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RAMI Modeling of Plant Systems for Proposed Tritium Production and Extraction Facilities

by

A. Blanchard

Westinghouse Savannah River Company
Savannah River Site
Aiken, South Carolina 29808

D. S. Cramer

J. A. Radder

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RAMI MODELING OF PLANT SYSTEMS FOR PROPOSED TRITIUM PRODUCTION AND EXTRACTION FACILITIES

J. A. Radder and D. S. Cramer

Introduction

The control of life-cycle cost is a primary concern during the development, construction, operation, and decommissioning of DOE systems and facilities. An effective tool that can be used to control these costs, beginning with the design stage, is called a reliability, availability, maintainability, and inspectability analysis or, simply, RAMI for short. In 1997, RAMI technology was introduced to the Savannah River Site with applications at the conceptual design stage beginning with the Accelerator Production of Tritium (APT) Project and later extended to the Commercial Light Water Reactor (CLWR) Tritium Extraction Facility (TEF) Project. More recently it has been applied to the as-build Water Treatment Facilities designed for ground water environmental restoration.

This new technology and database was applied to the assessment of balance-of-plant systems for the APT Conceptual Design Report. Initial results from the Heat Removal System Assessment revealed that the system conceptual design would cause the APT to fall short of its annual production goal. Using RAMI technology to immediately assess this situation, it was demonstrated that the product loss could be gained back by upgrading the system's chiller unit capacity at a cost of less than $1.3 million. The reclaimed production is worth approximately $100 million.

The RAMI technology has now been extended to assess the conceptual design for the CLWR-TEF Project. More specifically, this technology and database is being used to translate high level availability goals into lower level system design requirements that will ensure the TEF meets its production goal. Results, from the limited number of system assessments performed to date, have already been used to modify the conceptual design for a remote handling system, improving its availability to the point that a redundant system, with its associated costs of installation and operation, may no longer be required. RAMI results were also used to justify the elimination of a metal uranium bed in the design of a water cracker system, producing a significant reduction in the estimated construction and operating costs.

A preliminary RAMI assessment of round Water Treatment Units (WTU) was performed to determine how well the installed facilities will meet the established goal for availability. Recommendations have been made to ensure that the availability goal can be achieved, as well as provide an additional margin of availability for unexpected contingencies.

A RAMI analysis is most effective when incorporated during the early stages of a system design process. Early recognition of potential system problem areas allows corrective actions to be taken at a time when there is minimum impact on cost, schedule and other systems. Once a system has been fielded, improvements in facility design to improve performance are more likely to incur expenses that could have been avoided if a RAMI analysis had been provided in the design stage. A RAMI analysis of a facility can be used to:

- establish the requirements for reliability, availability, maintainability and inspectability at the subsystem and component levels
- influence the level of design redundancy
- estimate the contribution to life cycle costs from maintenance (e.g. spares, replacements, availability of personnel, etc.), and inspection (e.g. predictive maintenance technologies).
- translate RAMI results into system requirements for the construction and operation phases.
- model components that are in a stand-by condition with approximations in lieu of more detailed Markov models that model asymptotic conditions.
- determine strategies for lowering component failure rates.
- evaluate the impact of improved programs for preventive maintenance and inspection
- estimate the contribution of maintenance (e.g. spares, replacements) and inspection (e.g. predictive maintenance technologies) to life cycle cost.
- identify system sensitivities to RAMI input uncertainties.
- identify areas for potential technology development.

The availability of a facility is estimated using a mathematical model that incorporates the basic RAMI inputs, Mean Time between Failures (MTBF) and Mean Time to Restoration (MTTR), for each system component modeled. If the overall availability goal is met for the facility, then the values used for the MTBF and MTTR for the system components can become required specifications in purchasing, installing, operating, maintaining, or inspecting these components. Typically, initial MTBF and MTTR values for component availability are taken from historical data. However, these values are often adjusted to better represent any atypical conditions that may be anticipated, or intentionally implemented. If the overall availability goal for the facility cannot be met, then the design of the systems must be reviewed for possible improvements obtained by combinations of the following: component redundancy or programs for maintainability and inspectability that effectively increase component MTBFs or decrease MTTRs. It should be noted these adjustments do not necessarily represent a complete set of possible solutions. Other factors that can be important include matching of process flow through different systems in the facility, or the working conditions and procedures for operating personnel. Often a graded approach can be taken where more stringent requirements on MTBF and MTTR are imposed on only a limited number of critical components to achieve the required availability.

Tritium Extraction Facility (TEF) Project

The Commercial Light Water Reactor (CLWR) Tritium Extraction Facility (TEF) is in the conceptual design phase of development and a RAMI plan has been developed for the facility. The purpose of this RAMI plan is to establish initial, high level availability goals and requirements for the conceptual design that will enable the CLWR-TEF to meet the proposed tritium production goal. The TEF consists of the following systems and subsystems:

Remote Handling Area (RHA)

- Extraction Furnace
- Furnace Extraction and Water Cracker System
- Target Rod Preparation Module
- Master-Slave Manipulator Alternative
- TPBAR Transport Module
- Overpack Transfer Frame
- Module Stripper Connections and Filters
- Remote Handling Area Crane System
- Cask Handling System
- RHA Shield Doors

Balance of Plant (BOP)

- Heating Ventilation and Air Conditioning System
- Process and Building Chilled Water System
- Normal Electric Power System
- Liquid Nitrogen System
- Inert Gas System

Tritium Processing Area (TPA)

- Z-Bed Recovery System
- Glovebox and Purge Stripper Systems
- Module Stripper and Purge Systems
- Mass Spectrometer System
- Flow Through Bed System
- Product Evacuation (P-Evac) System
- Flush Gas Evacuation (FG-Evac) System
- Integrated Control System

FMEAs were performed for the following innovative system designs:

- Extraction Furnace
- Target Rod Preparation Module
- Master-Slave Manipulator Alternative
- TPBAR Transport Module
- Remote Handling Area Crane System

TEF RAMI Modeling and Assessment Process

In general, the RAMI effort is a series of process steps:

A. Estimate Overall TEF Availability Requirement

The overall availability budget is dictated by the annual production required. To estimate the total time or percentage of the calendar year required to produce this amount, an hourly tritium production rate will need to be assumed. The total annual production time is subtracted from the amount of time in a calendar year to obtain the allowable downtime, which is then divided between scheduled and unscheduled (corrective) maintenance. A rational estimate of the amount of time required for scheduled maintenance requires development of a maintenance plan. It is not a trivial endeavor and has not yet been performed. However, for preliminary analysis purposes, assumptions based on expert judgement will most likely be used to define the annual scheduled maintenance allocation. Typically, this consists of an annual scheduled outage of some weeks duration plus periodic scheduled shutdowns, lasting from hours up to days, during the remainder of the year.

Corrective maintenance is the term used to denote production shutdowns forced by random system failures that cannot be predicted or prevented by maintenance programs (e.g., PdM Programs). Probabilistic methods are used in the RAMI modeling process to estimate the expected value of time necessary for corrective maintenance. However, for the budget allocation process, an initial estimate of corrective maintenance will be made based on expert judgement. As the RAMI analysis progresses, this estimate will be refined based on iterations with the modeling results.

B. Allocate Top-Level Availability to TEF Segments

The top-level availability allocation presented above in A leads to an inherent system availability design requirement, which is the number of hours required for production divided by the number of hours scheduled. Inherent availability is the term used to denote the probability that the system will be operating when scheduled. Based on this top-level requirement, the inherent availability is allocated to each of the three lower-tier TEF segments using the following as a guide:

- For the initial allocation, the TEF segment(s) with the more complex systems are generally allocated a lower availability budget than those segments whose systems are not complex.

- Allocations should be based on the historical availabilities of similar systems in SRS facilities. For example, the 233-H Facility has systems that are similar to those contained in the TPA and BOP segments of the proposed TEF

- Expert judgement should be solicited in making the initial allocation, which is based on a top-down budget process. As results from the RAMI system models become known, the higher level segment availabilities are refined to reflect the knowledge from this bottoms-up budget process.

C. Develop RAMI System Models

The process begins by developing a mathematical model for each system contained in the TEF segments defined earlier. In this model, the system is represented as a collection of subsystems with each subsystem's availability calculated using the basic RAMI inputs, Mean Time To Failure (MTBF) and Mean Time To Restoration (MTTR). Appendix A of this plan presents the details on how this is done. In the present, conceptual phase of the TEF project, the MTBF and MTTR inputs are based on data from components that may be different from the actual components that will be used in TEF systems. Thus, if the system level parameters meet the desirable goals, they represent the required values that have to be met to achieve the associated TEF segment's availability budget. As a practical matter, they should be treated as component reliability, maintainability, and inspectability specifications that go into the System Design Descriptions (SDDs). If equipment vendors encounter difficulty in meeting the component specifications in an SDD, the system design will need to be reviewed for possible improvements such as redundancy. If this is not possible, the requirements will have to be revised, potentially placing an increased availability burden on other systems within the segment and, perhaps, other segments as well.

D. Roll-Up System and Segment Availabilities

Once all of the system availabilities have been estimated for a particular TEF segment in step C, they are rolled-up using a summation process to obtain an estimate of that segment's overall availability. This estimate is then compared to the segment's allocated availability value, which was established earlier in step B. If the estimate is greater than or equal to the allocation value, the estimate of availability becomes the segment's new allocation value. If the estimate is less than the allocation value, it is combined with estimated availabilities for the other two segments to determine whether the overall TEF availability allocation value, established in step A, is achieved. If the results from this determination prove negative, systems within the segment (having an availability less than the allocated value) are first identified and then evaluated for possible changes that would improve their availabilities. Changes that reflect design improvements are made to the RAMI models so that new system and segment availabilities can be estimated. This is an iterative process that continues until the top-level availability goal for the TEF is achieved.

E. Reliability

An MTBF value is provided for each component or module. This value can be either an MTBF for the actual component or an MTBF for a similar type component, where the MTBF is modified, based on engineering judgement, to account for any differences between the components or their service application. For example, the MTBF for a like component that sees no severe duty such as temperature or radiation, might be decreased by a factor of 5 to 10 to account for high temperature service combined with a radiation environment. It may also be helpful to perform a limited failure modes and effects analysis (FMEA) on a particular system that is not generally in common usage, in order to identify the likely failure modes prior to estimating the MTBFs.

F. Maintainability

An estimate of the MTTR is required to return a failed component or module to operable status. Considered in this estimate are the times required to: produce job work orders if not pre-written; perform pre-job tasks such as high-energy lockouts and radiation surveys; obtain spare parts, special tools, and qualified maintenance personnel; repair/replace the failed component(s); and perform any required post-maintenance testing. Also, when estimating the actual "wrench time", consideration should be given to such performance shaping factors as: component/module accessibility; whether or not this is a routine job that is done frequently; whether or not the work environment is harsh (e.g., high temperature, high radiation area) so that protective gear is required; and whether or not mockups are used for training in difficult or infrequently performed tasks.

G. Inspectability

Where applicable, the MTBF of a component or module may be effectively increased based on performing inspections such as those done in a predictive maintenance (PdM) program. As an example, a PdM program that provides periodic thermography inspections, combined with results trending, for rotating machinery might allow a facility to capture 75% of the incipient failures before they become disabling or catastrophic. In this case, capturing 75% of the rotating equipment failures is equivalent to increasing their MTBF by factor of 4 (i.e., only 25% of the failures are catastrophic). Other PdM examples might include: inspections of electrical equipment by thermography or transformer oil analysis; inspections of rotating machinery by vibration and lube oil analyses; and inservice inspections of components using ultrasonic testing (UT) to identify structural problems.

G. Special Considerations
Often because of immediate concerns regarding the value risk engineering portion of projects, it is necessary to use expert judgement to rank systems in decreasing order of perceived difficulty with respect to meeting any availability goal and the RAMI assessment performed in a graded approach.

Balance of Plant (BOP)

Normal Electrical Power Supply System
This BOP system supplies and distributes electrical power to systems and buildings within the boundary of the Tritium Extraction Facility (TEF). In general, the system consists of transformers, feeders, breakers, disconnect switches, switchgear, motor control centers, and 125 VDC power for the electrical supply system controls.

The system has an acceptable availability for the configuration with outdoor switchgear of 99.79%, whereas the availability for the configuration with indoor switchgear is 99.82%

Process and Building Chilled Water System
If any one of the three subsystems in the chilled water system becomes unavailable, the entire system is considered to be unavailable, resulting in a complete shutdown of tritium processing operations.

The Chiller Building ventilation accounts for the largest share of unavailability, because it is assumed that the chillers will be unavailable if either one of the ventilation fans fails to start or run during high ambient temperature months (May-September). The overall chilled water system availability could be slightly improved from 99.6 to 99.8% if there were a written administrative procedure in place that required portable fans to be brought into the Chiller Building, following a ventilation fan failure during high ambient temperature conditions.

Remote Handling Assembly

Remote Handling Assembly (RHA)
The segment availability allocations are 71.4% for Furnace Extraction and 38.3% for TPBAR Preparation. RAMI models were developed and quantified with the individual results rolled-up and compared against the allocation values for the above two segments. In all cases, the calculated segment availabilities based on the models exceeded the allocation values by a significant margin.

For the baseline system configurations, the Furnace Extraction and TPBAR Preparation segment availabilities were calculated to be 96.8% and 86.7%, respectively. Several alternative configurations were also examined, including one that eliminates a single uranium metal bed from the water cracker system and another that replaces the TRP Modules with MSM remote handling cells.

With one of the uranium metal beds eliminated from the water cracker system, availability of the Furnace Extraction segment decreases to 91.5%. However, this value is substantially higher than the required availability of 71.4% and represents an opportunity to reduce costs by removing a baseline item without impacting production goals. Trading out the two baseline TRP modules for two MSM remote handling cells increases TPBAR Preparation segment availability to 89.8%, and if the number of two MSM remote handling cells were reduced to one instead, the system availability would still be 88.3%. The MSM remote handling cells, as an alternative to the TRP modules, is advantageous because of the high uncertainty associated with developing a reliable TRP module (first-of-a-kind) that will be able to satisfy availability requirements.

Furnace Extraction Segment Models

Overall availability for the furnace extraction segment, using results from the baseline models, is 96.78%, which is higher than the required availability value of 71.4% by a significant margin. Therefore, the availability of two design alternatives were examined that could result in cost savings. The two alternatives are described below.

In Alternative 1, the availability decreases from 99.9% to 91.46%, which still exceeds the required allocation value by approximately 28 percent, as one of the three U-Beds in the furnace extraction and water cracker system is eliminated. Because details on U-bed performance are well known through site-specific experience, these availability estimates are made with a high degree of confidence. Therefore, a cost savings can be realized.

In Alternative 2, the availability is 87.77% for a single extraction furnace with a one year heating element life instead of two furnaces (baseline assumed 5 year element life). This achieves an availability that exceeds the required allocation value by greater than a 20 percent margin. Elimination of one furnace could result in significant cost savings.

TPBAR Preparation

Since required segment availability is exceeded in both the baseline and MSM alternative configurations noted above, a second alternative was considered for the purpose of identifying possible cost reductions without realizing a significant reduction in segment availability. In this alternative, the two baseline TRP Modules are replaced by just one MSM remote handling cell and one Overpack Transfer Module (OTM) is eliminated along with one Transport Module (TM). Segment availability for the second alternative is estimated to be 86.16%, which is nearly identical to that estimated for the baseline configuration. Consequently it is recommended that this alternative be investigated further as the overall RHA design evolves and more details become available.

Tritium Processing Area

The RAMI assessment for the Tritium Processing Area (TPA) determines how well the individual TPA systems meet their required availability goals, which are purposely assigned to ensure that the TEF meets its annual production goal. There are eight systems that make up the TPA.

Unlike the RHA and BOP of the Tritium Extraction Facility, a single top level availability goal could not be assigned to the TPA. Many of the TPA systems operate on a non-continuous basis because of batch processing requirements. As a result, individual availability goals for these systems cannot be integrated to yield a meaningful, overall goal that is representative of the TPA. Any discussion of requirements relating to TPA availability is then necessarily limited to a discussion of the individual system availability requirements.

With the possible exception of the Glovebox Stripper and FG-Evac Systems, all of the other TPA systems are expected to meet or exceed their required availability goals with margin. The situation for each of the two systems that has a potential availability deficit will be briefly covered in this presentation.

In the process of performing a RAMI assessment, several design weaknesses impacting availability can be discovered. For example, based on the current design of the Glovebox Stripper System, there is no direct connection between the high activity train and the Purge Stripper System. Consequently, the Glovebox Stripper is considered to be a one train system since pressure control for the high activity train is via the low activity train. What this means is that the high activity train cannot operate if the low activity train becomes unavailable. Results based on the RAMI models show that unscheduled downtime for the Glovebox and Purge Stripper Systems combined is approximately 60 hours per year. This corresponds to an availability of 99.3% for the current design, which is below the required goal of 99.9%. However, the RAMI assessment readily indicates that if the outlet of the high activity train were connected directly to the Purge Stripper System, model results indicate that unscheduled downtime would decrease from 60 to approximately 8 hours per year (a factor of 7). This proposed change would make the high and low activity trains truly independent of each other, and would provide margin that ensures that the system availability goal can be achieved.

For the FG-Evac System, it is not certain whether outgassing will require that one or two pumps be needed to maintain the vacuum when operating an extraction furnace. The RAMI assessment shows that if two are needed, the availability goal can only be achieved by adding a third "swing" pump to the existing design, increasing the total number of pumps to five to support two furnaces run concurrently. As an alternative solution, the extraction process availability goal can be achieved with the existing number of pumps if each pump were capable of handling 100% of the required pumping capacity. An engineering analysis or experimental data should be used to close the issue on the pumping capacity needed during all operating modes.

Except for the two stripper systems and the ICS, the other five TPA systems are expected to operate in a batch process mode, which means they will operate on an intermittent basis instead of running continuously like the other three. The interval between standby and run modes, including the length of time spent in each mode, can vary considerably from system to system. This does not allow a top level availability goal to be determined for the TPA segment, as was done for the BOP, because individual system availability goals cannot be easily integrated when the systems operate on different time schedules. In addition, certain TPA systems, such as P-Evac, have separate availability requirements for different parts of the system; i.e., the hydride beds are required to have a higher availability than the pump trains. This also makes integration of availabilities difficult. Consequently, the "availability goal" for the TPA segment is expressed in terms of the individual system availability goals that are developed and presented in each system's availability model section.

Zeolite Bed Recovery System Availability

The change-out time for a depleted Mg-bed meets goal unless the change-out time is frequently extended out by two or more weeks.

Glovebox and Purge Stripper Systems

The Glovebox Stripper System removes tritium, oxygen, moisture, and some hydrocarbons from the recirculated nitrogen atmosphere by catalytic oxidation of hydrogen isotopes, followed by capture of the resultant water vapor on zeolite beds (Z-beds). The system consists of two trains that have five zeolite beds. Glovebox atmospheres are always routed from the high activity stripper train through the low activity train.

Flush Gas Evacuation System

The Flush Gas Evacuation (FG-Evac) System removes process gases, containing various amounts of hydrogen isotopes (HT), from various TPA systems (Extraction Furnace Annular Space, Process Inputs,) and stores these gases in hold tanks until they can be transferred elsewhere. The FG-Evac System contains the following: three zeolite beds for water vapor removal. When placed in service, two of the three beds are normally lined up in series between one of the FG-Evac System inlet lines and the vacuum pump trains; a Normetex pump and Met-Bel pump connected in series; hold tanks.

Furnace extraction operations are expected to occur over a 5110 hour period out of the 7536 hours per year. This results in a maximum allocation of 2426 hours (7536-5110) per year for low activity maintenance evacuations when the furnace is not operating.

The availability is 98.03% based on 2 out of 2 trains in which two of the four FG-Evac pump trains are dedicated to evacuation of the furnace annulus. Availability is based on 2 out of 2 trains. This is the equivalent of 100.7 hours of unavailability per year. On the other hand, the availability becomes 99.7%, or 1.5 hours unavailability per year, if credit is given to a new spare backup train since the availability is based on 2 out of 3 trains. Still further, the availability is 99.99% if each pump can handle 100% of the outgassing from the furnace then the availability is based on one out of two trains.

For high activity tritium input from the extraction furnace annulus, the FG-Evac System has an estimated range of availabilities that vary from unacceptable to acceptable, depending on the pump train capacity and configuration chosen. For configurations involving pump trains with 50% capacity, spare trains must be added to the design to serve as backup to the two dedicated trains, or 100% capacity pumps are installed.

A sensitivity study was performed on the preliminary design for the Module Stripper System that involved elimination of one of the three blowers and one of the four Z-beds. In addition, the study yielded an acceptable availability as the Z-bed on-line times were reduced from 2.4 to 1.2 months to represent an extreme case based on high moisture in the RHA modules. This model represents an opportunity to reduce costs.

All of the RAMI models for the Flow Thru Bed System yield availability results that exceed the required goal with margin for the system operated continuously (99.5%) or on demand (98.7%). Where the difference is due to the valve line-up failures when the cracker is placed on-line. Consequently, 100% use of the catalytic cracker in the Flow Thru Bed System may be an option worth considering.

At the present time, the P-Evac System is required to have 30 day contingency storage capacity to allow for the possibility of 233-H not being able to accept low activity gas from the TEF. If it were possible to reduce this storage capacity requirement to just 16 days, then one of the three low activity hydride beds and storage tanks could be eliminated from the system. Also, since acceptable system availability can be achieved without taking credit for the fourth Z-bed and pump train in the RAMI model, it might be possible to eliminate these components as well.

Methodology

ET equations Versus Markov Models
To Compare ET Results to Markov Model Results, use MTTR where Event Tree Equations would use ½ MTTR

ET equations to model equipment in standby
With two out of three units required to operate, where each can provide only 50% of required capacity, the unavailability is approximated by:

All three running: 6(MTTR/MTBF+MTTR)^^2

Versus one in standby with a failure to start on demand probability of SF:

2(MTTR/MTBF+MTTR){ SF + (MTTR/MTBF+MTTR)}

Aging (Time Dependent Failure Rate λ)
For a normal operating facility component failure in essentially a random process and the failure rate λ, is treated as a constant. However, in the total life cycle of the facility, λ takes up different values for its three distinct phases (the famous 'Bathtub' profile). For the initial 'infant mortality' phase λ decreases with time, then remains constant during the normal steady state operation phase and finally increases with time in the 'aging' phase. The initial phase is of minimal importance in risk studies, but the 'aging' phase is relevant for many old facilities like SRS. Failure probabilities in the random steady state phase is adequately predicted by the Exponential model with constant λ, however, failures in 'aging' process is better estimated by the Weibull distribution.

Alternatively one can use a simplified estimate:
Modify λ by increasing it by 30% to 50% higher.
This yields reasonably good results especially in the time range of 1 to 2.5 MTBF.
In the time period beyond 3 MTBF, Weibull distribution is recommended for failure probability determination.

Conversion of Failure-on-Demand λ_d to an Hourly Failure Rate λ
Component failure rates are sometimes specified in probability of failure per demand, such as diesel generator fails-to-start or operate on demand. RAMI analyses require a MTBF which is the reciprocal of the hourly failure rate λ, i.e. MTBF = 1/λ. Therefore, a demand failure probability λ_d must be changed to an hourly failure rate λ and then expressed as a MTBF.

For most of the RAMI analysis to date the conversion has been done by assuming that the time period between successive component demands is one day and then dividing λ_d by 24 hours. Since for many standby components the period between successive demands ranges from 1 to 3 months or more, the assumption of daily demand period is quite conservative for many applications.

Credit for Maintenance Programs
Improvements in component reliability can be obtained with reduction in unscheduled and unanticipated component restoration through improved maintenance programs.

Preventive Maintenance (PM)
Under this maintenance program components are replaced or repaired to their original performance level every n years, instead of letting them remain in place until failure.

Replacement of components ahead of their MTBF improves reliability which can be expressed as follows:

Unreliability $UR(t) = 1 - 0.5(1+\exp(-\lambda^* tn))$ for $t \geq tn$

where tn is the initial replacement time

$= 1 - \exp(-\lambda t)$ for $t < tn$,

Example: Suppose a component would routinely be restored (repaired, replaced, etc.) every 18.8 years (165,017 hours=1/ λ =1/6.06E-6 per hour) as a MTBF, or an unadjusted failure rate λ. Instead, we elect to replace it every 5 years (43,800 hours). Then the unreliability, or expected chance of failure is within any 5 year period is given in general by:

$$1 - \exp\{-\lambda T\}$$

$$1 - \exp\{-T/(MTBF)\}$$

in this case: $1 - \exp\{-5/18.8\} = 0.234$

Thus, by replacing the component every 5 years, instead of letting it remain in place until it fails, the unadjusted failure rate λ can be multiplied by the expected chance of failure during the actual component residence time. This effectively lowers the failure rate to l=1.41E-6/hr, which is the equivalent of a MTBF of 81.0 years instead of 18.8. This adjusted value can then be used in the equations for availability and unavailability. We have worked out this relationship in general for T chosen to be anywhere in the range 0 to infinite time, where at infinite time we asymptotically approach the unadjusted failure rate λ.

Predictive/ Precision Maintenance (PdM/PcM)
PdM involves monitoring of equipment through non-intrusive tests/ inspections to detect component degradation and to identify potential problems and is a valuable tool in preventing failure. Commonly used PdM technologies such as:

- Vibration Monitoring and Diagnostics,
- Infrared Thermography,
- Lubricating oil analysis, Ferrography and Grease analysis,
- Acoustic/ Ultra-sonic tests,
- Radio Frequency monitoring, Polarization Index etc.

These programs have been credited to significantly reduce component failure rates and improve reliability at SRS and other facilities.

PcM utilizes Root cause Analysis technique to all significant incidents to better define and apply PdM technologies to suit specific components and applications. A 50% to 75% reduction in component failure rates resulting in 2 to 4-fold decrease in λ, has been observed in system/ facilities with successful PdM/PcM program.

Summary of the RAMI Process

In summary then, RAMI is a powerful tool that can be used to control the life cycle costs of a system or facility. RAMI is most effective when it is made part of the design evolution process, starting with the conceptual design phase. When applied in this manner, RAMI facilitates early identification and correction of problem areas that could later have a significant impact on both facility production goals and O&M costs.

In the early design phases, it is difficult to make precise estimates of MTTRs for system components due to incomplete knowledge regarding the actual components to be used and their placement within the system. Also, "infinite" facility repair resources" (e.g. around-the-clock maintenance support, spare parts availability) are usually assumed in the early RAMI models, because the project has not yet reached a stage where detailed plans are being made for such resources. The RAMI process addresses these uncertainties by having Operations and Maintenance (O&M) personnel, from similar types of facilities, review the MTTRs and their underlying assumptions. Based on the O&M group's input, the sensitivity of system availability to different maintenance and repair policies is determined using the existing system models. Knowing what effects these policies have on system availability and, ultimately, the facility production goal allows project management to make informed decisions regarding such policies.

RAMI is an iterative process. After the initial availability assessment for the facility conceptual design is completed, the RAMI process does not automatically terminate; it continues in parallel with the design evolution process. As new system designs and functional requirements evolve from previous work, they are reviewed to identify any changes that could impact the results of the original assessment. System models and availability goals are appropriately modified to reflect these changes, and a new set of availability estimates is obtained. As before, system designs that do not allow the availability goal to be met are examined for possible improvements, and these are communicated to system designers in the form of recommendations. The process of system design review and availability assessment is repeated for each major phase of the design evolution process.

The MTTR values will require the most critical review since "infinite" repair resources (e.g., around-the-clock maintenance support, available spares for all system components) are typically assumed in the availability models. If it is determined that the required repair resources cannot be obtained within the times assumed for the MTTRs, some or all of the MTTR values may increase dramatically, possibly causing the system availability estimates to be significantly reduced. Such a widespread change could have a negative impact on facility production goals as well and, if this occurs, project management will need to take a close look at the proposed maintenance and inspection policies.

Sam Patel

From: Mukesh Gupta
Sent: Friday, May 15, 1998 3:27 PM
To: Sam Patel
Subject: FW: Z-Bed Recovery System Accidents (U)

-----Original Message-----
From: marlene.moore@srs.gov [SMTP:marlene.moore@srs.gov]
Sent: Monday, May 04, 1998 10:15 AM
To: sam.patel@WXSMS.com; mukesh.gupta@WXSMS.com; mark.bowman@WXSMS.com
Cc: mike.kantz@WXSMS.com; william.gearman@srs.gov; thomas.foster@srs.gov
Subject: Z-Bed Recovery System Accidents (U)

Building 233-H Z-Bed Recovery Deflagration

The MAR of 0.605 kg used in the hazards analysis is based on the total volume (2200L) of one z-bed recovery tank at 1 atmosphere of pressure in the Z-Bed Recovery System. The z-bed recovery tanks are used to collect elemental hydrogen isotopes that are recovered when the uranium beds convert the tritiated waters from the stripper z-beds to elemental hydrogen isotopes. The Z-Bed Recovery System is operated at pressures between 200 to 700 torr. The regeneration process is run until the pressure in the z-bed recovery loop changes less than 10 torr/min relative to a loop pressure of 200 torr. The elemental hydrogen isotopes collected in the z-bed recovery tanks are sent to Building 232-H for further processing after the regeneration cycle is completed.

The MAR used in the hazards analysis table was conservatively derived assuming the total volume of a z-bed recovery tank was filled with essentially pure elemental tritium. However, this is not a representative case for facility operations. The z-bed recovery tanks are used as temporary holding tanks for hydrogen isotope mixtures recovered during the z-bed regeneration process. There are two z-bed recovery tanks in the z-bed recovery system, but they are not typically filled at the same time. Typically, the gas mixtures are transferred to Building 232-H for isotope enrichment and/or stacking of deuterium/protium gases with low tritium content after each regeneration cycle. The tritium content of the recovered hydrogen isotope mixture is determined by the tritium content of the tritiated waters stored on the z-beds. A review of the z-bed recovery data for Building 233-H determined that the maximum amount of tritium recovered from the Building 233-H zeolite beds was less than 1 gram.

The typical z-bed regeneration frequencies for the stripper systems are: 1) Primary Strippers, once every 5 months; 2) Secondary Stripper, once every 8 months; 3) Purge Stripper, once every 12 months. For each of the stripper systems there are three z-beds, so the beds can be alternated between regenerations. Based on the above information a more realistic, but conservative MAR can be estimated for use in the accident analysis. If it is assumed that the all four stripper system z-beds are regenerated on a monthly basis, and the recovered gas is allowed to accumulate in the recovery tanks over a 12 month period, the realistic, conservative MAR would be approximately 150 grams.

Tritium recovered =
4 strippers (3 z-beds/stripper)(1g/z-bed-month)(12 months) = 144 g

Therefore, a MAR estimate of 150 grams (tritium) should be used to disposition this z-bed recovery tank deflagration (Event No. 14) versus the mix tank deflagration (Event No. 11) in the accident selection process.