

Reliability-centred Maintenance and HAZOP

– Is there a need for both?

Phil Clarke and Stephen Young
The Asset Partnership Pty Ltd
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1 Introduction

Hazard and operability (HAZOP) analysis has a well-deserved reputation for systematic and thorough evaluation of industrial hazards. Organisations can easily justify process hazard analyses on the basis that the safety, environmental, and economic benefits of finding and correcting process weaknesses through HAZOP far outweigh their cost.

The recent development of a maintenance and reliability focus is in response to the recognition of the business benefits of organized approaches to maintenance programs. The leading maintenance strategy development tool is Reliability-centered Maintenance (RCM), where a structured decision logic is applied to the outputs of a Failure Modes and Effects Analysis (FMEA). This technique has been shown to significantly improve plant safety, reliability, and maintenance cost-effectiveness.

The two approaches have similarities to the extent that duplicated effort produces complimentary results.

This brief paper explains how, through the inclusion of some the aspects of HAZOP into an FMEA/RCM analysis, the aims of both analysis processes can be essentially satisfied with the minimum of effort.

2 HAZOP

In the 1960s, a form of “what-if” analysis was developed within ICI, and its application first became known as “Operability and Hazard Studies” and later “HAZOP”. The process had great success in identifying credible incident scenarios which had, or would have had, a significant impact on safety and operational capability.

HAZOP analysis is typically performed by review teams applying an agreed set of ‘guide words’ to identified system elements to identify possible deviations. Typical guide words would be NONE, MORE, LESS, AS WELL AS, REVERSE, BEFORE, AFTER, EARLY, LATE, etc. Possible causes and consequences of the deviation are then identified, along with any safeguards that may exist. Any actions that are required (such as design changes, need for procedures, etc) are then identified and responsibility for them assigned. HAZOP studies are best conducted during the detailed design phase of the system life cycle.

The HAZOP review team must have a detailed understanding of the system being analysed, and is typically made up of operators, designers, technical specialists, and maintainers in addition to the HAZOP facilitator. Users of the HAZOP process universally believe they learn a lot about their plants through its application.

For most HAZOP studies, 50-60% of the recommendations are intended to address product quality or plant operability issues, and not specifically safety or environmental concerns. The driving benefit is for engineering design teams to identify potential problems on paper during design, rather than in the field during startup.

The typical format and content of the output documentation of a HAZOP study conducted in accordance with AS IEC 61882 is shown on the following page.

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STUDY TITLE: PROCESS EXAMPLE								SHEET: 2 of 4		
Drawing No.:			REV. No.:			DATE: December 17, 1998				
TEAM COMPOSITION:			LB, DH, EK, NE, MG, JK			MEETING DATE: December 15, 1998				
PART CONSIDERED:			Transfer line from supply tank A to reactor							
DESIGN INTENT:			Material: A Source: Tank for A		Activity: Destination: Reactor		Transfer continuously at a rate greater than B			
No.	Guide word	Element	Deviation	Possible causes	Consequences	Safeguards	Comments	Actions required	Action allocated to	
4	MORE	Transfer A	More transfer Increased flow rate of A	Wrong size impeller Wrong pump fitted	Possible reduction yield Product will contain large excess A	None		Check pump flows and characteristics during commissioning Revise the commissioning procedure	JK	
5	LESS	Material A	Less A	Low level in tank	Inadequate net positive suction head Possible vortexing and leading to an explosion Inadequate flow	None	Unacceptable Same as 1	Low-level alarm in tank Same as 1	MG	
6	LESS	Transfer A. (at rate >B)	Reduced flow rate of A	Line partially blocked, leakage, pump under-performing, etc.	Explosion	None shown	Not acceptable	Same as 2	JK	

Source AS IEC 61882

3 Typical HAZOP Outputs

The typical outputs of a HAZOP analysis include:

- Identification of possible deviation states
- Identification of the possible causes for deviations
- Probable worst case consequence
- Documentation of existing safeguards
- Action required to reduce the risk
- Allocation of action to an individual or group

4 General comments on HAZOP

HAZOP studies can include recommendations for the inclusion of protective devices or procedures to prevent a hazardous situation from arising. Typical solutions include design changes such as the addition of high-high level switches, high pressure switches etc. In short, the HAZOP analysis tends to address risk issues through the addition of protective devices to initiate some action to avert the consequences.

It is our experience that HAZOP analyses do not necessarily address the possibility of the installed projective devices failing to operate as intended nor is there a methodology within a HAZOP analysis to develop a rigorous and defensible strategy for managing the reliability of protective devices, or indeed the reliability of the process equipment at all.

HAZOP is a very sound tool to identify operational risks within a plant but is unable to provide a robust framework for the development of strategies to manage those risks. As a result, most of the risk management strategies migrate towards the inclusion of further technology.

5 Reliability-centered Maintenance

Reliability-centred Maintenance (RCM) was developed in the aviation industry in the late 1960s as the outcome of a study into the inability of traditional maintenance programs to effectively manage aircraft reliability. The process is now applied throughout industry.

Today's RCM approach is to focus on a defined system using a multidisciplinary team of people including a facilitator, operators, craftsmen, and other specialists as required. The team:

- Defines the operating context of the system, including a description of what the system does and a list of the equipment within the system
- Defines all the functions of the system including primary functions, secondary functions (e.g., containment, contamination prevention, protection, economy, efficiency, support, appearance, environment), and protective functions (e.g., alarms, interlocks, devices for relieving abnormal conditions)
- Lists all the failure modes and effects for each function

- Uses a decision diagram to guide the decisions on how to maintain the function of the equipment in the most sensible manner to minimize the risk of equipment failure or process malfunction.
- For equipment failures which can not be prevented from failing, appropriate strategies are developed to minimize the impact of failure.

The system's Functions, Functional Failures, Failure Modes, and Failure Effects are defined in a Failure Modes and Effects Analysis (FMEA), to which the RCM decision logic is then applied.

As a result, the resultant risk management strategies depend not only on the failure characteristics of the maintainable item, but also on the consequences of the failure in terms of operational performance measured in cost, product quality and customer service but also on safety and environmental impact.

The RCM process is unique in the manner in which it both recognizes and manages hidden failures¹. Many components, particularly protective devices can fail in such a way that no one knows that the item has failed. These failures are known as hidden failures and the failure has no consequence until some other failure also occurs which requires the device to operate. Examples of hidden failures include:

- A relief valve that has an internal fault such that it will stick open when activated
- A high-high level switch (the process normally never reaches the high-high level, so there is no way to tell if the switch works without testing it)
- A low oil pressure trip (oil pressure is not normally low, so you must test the switch to confirm that it works)

As a result, an RCM analysis could determine that identical components in the same system should be maintained differently because the failure consequences of the components are different.

A typical analysis identifies all the maintenance and operational tasks required to achieve an agreed standard of performance in a complete and logical manner. The outcomes may also identify the need for new procedures and plant modifications.

An almost universal outcome of the analysis is that the RCM team learns an incredible amount about the system that is being analysed and as a result the process is especially helpful for complex systems that are difficult to understand.

The multidisciplinary team unites operations, maintenance, and engineering and meetings develop an understanding of the role of each other group in the overall plant operation effort.

The typical outputs of a RCM analysis in accordance with SAE JA1011 are shown in the FMEA and RCM Decision Worksheet on the following pages.

¹ A recent example of the consequences of a Hidden Failure was the failure of a high level shut off switch on an overflowing unleaded petrol storage tank at the Buncefield Oil Depot (UK) on 11 December 2005. Petrol continued to overflow from the tank at an initial rate of 550m³/hr and subsequently 850m³/hr when the main take level measuring device stuck at two thirds full. The resultant explosion when the petrol vapour cloud found an ignition source in a nearby car park was heard over 30km away and destroyed much of the fuel depot and destroyed or damaged buildings over many kilometres radius. The depot fire took days to extinguish, and was the largest in Europe since the end of World War II. (Reference www.buncefieldinvestigation.gov.uk)

Reliability-centred Maintenance and HAZOP

RCM II
INFORMATION
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SYSTEM	Southwest water reticulation system	No. 0	Compiled by TAP	Date 04-Jul-05	Sheet 1
SUB-SYSTEM	North East Pipeline	Ref. AC Pipeline	Reviewed by MCW	Date	of 3

FUNCTION	FUNCTIONAL FAILURE	FAILURE MODE (Cause of failure)	FAILURE EFFECT (What happens when it fails)
1 To supply a 'Normal' service connection with potable water (to ADWG std) at a flow rate of not less than 0.06 litres per second at a pressure not less than 120 kpa through AC pipe to a section that can be isolated to less than 20 services	A Unable to supply at all	1 Material failure due to manufacturing fault	Failure occurs under normal operation of the pipeline and would reduce the useful life of the asset. May be indicated by a small leak. Failure results in loss of supply to up to 20 normal services. Downtime to repair 8 hours at a cost of \$8000
1	A	2 Pipeline corrodes to the point of failure	Failure occurs under normal operation of the pipeline and would reduce the useful life of the asset. Failure results in loss of supply to up to 20 normal services. Downtime to repair 8 hours at a cost of \$8000
1	A	3 Pipe line crushed when external load exceeds design	Failure occurs under normal operation of the pipeline and would reduce the useful life of the asset. Failure results in loss of supply to up to 20 normal services. Downtime to repair 8 hours at a cost of \$1,000
1	A	4 Pipeline fails from fatigue during normal operation	Failure occurs under normal operation of the pipeline and would reduce the useful life of the asset. Usually ruptures with without warning but usually in response to a change in system pressure or cyclic external forces. May be indicated by a small leak. Failure results in loss of supply to up to 20 normal services. Downtime to repair 8 hours at a cost of \$8,000

Reliability-centred Maintenance and HAZOP

RCM II Decision Worksheet

RCM II
DECISION
WORKSHEET
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SYSTEM	Southwest water reticulation system	No.	Compiled by TAP	Date <i>04-Jul-05</i>	Sheet 1
SUB SYSTEM	North East Pipeline	Ref. <i>AC Pipeline</i>	Reviewed by MCW	Date	Of 1

Information reference			Consequence evaluation				H1 S1 O1 N1	H2 S2 O2 N2	H3 S2 O2 N2	Default tasks			Proposed Task	Initial Interval	Can be done by
F	FF	FM	H	S	E	O			H4	H5	S4				
1	A	1	Y	N	N	Y	N	N	N				NSM A response to leak within 2 hours will minimize occurrences	Per event	Response Grp
1	A	2	Y	N	N	Y	Y						Monitor pipe condition during maintenance work and replace as necessary	Per event	Response Grp
1	A	3	Y	N	N	Y	N	N	N				Redesign. Correct installation and modification to appropriate standards ate the time of load changes		Site Controller
1	A	4	Y	N	N	Y	Y						Monitor the condition of the pipeline and replace whole pipeline when incidents of fatigue failure increase by more than 10% in any year	1 Year	Construction
1	A	5	Y	N	N	Y	N	N	N				Redesign. Respond to incidents as they occur. Educate other utilities to obtain service locations		Response Grp
1	A	6	Y	N	N	Y	N	N	N				NSM. Respond to report of leak within 2 hours. Monitor the pipeline in that area. Maintain AC as priority replacement		
1	A	7	Y	N	N	Y	Y						Manage tress affecting pipeline	1 Year	Site Controller
1	A	8	Y	N	N	Y	N	N	N				No known failures		
1	A	9	Y	N	N	Y	N	N	N				No known failures		
1	A	10	Y	N	N	Y	N	N	N				Correct repair in accordance with procedure 2735 will prevent failure		
1	A	11	Y	N	N	Y	N	N	N				Redesign. Provide training on the correct operation of the system by operators, contractors and other utilities		
1	A	12	Y	N	N	Y	N	N	N				NSM		
1	B	1	Y	Y			Y						Monitor system water for asbestos and raise WO for pipeline replacement when level rises by more than 3% in a year	1 Year	Technician
1	B	2	Y	N	N	Y	N	Y					Test water for algae and flush as required	2 weeks	Response Grp

6 Typical RCM Outputs

The typical outputs of a Reliability-centred Maintenance analysis include:

- Listing of the functions the system and subsystems must perform
- Identification of the failed states including 'too much', 'too little' and 'not at all'
- Identification of the possible causes of the failed states including failures which have occurred before, failures which are the subject of the current maintenance regime (and so may have been prevented) and those failures which are thought to be possible under the operating context
- Probable worst case effect of the failure
- Allocation of the failure into the grouping of Hidden, Safety or Environmental, Operational and Non-operational
- Determination of the most appropriate failure management strategy including frequency and responsibility
- Determination of the most appropriate consequence mitigation strategy if the failure can not be prevented
- Determination of process, plant, operational or maintenance redesigns to reduce risks, costs or consequences

7 General comments on RCM

A significant proportion of RCM recommendations are for the management of protective devices used to identify operational problems, which if left undetected would result in a serious hazard.

SAE JA 1011 compliant RCM rigorously assesses the possibility of projective devices failing to operate as intended and develops a function check of these devices based on a proven algorithm considering the probability and consequences of failure. Further, RCM uses a rigorous, defensible and auditable process for developing the most appropriate strategy for managing the reliability of assets.

RCM is a very robust tool with a proven track record for the management of operational risk.

FMEAs can be either component or system based, and the modern evolution of RCM as developed by John Moubray, uses a process based functional FMEA analysis. RCM II clearly identifies the process functions and the failures which can affect the performance of that process. Identified failures include equipment malfunction, equipment degradation, human error and inappropriate or incorrectly designed or installed plant.

The RCM II process then seeks to find the most appropriate method to manage each one of those risks.

8 Similarities between HAZOP and RCM

As Table 1 below illustrates, there are a great many similarities between HAZOP and RCM processes, and an organization completing both studies will incur a considerable expense in essentially duplicated effort and resources.

However, as a review of the outputs of each process indicates, the completion of a HAZOP analysis does not provide the benefits of an RCM analysis. On the other hand, the completion of an RCM II analysis essentially produces the outputs of a HAZOP analysis.

Table 1 – Comparison of HAZOP and FMEA/RCM

Activity or Outcome	HAZOP	RCM	Comment
Project definition and planning	Yes	Yes	The objectives and scope of the study are defined, and potential team members identified.
Detailed preparation and planning	Yes	Yes	All design and other documentation relating the analysis are gathered, including PIDs, drawings, operating and maintenance manuals, etc. Functional breakdown and defining of system boundaries for analysis, estimation of duration, and development of analysis schedule are also performed.
Training for team members	Yes	Yes	The Aladon RCM II training course has been delivered and developed in over the last 20 years in more than forty countries and is widely regarded as setting the benchmark in SAE JA-1011 compliant RCM training.
Team comprises operations and maintenance people working together	Yes	Yes	Both processes use people who know the process best including operations and maintenance people and technical specialists as required
Analysis managed by highly trained Facilitator	Yes	Yes	The facilitator in both cases needs to have a comprehensive understanding of their methodology and be able to facilitate the analysis group.

Reliability-centred Maintenance and HAZOP

Activity or Outcome	HAZOP	RCM	Comment
Documentation of the plant process	Yes	Yes	<p>The Failure Modes and Effects Analysis (FMEA) of the RCM II analysis is functionally based and therefore documents how the users intend the plant to operate. The process documents the failed states and captures all likely failure modes, including those which may be operator induced those which result from the failure or degradation of plant components and failures which are the result of the plant's inability to perform as required, i.e. design errors.</p> <p><i>Note: IEC 61882 standard suggests in paragraph 5.2 that FMEA is a component based analysis (as described in IEC 60812) and hence can not be used for process analysis. However, FMEA (and FMECA) can be functionally based, as described in other widely used standards such as MIL-STD-1629(A) and therefore can also be process based. The FMEA used in an RCM II analysis is functionally based, not component based.</i></p>
Documentation of the ways in which the plant can fail	Yes	Yes	<p>The RCM process does not formally use the HAZOP style guide words for defining Functional Failures. However, Functional Failures describe the failed states of the system in the same manner, and guide words can be used.</p>
Documentation of the possible failure modes	Yes	Yes	<p>HAZOP lists failure modes to cover human error and process error and groups failure modes which result in a common effect together, e.g., pump impeller worn, pipe work partially blocked, leakage etc</p> <p>RCM lists all likely failure modes including human error and keeps failure modes with common effects separated to allow failure management policies to be developed.</p>

Reliability-centred Maintenance and HAZOP

Activity or Outcome	HAZOP	RCM	Comment
Documentation of failure consequences	Yes	Yes	<p>In RCM terms, HAZOP uses free text and the Facilitator to define the Failure Effects.</p> <p>The RCM FMEA uses free text to describe the failure symptoms and the effort needed to correct the failure and secondary damage. (Called Failure Effects). Failure consequences are later defined by the RCM decision logic as Hidden, Safety/Environmental, Operational, Non Operational. Failure management strategies are developed according to the failure consequences</p>
Identification Safeguards	Yes	Yes	<p>HAZOP utilizes a column on the worksheet to document any safeguards for a particular hazard. In FMEA/RCM, safeguards are documented in the Failure Effects column to ensure the analysis team is aware of the safeguards during the development of risk management strategies.</p> <p>RCM includes safeguards as a function eg, "To provide an alarm in the event the pressure exceeds 250kPa".</p>
Development of design change recommendations to address process shortfalls	Yes	Yes	
Development of risk management (maintenance) strategies	No	Yes	<p>RCM takes to conclusion the development of strategies to manage the identified risk. Strategies include the proactive maintenance tasks of On Condition Maintenance, Scheduled Restoration and Scheduled Discard. In the event the failure can not be prevented, management strategies work to minimize the failure consequences including Failure Finding and Redesign. No Scheduled Maintenance is an option for failures where the failure of the component or asset is tolerable</p>

Reliability-centred Maintenance and HAZOP

Activity or Outcome	HAZOP	RCM	Comment
Development of maintenance task intervals based on risk and consequence	No	Yes	RCM utilizes a robust process to define the most appropriate management strategy based upon the failure characteristics. In the event a failure can not be prevent by a proactive task and the failure has hidden consequences, the interval for the functional check of the device is determined based upon a mathematical equation linking risk and consequence. Risk is determined by the demand rate for the device and the probability the item will be in failed state when required
Document actions required	Yes	Yes	HAZOP defines the task required to correct the failed state from an operational perspective RCM defines the task and frequency of the task to ensure the function of the asset is maintained, be it operational, maintenance, engineering redesign, operational procedures, training, etc
Task allocation	Yes	Yes	
Development of asset maintenance strategies	No	Yes	
Development of Fault Finding Guide	No	Yes	RCM utilizes the Failure Effects information to populate a key word symptom driven fault finding guide

9 Changes to an RCM analysis to generate acceptable HAZOP outputs in addition to traditional RCM analysis outputs

As illustrated in Table 1, there is a great deal of commonality between the HAZOP and RCM processes from the manner in which they are applied, the types of people included on the teams through to the information collected and documented.

The most significant difference occurs with the decision making process within the RCM Decision Logic for developing the most appropriate risk management strategies.

Accordingly, it is considered that with some minor alignment of wording used during the FMEA stage of the RCM analysis, the requirements of both processes can be satisfied with a minimum of effort and a significant saving in time, effort and documentation.

It is considered there are two areas where a minor alignment of wording and emphasis should be applied, namely:

- **RCM II Functional Failures and the use of HAZOP guide words**

The guide words used within HAZOP have very similar intent to the description of Functional Failures within RCM II.

For example, functional failures in RCM II can define the failed states in terms of:

- Too Much (pressure/ temperature/ flow/ contamination/ mixing/ etc)
- Too Little (pressure/ temperature/ flow/ contamination/ mixing/ etc)
- Not at all (No pressure/ temperature/ flow/ contamination/ mixing/ etc)

For example, a Function for a heat exchanger might be:

“To maintain the temperature of the process fluid between 38°C and 42°C”

This defined the operation or process parameters for the asset and ensures the focus of the team and the actions recommended by the analysis teams is aimed at ensuring the asset continues to function.

Accordingly, the failed states, i.e. the Functional Failures would be:

- A. Unable to control the temperature at all
- B. Unable to heat the process fluid above 38°C
- C. Unable to cool the process fluid below 42°C

The standard RCM II process therefore satisfies the general intent of the HAZOP guide words. However, by applying the RCM II process using the recognized HAZOP guide words the HAZOP intent is even clearer and the RCM II process not compromised.

The HAZOP 'possible causes' of the failed states are listed in an RCM II analysis as Failure Modes.

In Table 2, adapted from IEC 61882 we have included a further column on the right hand side to illustrate the type of wording which could be used to define the failed states in accordance with both SAE JA1011 and IEC 61882.

Other key words which may be appropriate to define process Functional Failures are as follows:

- Insufficient Flow/Pressure (Too little)
- No Flow/Pressure (Not at all)
- Too Much Flow/Pressure (Too much)
- Intermittent Flow/Pressure (Too little)
- Adversely Affected Fluid (Too much/Too little/Not at all)
- Can not operate at the required duty cycle (Too much/Too little/Not at all)

Table 2 – HAZOP Guide Word and RCM FMEA Functional Failures

Derivation	Guide Word	Example interpretation from process industry	Example interpretation for a Programmable Electronic System PES	RCM II Typical Functional Failure Wording (in response to appropriate Function definition)
Negative	No	No part of the intention is achieved e.g. no flow	No data or control signal	Unable to provide flow at all
Quantitative modification	More	A quantitative increase e.g. higher temperature	Data is passed is passed at a higher rate than intended	Temperature greater than "x" deg C
	Less	A quantitative decrease e.g. lower temperature	Data is passed at a slower rate than intended	Temperature less than "y" deg C
Qualitative modification	As well as	Impurities present Simultaneous execution of another operation/step	Some additional or spurious signal is present	Allows product contamination Enables simultaneous operation of plant process
	Part of	Only some of the intention is achieved, i.e. only part of an intended fluid transfer takes place	The data or control signals are incomplete	Unable to complete fluid transfer within "x" minutes
Substitution	Reverse	Covers reverse flow in pipes and reverse chemical reactions	Normally not relevant	Allows reverse flow in pipework
	Other than	A result other than the original intention is achieved, i.e. transfer of wrong material	The data in control signals are incorrect	Allows wrong material to be transferred

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Derivation	Guide Word	Example interpretation from process industry	Example interpretation for a Programmable Electronic System PES	RCM II Typical Functional Failure Wording (in response to appropriate Function definition)
Time	Early	Something happens early relative to clock time, e.g. cooling or filtration	The signals arrive too early with reference to clock time	Initiates cooling too early
	Late	Something happens late relative to clock time, e.g. cooling or filtration	The signals arrive too late with reference to clock time	Initiates cooling too late
Order or sequence	Before	Something happens too early in a sequence, e.g. mixing or heating	The signals arrive earlier than intended within a sequence	Initiates mixing too early
	After	Something happens too late in a sequence, e.g. mixing or heating	The signals arrive later than intended within a sequence	Initiates mixing too late

- **Documenting Safeguards and Criticality within and RCM II analysis**

The RCM process as defined by SAE JA1011 does not require the allocation of a criticality ranking or the listing of existing safeguards in a rigorous manner.

However DEF STAN 02-45, of the UK Ministry of Defence standard recommends the inclusion of a criticality ranking to aid the decision making process on which hazards to address first.

The generation of a criticality ranking is a combination of the Probability of Occurrence (POC) and Consequence of the failure. POC is a simple scale of A to E ranking Probable through to Improbable. Consequence is again a scale of 1 to 4 ranking from catastrophic to negligible. Using a simple five by four matrix, the Criticality Ranking can be determined.

Closely linked to criticality, Safeguards within the HAZOP process provide information to the analysis team to determine, in an imprecise manner, the criticality ranking with the assumption being that a safeguard is in place then the consequences should be less and the probability of the failure reaching worst state condition reduced.

Within RCM II there is no field provided for the documentation of either criticality or safeguards. However, by utilising the DEF STAN 02-45 Failure Effects format, the following is a guide to the Failure Effects description:

- Criticality
- Local Effect
- Next Higher Effect
- End Effect
- Compensating provisions/Safeguards
- Alarms
- Actions (to restore the function)

For example, the failure of a turbine over speed trip on a steam turbine might result in the following Failure Effect.

- **Criticality:** Medium
- **Local Effect:** In the event of a generator trip and the failure of the speed control system the turbine will run into over speed
- **Next Higher Effect:** May result in the explosive failure turbine
- **End Effect:** Destruction of the turbine and rupture of the turbine casing. May result in serious injury to personnel within 30 metres of the turbine
- **Compensating provisions/Safeguards:** Two stage over speed alarm system provides for audible warning of 5% over speed and boiler shut down and blow off at 15 % over speed
- **Alarms:** Generator trip, over speed alarm, then boiler shut down alarm, plus audible steam release to atmosphere as boiler pressure is vented
- **Actions (to restore the function):** Replace turbine and repair turbine hall. Cost \$35 million plus cost of 3 month's lost generation

10 Conclusion

As illustrated within this paper, there is a great similarity between the HAZOP and the preliminary stages of an RCM II analysis. The sequential application of HAZOP and RCM analyses within an organization therefore wastes precious resources for no benefit.

It is clear that with a very subtle modification of the RCM II process, the information can be collected and the decisions made which will satisfy the requirements of HAZOP but a HAZOP in isolation is unable to generate the same outputs as an RCM II analysis.

11 References

- 1 AS IEC 61882 – 2003 Hazard and operability studies (HAZOP Studies) Application guide
- 2 IEC 61882 -2001 Hazard and operability studies (HAZOP Studies) Application guide
- 3 IEC 68102 – 2nd ed 2006-01 Analysis techniques for system reliability –Procedure for failure modes and effects analysis (FMEA)
- 4 MIL STD 1629A Procedures for performing and a Failure Modes, Effects, and Criticality Analysis.
- 5 Def Stan 02-45 Requirements for the Application of Reliability-Centred Maintenance Techniques to HM Ships, Submarines, Royal Fleet Auxiliaries and other Naval Auxiliary Vessels (Category 2)
- 6 Victoria Worksafe Guidance Note – Major Hazard Facilities Regulations – Guidance Note GN-13 – Hazard Identification
- 7 Reliability-centred Maintenance II – John Moubray
- 8 Safety and Reliability: A synergetic Design Approach. Paper from 5th Biennial Process Plant Safety Symposium, American Institute of Chemical Engineers, 2001, Houston, Texas
- 9 Putting the “OP” back in HAZOP – Paper from Maintech South 98 Conference and Exhibition, Houston, Texas
- 10 Paper, Blending HAZOP and RCM Part III and Part IV C&K Management Limited