gas Handling System have been compared. This comparison is on a limited set of components, but there is a good variety of data sets in the comparison. The data compared reasonably well. The most reasonable failure rate values are recommended for use on next generation tritium handling system components, such as those in the tritium plant systems for the International Thermonuclear Experimental Reactor and the tritium fuel systems of inertial fusion facilities, such as the US National Ignition Facility. These data and the comparison results are also shared with the International Energy Agency cooperative task on fusion component failure rate data.

I. INTRODUCTION

Tritium fuel handling for fusion facilities is an important safety issue. Inadvertent releases of tritium from the fuel cleanup, handling, and storage facility of a fusion experiment can be a dominant contributor to off-site radiological dose. Analyzing the reliability of the system equipment and the secondary confinement barriers can lead to improvements in system safety and also prove the regulatory case that the public is protected from exposure to tritium. Improved tritium confinement also protects facility workers and the environment. Existing tritium facilities operated for fusion research have considered reliability field experience data to be valuable enough to devote time and resources to collecting and analyzing the component failure information. These facilities include the Tritium Systems Test Assembly (TSTA) in the US, the Joint European Torus (JET) Joint Undertaking in the United Kingdom, the Tritium Process Laboratory (TPL) in Japan, and the Tritium Laboratory Karlsruhe (TLK) in Germany. The safe operation of these facilities, and the quantitative fault modeling of near-term designs that has been made possible by data collection activities, serve to demonstrate that fusion tritium handling systems and facilities are a mature technology that should not contribute significantly to the accident risk of a fusion experiment. Some safety personnel have suggested that this effort to collect and analyze tritium component data may be misplaced since tritium facilities for other purposes have already been licensed and operated. Most notably, military and commercial fission power reactor tritium removal facilities in several countries have been granted permission to operate by their governments. The distinction must be made that military facilities are not licensed by energy development agencies, and commercial fission reactor tritium facilities such as those in Canada do not perform all of the tritium separation and removal tasks as fusion facilities, and they are licensed by fission reactor authorities. Any experiences or data that these other facilities can share with fusion can be very valuable, but fusion facilities will need to demonstrate their own safety. Making the fusion regulatory case for tritium usage is expected to progress in increments, proving each successive step. This “stair stepping” has been seen with JET (site limits 0.1 g-T for the Preliminary Tritium Experiment and an administrative limit of 20 g-T for the Deuterium-Tritium Experiment)[1,2] and the Tokamak Fusion Test Reactor (TFTR, 5 g-T site limit) experiences[3] in magnetic fusion, and with the National Ignition Facility in inertial fusion.[4] An ITER-size tritium facility (< 3 kg-T site limit)[5] is another step forward for fusion and is expected to require a rigorous safety assessment. JET required both traditional and probabilistic safety analysis for tritium operations. Both JET and TFTR have demonstrated the value of probabilistic safety assessment for tritium systems, and the ITER design team has also used PSA techniques in the tritium systems safety assessment.[6]

The data that have been collected and analyzed from fusion tritium facilities are shared with task participants in the International Energy Agency’s Implementing Agreement on the Environmental, Safety and Economic Aspects of Fusion Power (IEA/ESE-FP).[7,8] The operating experience task in the IEA/ESE-FP gathers data from existing facilities for application to probabilistic safety assessment of the next successive step in fusion. Several tokamaks share data, including JET, the Frascati Tokamak Upgrade, Tore Supra, TFTR, and DIII-D. Other data values are found from records kept at other fusion facilities, such as the tritium labs. Literature sources and safety reports also supply data. Applicable data are also borrowed from other endeavors, such as the fission power, aerospace, and chemical process industries. Together, these data sets allow quantification of accidents in fusion facilities, which is part of the regulatory process in the US and some other countries.

This paper gives the results of a comparison of data values collected from TSTA, TPL, JET, and TLK. It is an extension of previous work that compared only US and Japanese data.[9] The comparison process helps to validate the data and make selections of best estimate values. The data values presented here compared reasonably well.

II. DATA VALUES

Two objectives of the TSTA mission were to demonstrate the long-term safe handling of tritium and to demonstrate the long term reliability of components.[10] In late 1999, the US Department of Energy (DOE) determined that the TSTA mission was complete and an orderly shutdown of the facility began in 2001. Facility stabilization was completed in 2003 and final cleanup is in progress. The component failure data records remaining at the site were electronically transmitted to the INEEL in August 2003 for inclusion in an update of the failure rate data values. Detailed examination of the transmitted data revealed that these electronic records were from the database inception in 1983 to the time that the KnowledgeMan database manager program originally used to store and sort the failure report data[11,12] was converted to the R-base program for data storage. The conversion occurred in early 1990. Therefore, the transmitted records believed to be an update of past information were of limited use since they had already been included in past data analyses. It appears that the post-1990 data may have been lost. Despite the inability to perform a significant update on the TSTA component failure rate data values, comparing the collected data sets from TSTA[13-16] and other facilities remains a valuable exercise to validate the data.

Pinna[17] has reported on an extensive data analysis performed on JET and TLK. Yamada et al.[18,19] have reported two data sets on TPL. The second TPL data set has expanded some of the initially reported values and also examined some new components. The mean, or point estimate, failure rate values from the sets of failure reports or other recorded data at a given facility are given in Table I. Where relevant, both TPL data values are reported for a given component; the more recent values are used for comparison since longer periods of operating time generally result in more accurate failure rates. The second set of TPL values usually are smaller than the initial set. The table shows the expected result that some data values are very similar and some disagree. The IEA data task participants have concurred that values which agree to within a factor of 3 are considered a good comparison, those values that agree to within a factor of 10 are a fair comparison, and those values that vary more than a factor of 10 are a poor comparison.[8] On a general level, facilities of similar age with similar types and numbers of components, and with similar duty factors and maintenance, usually produce comparable failure rate data. There can be many factors that affect individual results and make facility-to-facility comparisons poor, such as the influence of environmental conditions, the methods or style of component and system operation, and the maintenance approach of corrective versus predictive versus preventive. The TSTA data spans, on the order of 6 or more years of operation, are large enough for continuously operated components to produce mature failure rate values.

Some components listed in Table I do not have entries from each facility analyzed. Some facilities did not collect information on some types of components, and the data analyses did not focus on some types of components or systems. For example, from Table I it is obvious that TSTA and TPL researchers collected and analyzed glovebox data, while the JET and TLK analyses did not. Conversely, the JET analysis focused more on electronics while the TSTA, TPL, and TLK analyses did not. As more data are collected, broader sets of components can be analyzed and compared.

Failure rate comparisons are not easily made due to differences in components, differences in data reporting, and variations in the analysis. One example of reporting differences is the identification of failure modes. As seen in Table I, some components had 'all failure modes' failure rates, and other failure rate values had more specific modes. Often this discrepancy is due to the level of detail recorded in the component failure report and on a few occasions it is due to the chosen analysis technique of binning all of the data for an aggregate result. Overall, the number of 'good' comparisons was slightly higher than the number of fair and poor comparisons combined. Thus, the data compared reasonably well.

The values in Table I show that in general, some of the JET data produced the lowest values, in the 1E-06 and 1E-07 per hour range, while the TSTA and TPL data generally compare more closely in the 1E-05 per hour range. The JET Active Gas Handling System (AGHS) has not operated differently than the other facilities, and the components used at JET are believed to be similar to the other facilities. It is possible that the AGHS had larger populations of components, or perhaps the AGHS, being a fusion fuel processing system at a tokamak facility, had the impetus of experiment operations concerns that made maintenance more intensive than at the laboratory facilities.

TABLE I. Tritium component failure rate comparison

Component and failure mode	TSTA point estimate and (upper bound)	TPL point estimate and (upper bound)	JET point estimate and (upper bound)	TLK point estimate and (upper bound)	Comparison
Blower, fail to function	--	7.3E-05/h (1.9E-04/h)	2.2E-05/h (4.6E-05/h)	--	fair
Gas chromatograph, fails to function	6.8E-02/d (1.6E-01/d)	--	--	5.81E-06/h (1.46E-05/h) [all modes]	not comparable
Motor operated valve, fails to open	5.0E-04/d (8.5E-04/d)	--	--	2.06E-05/h (6.49E-05/h) all modes	not comparable
Compressor, fails to start	3.1E-05/d (9.5E-05/d)	1.1E-04/d (1.2E-04/d) 5.2E-05/d (5.67E-05/d assumed)	--	--	good, later TPL data to TSTA data compares well
Compressor, fails to run	6.3E-05/h (1.6E-04/h)	8.1E-04/h (2.1E-03/h) fail to function 7.4E-04/h (1.93E-03/h assumed) failure	--	3.62E-05/h (1.72E-04/h) fails to run	good, for TSTA data to TLK data, otherwise TPL data is much higher
Manual valve, fails to operate	1.8E-03/d (3.2E-03/d)	9.8E-04/d (5.4E-03/d) fails to function	--	--	good
Humidity indicator, gives incorrect value	1.7E-05/h (3.9E-05/h)	2.1E-05/h (3.9E-05/h)	9.8E-07/h (1.4E-06/h) indicator, erratic		good, for TSTA to TPL data; JET much lower
Pressure transducer, gives incorrect value	5.3E-06/h (1.4E-05/h)	--	4.3E-07/h (1.3E-06/h) transducer, erratic		poor
Recombiner, fails to function	4.2E-05/h (1.3E-04/h)	--	--	--	--
Room air monitor, reads high	2.2E-06/h (1.0E-05/h)	1.1E-05/h (2.2E-05/h) fails to function	8.8E-07/h (4.2E-06/h) ion chamber, erratic or no output	--	TSTA data to JET data good, TPL data is much higher
Room air monitor, reads low	2.2E-06/h (1.0E-05/h)	1.1E-05/h (2.2E-05/h) fails to function	8.8E-07/h (4.2E-06/h) ion chamber, erratic or no output	--	TSTA data to JET data good, TPL data is much higher

TABLE I. Continued.

Component and failure mode	TSTA point estimate and (upper bound)	TPL point estimate and (upper bound)	JET point estimate and (upper bound)	TLK point estimate and (upper bound)	Comparison
Glovebox pressure controller, overpressure	3.0E-01/year (4.0E-01/year)	2.9E-02/year (1.4E-01/h) fails to function 6.9E-02/year (3.3E-01/year assumed), negative pressure control failure	--	--	poor
Glovebox pressure controller, underpressure	2.0E-01/year (3.0E-01/year)	2.9E-02/year (1.4E-01/year) fails to function 6.9E-02/year (3.3E-01/year assumed), negative pressure control failure	--	--	poor
Glovebox pressure controller, continuously purges	4.0E-02/year (1.0E-01/year)	6.9E-02/year negative pressure control failure	--	--	good
Glovebox, air inleakage	1.0E-01/year (5.0E-01/year)	1.14E-01/year (2.6E-01/year)	--	--	good
Glovebox, small scale tritium release to room	4.0E-02/year (1.0E-01/year)		--	--	--
Oxygen monitor, all failure modes	3.4E-07/h (2.3E-06/h)	7.2E-06/h (1.3E-05/h) fails to function 3.0E-06/h oxygen sensor failure	--	--	fair
Small compressor, fails to run	6.3E-05/h (1.6E-04/h)	8.1E-04/h (2.1E-03/h)	--	--	poor
Small compressor, fails to start	3.1E-05/d (9.5E-05/d)	1.1E-04/d (1.2E-04/d)	--	--	poor
U getter bed with heaters	--	--	--	8.04E-04/h (2.02E-03/h) all failure modes	--
ZrCo getter bed with heater	--	--	--	1.53E-02/h (3.84E-02/h) all failure modes	--
Molecular sieve bed	--	--	--	3.56E-07/h (8.94E-07/h) all failure modes	--

As an initial approach to obtaining generic failure rates, the values in Table I were combined using a geometric mean to produce average failure rates. Then the values were rounded up to the nearest half-order of magnitude. The upper bounds are 90 or 95% confidence interval values. These failure rates and their error bounds are considered to be the generic average based on the operating experience of the facilities. The results are given in Table II. These generic failure rate values can be used for preliminary safety assessment when components are not well defined or do not have input data from the manufacturers. Pinna[17] also reported some generic values based on the JET AGHS data results.

III. CONCLUSIONS

The collection of system and component operating experience at multiple facilities has allowed analysts to calculate component failure rates for tritium-bearing components. These are truly fusion-specific data sets, and they allow direct application of probabilistic safety assessment to fusion tritium systems. These data are more accurate and applicable to fusion than analyst judgment, generic gas system data, or tritium system data from military or other applications. Collecting the operating experience data is an important part of proving that tritium can be handled safely for fusion experiments and having these data advances the state-of-the-art for probabilistic safety assessment in fusion applications. The data can support facility-specific uses, such as a safety assessment update needed when petitioning to increase the allowable tritium inventory. The data values in Table I compared reasonably well, although in a few cases there were large variations in the data. For components that have wide variation in values, using generic results may offer the best quantification unless facility-specific data are to be used. The generic failure rates given in Table II can also be used for preliminary safety assessments when only the types of system components are known. All of these data can be shared with the IEA/ESE-FP task on component failure rate data collection for safety support.

ACKNOWLEDGMENTS

This work was prepared for the US Department of Energy (DOE), Office of Fusion Energy Sciences, under the DOE Idaho Operations Office contract number DE-AC07-99ID13727.

TABLE II. Generic tritium component failure rates

Component and failure mode	Generic failure rate	Upper bound failure rate
Blower, fails to function	3E-05/h	1E-04/h
Compressor, fails to start	3E-05/d	1E-04/d
Compressor, fails to run	1E-04/h	3E-04/h
Manual valve, fails to operate	1E-03/d	3E-03/d
Humidity indicator, incorrect output	1E-05/h	3E-05/h
Pressure transducer, incorrect output	1E-06/h	3E-06
Room air monitor, reads high	3E-06/h	1E-05/h
Room air monitor, reads low	3E-06/h	1E-05/h
Glovebox pressure controller, overpressure	1E-01/year	3E-01/year
Glovebox pressure controller, underpressure	1E-01/year	3E-01/year
Glovebox pressure controller, continuous purge	1E-01/year	3E-01/year
Glovebox, air inleakage	1E-01/year	3E-01/year
Oxygen monitor, all failure modes	1E-06/h	3E-06/h
Small compressor, fails to run	3E-04/h	1E-03/h
Small compressor, fails to start	3E-05/d	1E-04/d

note: /h is per operating hour, /d is per demand to function

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