Probabilistic Evaluation of Turbine Valve Test Frequency

Non-Proprietary Version

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Revision History

Revision	Page	Description
0	All	Original Issue
1	- (Abstract) 4.3-1	The sixth sentence of the third paragraph is modified as follow. "Missile ejection probability for an integral rotor under design overspeed condition had been demonstrated to be extremely low compared to the missile ejection probability by reaching a destructive overspeed in the document, MUAP-07028(R0) or MUAP-10005(R0) ‘Probability of Missile Generation from Low Pressure Turbines’." The first sentence of the fifth or seventh paragraph in Section 4.3 is added "or MUAP-10005(R0), June 2010," before “Probability of Missile Generation from Low Pressure Turbine”.
2	- （Abstract） 4.3-1	The sixth sentence of the third paragraph is modified as follow. "Missile ejection probability for an integral rotor under design overspeed condition had been demonstrated to be extremely low compared to the missile ejection probability by reaching a destructive overspeed in the document, MUAP-07028(R1) or MUAP-10005(R0) ‘Probability of Missile Generation from Low Pressure Turbines’." The first sentence of the fifth or seventh paragraph in Section 4.3 is modified to "MUAP-07028(R1), January 2011”.
3	- （Abstract） 4.3-1	The sixth sentence of the third paragraph is revised as follow. “Missile ejection probability for an integral rotor under design overspeed condition had been demonstrated to be extremely low compared to the missile ejection probability by reaching a destructive overspeed in the document, MUAP-07028(R2) ~~or MUAP-10005(R0)~~ ‘Probability of Missile Generation from Low Pressure Turbines’.” The first sentence of the fifth paragraph in Section 4.3 is revised as follow. “P(M/A) was obtained from probabilistic reports on missile ejection from fully integral low pressure turbine rotors (MUAP-07028(R2), June 2013 ~~or MUAP-10005(R0), June 2010~~, “Probability of Missile Generation from Low Pressure Turbine”). The seventh paragraph in Section 4.3 is revised as follow. “Section 3.0 of MUAP-07028(R2), June 2013 ~~or MUAP-10005(R0)~~, June 2010, “Probability of Missile

		Generation from Low Pressure Turbine" shows the probability of missile ejection depending on the inspection interval and concludes that the probability of a missile ejection for a full integral rotor with low yield strength is extremely low when the rotor rotating speed is suppressed under "Design overspeed" or "Intermediate overspeed"."

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Abstract

The purpose of this report is to provide a detailed probabilistic basis for the valve test interval to secure missile ejection from a low pressure turbine equal or less than the criteria specified in NUREG-800 SRP Section 3.5.1.3.

The annual probability of turbine missiles ejection is the sum of three (3) factors;

(1) Product of probability reaching design overspeed and conditional probability of missile ejection,

(2) Product of probability reaching an intermediate overspeed and conditional probability of missile ejection,

(3) Probability of reaching a destructive overspeed ([ ] percent of rated speed).

In this analysis, item (1) and item (2) had been regarded as nil in light of applying a fully integral rotor. Significant changes have occurred in the design of low pressure rotors and rotor discs in recent years. The general trend has been toward designs that reduce or eliminate the problem of disc stress corrosion cracking. This, in turn has resulted in significant reductions in the probability of missile ejection at design overspeed. This should have the effect of further reducing the probability of missile ejection at the design and intermediate overspeed, and these overspeed events will contribute even less to the total probability of turbine missile ejection. Missile ejection probability for an integral rotor under design overspeed condition had been demonstrated to be extremely low compared to the missile ejection probability by reaching a destructive overspeed in the document, MUAP-07028(R2) ‘Probability of Missile Generation from Low Pressure Turbines’. Probability of item (3) therefore is the dominant factor to be taken into consideration in the valve test interval analysis. Section 4.0 of this report discusses the basis for the analysis of turbine overspeed.

The annual probability of overspeed control and valve system failure, which leads to destructive overspeed has been calculated using detailed nuclear turbine operating data. Testing of turbine valves affects the probability that the valves will be incapable of closing after loss of load. The failure or unavailability of the turbine valve safety function affects or contributes to the probability that the turbine will go into overspeed and eject a missile.

Section 5.0 of this report contains the detailed results of the probabilistic investigation. Figure 5.3-1 show the total probability of turbine missile ejection as a function of the turbine valve test interval. Test intervals of one month to twelve months were considered in the study.

Evaluation showed that the probability of turbine missile generation with [ ] is less than the evaluation criteria specified in NUREG-800 SRP Section 3.5.1.3.

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List of Acronyms

The following list defines the acronyms used in this document.

DEH	Digital Electro-hydraulic
IV	Intercept Valve
MS/R	Moisture Separator/Reheater
MTCV	Main Turbine Control Valve
MTSV	Main Turbine Stop Valve
N	Number of main steam pipes
n	Number of valve tests per month
P	Annual Probability of Turbine Missile Ejection
P(A)	Annual Probability of Design Overspeed
P(B)	Annual Probability of Intermediate Overspeed
P(C)	Annual Probability of Destructive Overspeed
P(M/A)	Conditional Probability of Missile Ejection at Design Overspeed
P(M/B)	Conditional Probability of Missile Ejection at Intermediate Overspeed
P(M/C)	Conditional Probability of Missile Ejection at Destructive Overspeed (Assumed to be one (1) in this study)
Q_{MTSV}	Failure rate of MTSV
Q_{SC}	Failure rate of MTSV control system
Q_{MTCV}	Failure rate of MTCV
Q_{CC}	Failure rate of MTCV control system
Q_{SS}	System Separation Probability
q_{MTSV}	Failure rate of MTSV per month
q_{SC}	Failure rate of MTSV control system per month
q_{MTC}	Failure rate of MTCV per month
q_{CC}	Failure rate of MTCV control system per month
RSV	Reheat Stop Valve

1.0 INTRODUCTION

In recognition of the effects of turbine valve testing on the probability of low pressure turbine missile ejection, Mitsubishi Heavy Ind. Ltd. evaluated the need for periodic valve testing and to establish appropriate test intervals. This report contains the results of that evaluation.

The evaluation performed consisted of an estimation of the component failure rate and the annual probability missile ejection. Failures of turbine valves and overspeed protection components were evaluated on the basis of Japanese nuclear steam turbine operating experience. The annual probability of missile ejection was calculated for various test intervals.

2.0 TURBINE VALVE TESTING AND IMPACT

Testing is conducted to verify that equipment is capable of performing its intended function. The turbine valves function to control and protect the main turbine. They must be capable of moving freely in response to control and protection signals. Valve testing ideally tests these abilities or detects non-performance of these abilities. There are two degrees of performance or non-performance that testing may potentially demonstrate:

A. Equipment failure – the complete non-performance of equipment function.

B. Equipment failure precursors– identification of equipment conditions that will eventually lead to failure if not corrected.

A test which only identifies equipment failure is useful in limiting the time after the failure that the faulty equipment may be relied on. A test which identifies failure precursors can impact the time between and the number of failures if the precursors are acted upon. This section of the report addresses turbine valve testing and its implications on valve failure rate.

2.1 Turbine Valve Testing

Periodic testing of turbine valves consists of movement of each of the turbine valves through one cycle (from the valve position prior to testing, to full close, and returning to the original position.) Typically, this test is conducted by the control room operator with an observer at the valve. Valve testing verifies freedom of movement of the valve stem and plug and the actuator rod and piston. It also verifies proper operation of either the servo valve, servo motor, or dump valve, depending on which valve is being tested, and the associated drain line (return line) to the reservoir. Testing verifies closure of the turbine valves as testing is now considered as having nothing is inhibiting closure. This type of testing is beneficial for, (1) detecting sluggish or non-operation of the valves, and (2) identification of gross outward appearance of valve condition.

In addition to periodic testing, valve inspections during a shutdown can detect distress or conditions that would lead to future valve failure. In the current study, the valve inspection interval was not an input parameter. However, actual service experience has been used in the calculation of valve failure rates (Section 5.0). It is believed that these failure rates reflect the average practice of the nuclear industry with respect to inspection and maintenance of turbine valves.

2.2 Surrogate Valve Testing

Periodic valve testing primarily demonstrates the ability of the valve to respond to a signal and close upon demand. Both planned and unplanned turbine trips can also demonstrate these abilities and can be considered surrogate valve tests for which a valve test "credit" can be taken. All turbine trips result in the dumping of emergency trip oil and the operation of systems which dump high pressure oil or electrohydraulic fluid from the turbine valve actuators.

For planned trips, plant operator observe at the valves to visually check valve operation during the trip which qualifies as a surrogate valve test provided there has been no evidence of malfunction of the main turbine control valves during normal operation. For unplanned trips, the only significant difference from a planned trip or a typical valve test is the absence of an observer at the valves. In this case, sufficient evidence of proper valve operation can be obtained if an operator looks at each turbine valve shortly after the trip and verifies that all va1ves are in the closed position and that the conditions with respect to the valves appear normal.

This operator activity would then qualify as a surrogate valve test.

2.3 Valve Failure Modes and Impact of Testing

The dominant occurrence of valve failure modes, such as sticking and mechanical damage, can be attributed to the following:

1. Movement or loss of valve internal components

2. Cracking or breaking of the muffler

3. Piston seal ring-bonnet, bushing, or liner galling or distress

4. Misalignment of valve linkage

These conditions are primarily internal to the valves, and periodic testing would identify these conditions only to the extent that they are apparent to an observer or if they prevented valve operation. Periodic testing most often identifies failures. Failure precursors that do not noticeably affect the rate of closure or final position of a valve are not easily detected in testing. For example, a cracked muffler could potentially result in later muffler failure and subsequent internal valve binding; however, the "precursor" could not be detected during testing, only the subsequent failure of the valve could be detected.

For the above reasons, periodic valve testing does not have an impact on the valve’s failure rate for these types of valves in that it has not readily identified failure precursors, only failures. Therefore, increasing the periodic test interval will have no adverse impact on observed failure rates or valve lifetime. Testing that does not identify repairable defects cannot influence valve degradation and therefore the valve failure rate.

Based on the above discussion, it can be concluded that valve test frequency will not impact the turbine valve failure rate.

3.0 DESCRIPTIONS OF TURBINE VALVES AND OVERSPEED CONTROL

The following sections describe the turbine valves and its control system. The turbine valve arrangement for US-APWR is shown in Figure 4.1-1, and the turbine control oil system is shown in Appendix – A.

3.1 Turbine Valves

Main turbine stop valves (MTSVs), main turbine control valves (MTCVs) in the steam chest design and intercept valves (IVs) and reheat stop valves (RSVs) are located in the steam lines to the high and low pressure turbines as is shown in Figure 4.1-1. MTSV close automatically in response to the dumping of emergency trip oil (MTSV&RSV) which would occur in an overspeed trip. The controls and trips that dump emergency trip oil are discussed in Section 3.2. In normal operation, each MTSV is held open against a closing spring force by high pressure oil acting on the servo-actuator piston. Each MTSV has a dump valve that opens if the emergency trip oil (MTSV&RSV) pressure is dumped. This in turn, routes the high pressure oil to drain and the MTSV, equipped with large closing springs, closes rapidly.

MTCV adjust the inflow of steam to the turbine in response to the speed or load demand placed on the turbine-generator. Each has a servo valve and a dump valve. The servo valve receives an electrical input from the electronic controller and positions the steam valve through the control of high pressure oil to the servo-actuator. The electronic controller and/or digital processor receive the turbine speed and first stage pressure inputs. The MTCV will move rapidly to the fully-closed position if the dump valve is opened by a trip or protective device that dumps the emergency trip oil (MTCV&IV). Various controls and trips, discussed in Section 3.2, are designed to dump the emergency trip oil (MTCV&IV) on loss of load or overspeed.

IV and RSV are held open by high pressure oil operating on the pistons of the servo-actuators. Each IV has a dump valve that is connected to an emergency trip oil (MTCV&IV) header.

The dump valves will open in response to a dump of the emergency trip oil and close the IVs. RSVs have dump valves that are connected to the emergency trip oil (MTSV&RSV) header.

RSVs will close in response to a dump of the emergency trip oil (MTSV&RSV).

3.2 Turbine Control and Overspeed Protection

The DEH control system controls the flow of steam to the turbine and permits the selection of the desired turbine speed and acceleration rates. The primary speed channel and turbine first stage pressure are the primary inputs to the valve electronic controller which positions the main turbine control valves. If the turbine accelerates from its normal speed, the primary speed channel and servo valve on each main turbine control valve will rapidly reduce the oil pressure acting on the main turbine control valve servo-actuators. This causes the main turbine control valves to close until the turbine returns to normal speed.

Three additional overspeed protection controls are available to prevent overspeed.

First, the overspeed protection controller will activate with loss of load or at an overspeed setpoint depending on the load unbalance and will automatically open the solenoid valves that will drain the emergency trip oil (MTCV&IV) and cause the MTCVs and IVs to close.

Second, a mechanical overspeed trip valve, consisting of an eccentric weight, trigger, and a cup valve, will activate at an overspeed setpoint that does not exceed [ ], and the autostop oil will drain. This releases pressure on the diaphragm of the emergency trip valve (interface piston valve) which then opens and drains the emergency trip oils.

Third, an electrical overspeed trip mechanism consisting of a diaphragm and turbine trip solenoid valve will activate with system separation due to a generator trip signal. The turbine trip emergency valve drains the emergency trip oil (MTCV&IV) and emergency trip oil (MTSV&RSV) which causes the turbine valves to close. The solenoid valve is also activated by an overspeed signal of [ ].

In the event of a turbine trip prior to a generator trip, the opening of the generator output breakers is delayed for [ ] following turbine trip. During this period, the turbine is allowed to motor; and turbine speed is governed by grid frequency. The delayed generator trip usually results in negligible overspeed.

4.0 BASIS FOR ANALYSIS

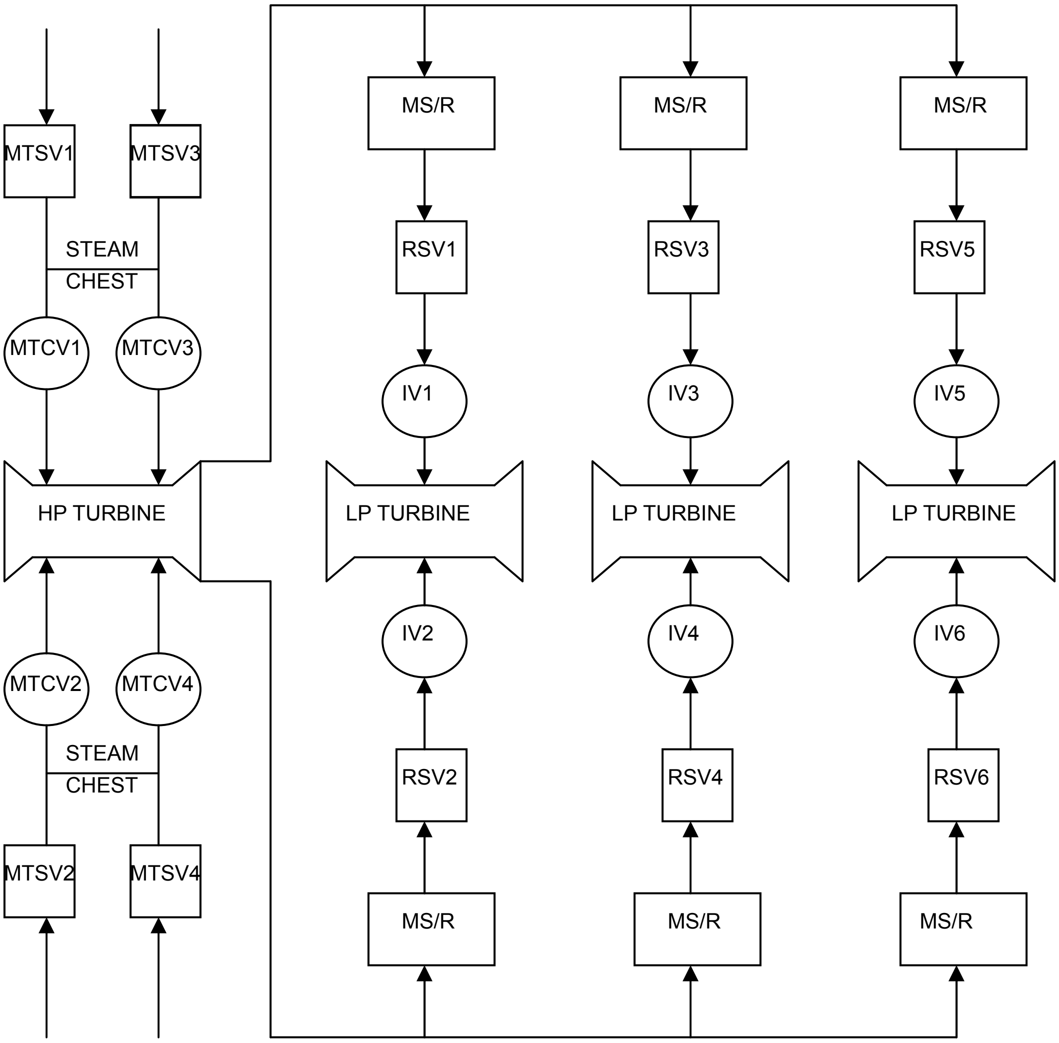
4.1 Turbine Valve Arrangement and Control Oil System

Figure 4.1-1 describes the turbine valving on the steam inflow lines to the high pressure turbine and the low pressure turbine.

The steam turbine for the US-APWR plant in the study has the DEH system. Appendix - A shows the applicable control oil system drawing.

The trip components were described in Section 3.0 of this report. Control oil system for the US-APWR steam turbine has a mechanical overspeed trip device and a cup valve which dump the autostop oil in a manner to close all the steam valves including MTSV, MTCV, RSV and IV. The dump of autostop oil causes an emergency trip valve (interface piston valve) to open, which dumps the emergency trip oil (MTSV&RSV) and emergency trip oil (MTCV&IV).

This system also includes two sets of overspeed protection control solenoid valves, either of which will dump the emergency trip oil (MTCV&IV).



Legend

MTSV:	Main Turbine Stop Valve
MTCV:	Main Turbine Control Valve
RSV:	Reheat Stop Valve
IV:	Intercept Valve
MS/R:	Moisture Separation/Reheater

Figure 4.1-1 Arrangements of Turbine Valves

4.2 Identification of Overspeed Events

Before discussing the type of overspeed events that are of concern in this study, it should be pointed out that turbine overspeed is sometimes planned for the purpose of testing overspeed trip mechanisms. Usually, test conditions are controlled so that the turbine speed reaches, but does not greatly exceed the overspeed trip setpoint of the turbine. This setpoint is in the range of [ ] of the rated speed. The risk of missile ejection at these low overspeeds is believed to be small and was not evaluated in this study. The current study focuses on overspeed events that occur inadvertently following a system separation or loss of load. These events generally involve system failure sequences causing overspeeds that approach or exceed the design overspeed of the turbine.

“Design overspeed”, “Intermediate overspeed” and “Destructive overspeed” were taken into consideration in this study.

The "Design overspeed" event is one in which the maximum speed of the turbine approaches but does not exceed an overspeed of [ ]. “Design overspeed” will be approached if the overspeed protection controller (OPC) or the MTCVs or IVs fail to function and the MTSVs and RSVs close after the turbine speed reaches the overspeed trip setpoint.

The following is a description of the basis for “Design overspeed”.

1. System separation occurs.
2. One or more MTCVs, or two or more IVs, fail to close immediately following loss of load.
3. Successful overspeed trip: the MTSVs and RSVs close.

“Intermediate overspeed” has been estimated to be [ ] above design overspeed. Generally, intermediate overspeed involves the failure to block the low pressure turbine. The failure of the RSVs and IVs to close at the overspeed trip setpoint results in a transfer of energy to the low pressure turbine for a longer duration than what occurs in design overspeed.

The following is a description of the basis for “Intermediate overspeed” for the turbine:

1. System separation occurs.
2. One or more alignments of RSV/IV remain open.

“Destructive overspeed” results from failure of one or more MTSVs to close and failure of one or more MTCVs downstream of the failed MTSV (in the same steam path). Destructive overspeed is on the order of [ ]. Failure of RSV or IV has no impact on this event. The following is an abbreviated description of the basis for “Destructive overspeed”:

1. System separation occurs.
2. One or more MTCVs fail to close.

3. One or more MTSVs, in the same steam path as the failed MTCV, fail to close.

4.3 Basis for Calculation of Missile Ejection Probability

The regular testing of turbine valves and the regular inspection of the low pressure turbine rotors are two effective ways of controlling and managing the risk of turbine missile ejection. The main goal of this study was to determine the probability of turbine missile ejection and the effect of the turbine valve test interval on this probability. Turbine valve testing affects only the probability of missile ejection resulting from overspeed of the turbine. Therefore, this study concentrated on missile ejection from overspeed.

Before discussing the basis for calculating the probability of missile ejection due to overspeed, it should be mentioned that all of the plants have a program of low pressure rotor inspection. In the deterministic program, the LP rotors are inspected and the time that it takes for a hypothetical crack in the rotor to grow to critical size (the crack size that is just large enough to result in rotor failure) is calculated. If the inspection indicates the presence of cracks, the inspection time is further reduced. [ ] is generally used as a deterministic basis for establishing the length of time before the next rotor inspection. This program effectively assures that the risk of missile ejection at running speed is very small because a very conservative criterion is used to establish the time interval to the next inspection.

The effect of varying the turbine valve test interval was evaluated by calculating the total probability of turbine missile ejection, P, for the three identified overspeed events. The formula used to calculate P is reproduced in Table 4.3-1 and is discussed in the following paragraphs.

The probability of missile ejection due to design overspeed is the product of the probability of design overspeed, P(A), and the conditional probability of missile ejection at design overspeed, P(M/A). In words, P(M/A) is the probability of ejecting a missile given that the turbine reaches design overspeed. A product of P(B) and P(M/B) results in the probability of missile ejection for the intermediate overspeed event. P(C) by itself denotes the probability of missile ejection for the destructive overspeed event because the conditional probability, P(M/C), is assumed to be one in the study.

P(M/A) was obtained from probabilistic reports on missile ejection from fully integral low pressure turbine rotors (MUAP-07028(R2), June 2013, “Probability of Missile Generation from Low Pressure Turbine”). It involves a calculation of the probability of failure of low pressure turbine rotors based on Mitsubishi Heavy Ind. Ltd. crack growth data, the stress generated at design overspeed, and the resultant critical crack size.

The probability of low pressure turbine rotor failure is broken into two parts: the probability that a crack initiates and the probability that the crack has grown beyond critical size after a certain interval of time.

Section 3.0 of MUAP-07028(R2), June 2013, “Probability of Missile Generation from Low Pressure Turbine” shows the probability of missile ejection depending on the inspection interval and concludes that the probability of a missile ejection for a full integral rotor with low yield strength is extremely low when the rotor rotating speed is suppressed under “Design overspeed” or “Intermediate overspeed”.

Based on the above discussion, it can be concluded that probability of P(A)*P(M/A) and P(B)*P(M/B) is negligibly small compared to P(C) in the case of a full integral rotor with low yield strength which will be applied to the US-APWR low pressure turbine rotor.

Section 5.0 of this report gives the detailed results of the evaluation of P for the various turbine valve test intervals.

Table 4.3-1 Basis for Calculation of P
(Resulting from Turbine Overspeed)

$$P = P(A)*P(M/A) + P(B)*P(M/B) + P(C)$$

Where:

P = annual probability of turbine missile ejection
P(A)= annual probability of design overspeed
P(B)= annual probability of intermediate overspeed
P(C)= annual probability of destructive overspeed
P(M/A)= conditional probability of missile ejection at design overspeed
P(M/B)= conditional probability of missile ejection at intermediate overspeed

4.4 Assumption (Basis for Analysis)

The assumptions below pertain to the basis for analysis.

- A failure sequence consisting of a failure of a MTCV and RSV/IV combination along with a failed-open MTSV bypass valve has not been analyzed because the probability of failure of four dissimilar valves is assumed to be very small.

- The design overspeed events are assumed to result in [ ] overspeed even though it is likely that the actual overspeed would be less. This gives additional conservatism to the analysis.

- P(A)*P(M/A) and P(B)*P(M/B) is negligibly small compared to P(C) and these probability factors can be regarded as zero(0).

5.0 FAILURE DATA AND ANALYSIS OF BASIC FAILURE PROBABILITY

5.1 Sources of Failure Data and Method of Analysis

The primary source of basic failure data in this report was from the operating experience of Mitsubishi heavy Ind. Ltd. nuclear steam turbine. A total of 23 nuclear units' data was used for this study.

The basic service experience data and years of service data is given in Table 5.1-1 and Table 5.1-2.

Table 5.1-1 Basic Service Experience Date in Japanese Nuclear Power Stations

Table 5.1-2 Years of Service for Units and Components in Japanese Nuclear Power Stations

5.2 Determination of Failure Rate of Each Component

Failure rate of each component including the main turbine stop valve (MTSV), MTSV control system, main turbine control valve (MTCV) and MTCV control system were obtained based on the following equation and the calculated results with 95% confidence are shown in Table 5.2-1 and Table 5.2-2.

Failure Rate : $\lambda(\alpha)/2$
$\lambda(\alpha)$: $X^2(\varphi,1-\alpha)/T$
X^2 : Chi square distribution
T : Accumulated operating hours
φ : Degree of freedom = $2f + 2$
f : Number of observed failures

Table 5.2-1 Failure Rate of Each Component [ ]

Table 5.2-2 Upper Limit Failure Rates

5.3 Determination of Annual Probability of Turbine Missile Ejection

According to the discussion in Section 4.0 in this report, probability of turbine missile ejection for the US-APWR was determined by the following equations.

Table 5.3-1 and Figure 5.3-1 demonstrates the calculated results showing the relationship between the annual probability of turbine missile ejection and the time interval of valve tests.

System Separation Rate, Q_{SS} is evaluated based on 23 Japanese PWR nuclear plant experiences.

Table 5.1-1 and 5.1-2 show the number of system separations that occurred during turbine on-load conditions and the accumulated operating hours of the 23 PWR units. This data leads to the conclusion that the probability of system separation during operation is [ ]. In order to make the evaluation conservative, ten (10) times the probability of the system separation above, [ ], is adopted in this evaluation.

$$\mathbf{P = N*2*(Q_{MTSV} + Q_{SC})*(Q_{MTCV} + Q_{CC}) *Q_{SS}}$$

P:	Probability of turbine missile ejection	1/Time Interval
Q_{MTSV}:	Failure rate of MTSV = $q_{MTSV}/2n$	1/Time Interval
Q_{SC}:	Failure rate of MTSV control system= $q_{SC}/2n$	1/Time Interval
Q_{MTCV}:	Failure rate of MTCV= $q_{MTCV}/2n$	1/Time Interval
Q_{CC}:	Failure rate of MTCV control system = $q_{CC}/2n$	1/Time Interval
Q_{SS}:	System Separation Probability	1/Time Interval
N:	Number of main steam pipes	-
n:	Number of valve tests per month	-
q_{MTSV}:	Failure rate of MTSV per month	per month
q_{SC}:	Failure rate of MTSV control system per month	per month
q_{MTCV}:	Failure rate of MTCV per month	per month
q_{CC}:	Failure rate of MTCV control system per month	per month

"Time Interval" denotes "Time Interval between Valve Tests".

Table 5.3-1 (1/3) Annual Probability of Turbine Missile Ejection [ ]

Table 5.3-1 (2/3) Annual Probability of Turbine Missile Ejection [ ]

Table 5.3-1 (3/3) Annual Probability of Turbine Missile Ejection [ ]

Figure 5.3-1 Annual Probability of Turbine Missile Ejection [ ]

6.0 CONCLUSIONS

The relation between the probability of turbine missile ejection and valve test frequency had been analyzed based on the past experience of loss of load, valves/control system failure in nuclear power station operation. The result of this analysis is graphically shown in Figure 5.3-1 in this document and shows that [ ] is satisfactory to limit the turbine missile ejection probability to equal or less than 1.0E-5 per year.

Missile ejection probability is conservatively obtained in a manner that the probability of system separation, which is one of the major factors to determine the probability of missile ejection, is ten (10) times larger than that of statistics in the past. The [ ] is therefore short enough to secure the valve failure rate to equal or less than 1.0E-5 per year, which means that a longer valve test interval could be adopted depending on the user's requirement.

Appendix – A Control Oil Diagrams