Comparison of Qualitative (AP-913) and Quantitative (Generation Risk Assessment) Equipment Reliability Assessment Technique

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ABSTRACT

In the analysis of the impact of plant structures, systems and components (SSCs) on nuclear safety and plant generation, both qualitative and quantitative techniques have been employed to classify the functional importance of SSCs and to support prioritization in business decision-making. With respect to the potential impact of SSCs on plant generation, this classification has typically been accomplished via qualitative techniques that support equipment reliability programs and the implementation of INPO AP-913. For applications where a quantitative estimate of the impact of SSC failures on plant generation is necessary, such as for long-term planning and asset management decision-making, Generation Risk Assessment (GRA) has been applied as an approach to obtain these results.

In this report, the results obtained from qualitative and quantitative analysis methods applied to SSCs important to power production at an operating nuclear plant are compared. Specifically, the following questions are addressed:

- Are current techniques for identifying critical equipment adequate to support long term planning and business decisions?
- Do the additional insights from the results of a GRA application justify the greater resources perceived to be needed?
- Are GRA and the approaches used to assess component criticality to meet AP-913 compatible and do they produce similar results with similar levels of effort?

As a result of this research, it is concluded that although the two approaches have different objectives, they are complimentary and can be used to augment each other to enhance long-term reliable SSC performance and support effective asset-management decision-making. Although this is true for operating plants, application of both approaches at the design stage will be particularly beneficial for next generation plants to ensure long-term reliability, availability and maintainability of these assets.

A key outcome of this research is the presentation of an applications matrix that provides a simple aid to personnel who need to evaluate and rank plant components. The matrix is intended to provide information so that the personnel responsible for conducting the analysis and making the decision(s) can evaluate the various techniques and choose those that best meet the objectives of the organization in the most cost-effective manner possible.

Keywords

Equipment Reliability
Equipment Criticality
Generation Risk Assessment
Nuclear Asset Management

CONTENTS

1
INTRODUCTION TO EQUIPMENT RELIABILITY ANALYSIS METHODS AND APPLICATIONS

Numerous analytical techniques have been employed to assess equipment reliability (ER) effects within nuclear power plant applications. These include both qualitative and quantitative techniques and involve applications to both nuclear safety and plant economic issues. This introduction provides a brief description of a number of techniques that have been used in commercial nuclear power applications. It is intended to provide some guidance in their advantages and disadvantages for various applications so that practitioners (particularly station system engineers) may chose a technique(s) that is appropriate for the particular application of interest. Note that in the selection of a particular analysis technique to a given application, it is important to ensure the technique will provide the necessary information to support any decisions which will be made based on the analysis. For example, in analysis of a business case in which a quantitative measure of benefit is required (such as Net Present Value or Internal Rate of Return), a method that either directly provides quantitative results (or one that can be modified to provide them) is required and a purely qualitative method is inappropriate for this type of application. Equally important in the selection of an analysis technique is for the practitioner to understand the limitations of the methods under consideration. This is particularly important if the analysis may be used for additional future applications beyond addressing the immediate issue.

1.1 Equipment Reliability Analysis Methods

To achieve this objective, a catalog of potential analysis techniques is provided. This catalog is not intended to be exhaustive. Rather, it is intended to provide the user with a listing of those techniques that have been applied in the commercial nuclear industry. Techniques that have limited applicability or are very specialized in nature (e.g. Markov models, etc.) are not listed, although should be recognized as being available for specific applications. To assist the practitioner, a brief description of the outcomes and limitations of each method is provided.

The following provides a discussion of qualitative evaluation methods.

Single Point Vulnerability Analysis (SPV)

A SPV analysis consists of a list of trains, components or tag IDs, any which could result in a plant shutdown or significant load reduction were the affected equipment be unable to perform its function in supporting generation. A SPV analysis produces a subset of the components or tag IDs that are identified as a part of an AP-913 based component criticality analysis.

The SPV list may or may not be accompanied by a description of the generation related functions that each component or tag id performs or the failure mode that supports each function. Neither probability of failure of the components or tag IDs nor durations of any resulting outages typically are provided in the analysis.

Critical Equipment List (e.g., AP-913 Criticality List)

A critical equipment list consists of list of trains, components or tag IDs that could contribute to the occurrence of a plant shutdown, significant load reduction or significant expenditures were the affected component be unable to perform its function in supporting generation. Included in this list are not only SPV components or tag ids but components which result in a significant loss of redundancy in being able to provide generation related functions (e.g., failure of the component could result in a plant shutdown or significant load reduction if an additional, redundant component also were to fail). Additionally, this list can contain components or tag IDs that are critical for reasons other than lost generation (e.g. nuclear safety impact, inability to meet a corporate commitment, etc.)

Consistent with AP-913 guidance [1], components on the critical equipment list are considered critical (if they are SPV components) or non-critical (if they simply cause a reduction in redundancy or significant costs were they to fail). Various preventive and predictive maintenance strategies are assigned to the components based on the criticality classification of the particular component.

The critical equipment list is not necessarily accompanied by a definition of the functions that the components or tag IDs provide or their failure modes (AP-913 encourages this prior to selection of appropriate maintenance activities). Neither probability of failure of the components or tag IDs nor durations of any resulting outages typically are provided in the analysis.

Critical Equipment List with FMEA

For purposes of assessment of the impact on generation, a critical equipment list generated from a failure modes and effects analysis (FMEA) consists of a collection of trains, components or tag IDs that could lead to a plant shutdown, a significant load reduction or significant expenditures were the affected components to be unable to perform their intended functions. Also included are components that would result in loss of redundancy in providing generating related functions were they to fail. Since a FMEA is a comprehensive (albeit qualitative) analysis method, plant components or tag IDs typically also are analyzed for their explicit impact on other important functions (e.g. nuclear safety impact, technical specification impact, etc.).

The difference between this list and the preceding critical equipment list is that it is accompanied by failure modes and effects analysis (FMEA) information including identification of the generation related function that the components or tag IDs perform and the failure modes potentially affecting these functions. Although probability of failure of the components or tag IDs and durations of any resulting outages are not provided in the analysis (as a quantitative output), these aspects often are addressed in a qualitative manner in the criticality classification (e.g. a component or tag ID may be assigned a lower criticality classification than its effect would require due to a qualitative assessment that the failure mechanism(s) have a low likelihood of occurrence).

The following provides a discussion of quantitative evaluation methods.

Reliability Block Diagram (RBD)

An RBD is a graphical representation of a system in which blocks (representing individual trains of equipment within the system) are connected to nodes (representing the points in the system at which one or more trains join to provide a given function). The components or tag IDs within each block, were any of them to fail, have the same functional effect on the operation of the train represented by the block. A success criterion is established at each node in terms of how many of the trains entering the node are needed to support the system function. Probabilities of failure for each of the components or tag IDs are required to estimate the probability of failure of each train (often is obtained as a simple sum).

Automated RBD tools are available to roll up the component/failure mode probabilities in deriving an overall reliability for the system and its dominant contributors. For a power plant, this reliability value can be in units of probability of trips or significant load reductions. These results do not necessarily include load reduction magnitude or outage durations. Some commercial software tools also can convert the RBD into fault tree format.

Critical Equipment List GRA

A critical equipment generation risk assessment (GRA) [2] consists of a list of trains, components or tag IDs that could lead to a plant shutdown, a significant load reduction were the affected components to be unavailable, and is accompanied by a definition of the functions they support and the failure mode for each component or tag ID. Also included are components that would result in loss of redundancy in providing generating related functions were they to fail. In addition to failure modes, a quantitative estimate of the consequences of each failure is developed (it terms of magnitude of load reduction) as well as a mean time to repair (or outage duration).

The critical equipment list GRA is essentially the same as the critical equipment list with FMEA information except that it includes detailed information on the resulting load reduction level and duration were a component or tag id to be unable to perform its generation related function. The failure probabilities are used to derive trip and derate frequencies, the consequences are then used to convert this information to units of capacity factor or lost generation (MWh). Thus, this approach can be considered to be an augmented FMEA with some degree of quantification. The critical equipment list GRA is capable of translating reliability information directly to units of generation (e.g., MWh or capacity factor) for AP-913 critical and non-critical tag ids or components, trains, systems or the plant as a whole. Note that this approach not only permits classification of components or tag IDs into a discrete set, as occurs for the qualitative methods discussed previously, but can provide a continuous quantitative ranking for those components that are considered critical.

Detailed GRA Model

A detailed generation risk assessment (GRA) model consists of an explicit logic model, most likely a fault tree, representing the logical relationship between components and tag IDs that provide generation related functions and their mathematical relationships to those functions. The results of a detailed GRA model are most often the combinations of component or tag ID failure modes that must occur to result in a plant shutdown or significant load reduction. We note that a RBD also can be used to produce similar results.

Combined with the magnitude of load reduction associated with each logic model and the outage duration (or mean time to repair for each component), the results also provide a quantitative estimate of the frequency of shutdowns and load reductions as well as the expected total generation (MWh) lost as a result of equipment failures. The detailed model GRA is capable of translating reliability information directly to units of generation (e.g., MWh or capacity factor) for the plant as a whole, any system, train, component or tag ID (including those classified by AP-913 efforts as critical, non-critical as well as run-to-failure). This approach also permits continuous discrimination (via risk-ranking metrics discussed in the body of this report) for the classification of components or tag IDs.

1.2 Equipment Reliability Assessment Applications

In commercial applications, the analysis and classification of components is performed to achieve some desired outcome. In nuclear power applications, this can encompass a wide variety; examples including meeting regulatory requirements, determination of the best investment of capital expenditures, prioritization of activities for specialized personnel, etc. Listed below are common applications for which analysis of the impact of plant components on power generation could constitute a key input into the decision process.

Component Prioritization

These activities involve the identification of those components and O&M activities that should be given priority in the assignment of finite resources (labor and monetary). Specific applications include:

- Preventive/Predictive/Corrective Maintenance Prioritization - Selection of appropriate maintenance strategies for plant components.
- Station Major Maintenance Activity Prioritization - Scheduling of maintenance for potentially high cost components and estimation of the effects of such maintenance (or the potential consequences and risk associated with its deferral).
- Capital Spares Procurement Analysis and Optimization - Identification of components having the highest potential for lengthy outages if replacement parts are unavailable (risk tradeoff of stocking/not stocking spares).
- Project Prioritization - Ranking of projects (capital improvements, major maintenance, performance programs) based on which provides greatest impact per dollar spent (cost-benefit).
- Operating Experience Review - As the plant or industry experiences failures or performance issues, focusing internal resources on the subset of components subject to these issues based on importance to generation.
- Operating/Maintenance Procedure Training Prioritization - Focusing training efforts on those components/activities that have the greatest impact on generation and reduce effort on those activities that have little or no impact on risk.
- Quality Assurance Audit Prioritization - Focusing auditing efforts where component performance provides the greatest impact.

Risk Tradeoff Determination

These activities involve the selection of appropriate operations and maintenance strategies given the various alternatives by evaluation of the competing risks and benefits. Specific applications include:

- On-line/Outage Maintenance Trade-offs - Determination of the risks of performing a repair while the plant is in operation versus taking a shutdown and optimizing the time and conditions under which the repair is performed.
- Online/Shutdown Tradeoffs given Degraded Equipment Performance - Estimating the risks (from a random trip or derate) of operating with degraded equipment until a convenient time to shutdown and make repairs (such as a weekend when power prices are low) versus a implementing a near term shutdown.
- Major Equipment Refurbishment/Replacement/Repair Decisions & Optimization - Replacement of aging equipment versus continued performance of periodic and corrective maintenance.
- Refueling Outage Schedule Optimization - Selecting appropriate activities to schedule for maintenance during major outages considering the critical path and required outage staffing levels.

Evaluation of Absolute Risk Levels

These activities involve the evaluation of the potential for trips and derates (including uncertainties) for operational decision-making. Specific applications include:

- Trip Monitor - Plant configuration control with a determination of the:
  - potential for plant trip or derate,
  - components/trains to protect during a given configuration,
  - priority of equipment to return to service.
- Bulk Power Trading Input - Providing power traders with the probability of being able to generate selected levels of plant output and/or achieve specific levels of availability over the short term (1-2 days) for the purpose of bulk power sales and determining whether to hedge against lost generation.

Cost/Benefit Analyses

These activities involve conducting formal business evaluations (to varying degrees of depth). Specific applications include:

- Quantitative evaluation of system and component design changes.
- Equipment Design Modification Optimization - Translation of reliability changes on individual components due to design changes (whether for performance improvement or predictive maintenance purposes) into units of generation (MWh).
- Capital improvement assessments - Evaluation of the effects of system design changes (redundancy/diversity) on generating capability.

Procedure/Training Activities

These activities involve the prioritization of operation and maintenance training and identification of candidate procedural improvements. Specific applications include:

- Treatment of Risk from Human Errors - Identification of most important human actions such as
  - operator actions in response to equipment failure and development of strategies to minimize the possibility of errors.
  - selection of strategies to prevent maintenance errors (such as calibration and restoration errors).
- O&M Procedural Improvements - Identification of candidate procedural enhancements for
  - post equipment failure operator actions,
  - maintenance activities.

Life Cycle Management

These activities involve selection of components for life cycle management (LCM) and input to the integration of engineering, operations and maintenance activities surrounding the long term performance of these components. Specific applications include:

- Plant Level LCM planning - Selection of system/components most important to be subject to LCM activities.
- Component Aging Management - Evaluation of the effect on generation of various aging mechanisms (e.g., implementation of quantitative aging models) and estimation of the benefits of selected maintenance strategies to address these aging mechanisms.
- Component Obsolescence Management - Evaluation of the sensitivity of plant generation to the mean time to replace components which are no longer available from the manufacturer (e.g., mean time to repair, scavenge parts from other equipment, obtain from another plant or source, replace with new design or redesign).

Corporate Business Support

These activities involve input to fleet or enterprise wide expenditures, planning and investments. Specific applications include:

- Insurance Applications
  - Comparison of insured assets with dominant contributors to lost generation.
  - Negotiation of insurance premiums.
- Business Plan Optimization - Determination of the potential to meet asset/fleet business plan objectives and determination of dominant contributors to failing to meet plan.
- Mergers and Acquisitions - Support of due diligence in acquiring/selling assets.

1.3 Applications Matrix

Table 1-1 provides a matrix that evaluates the analysis techniques discussed in Section 1.1 against the activities listed in Section 1.2. This applications matrix is intended to be a simple aid to personnel who need to evaluate and rank plant components for input in business decision-making. The matrix is intended to provide information so that the personnel responsible for conducting the analysis and making the decision(s) can evaluate the various techniques and choose those that meet the objectives of the organization in the most cost-effective manner possible.

Table 1-1 - Equipment Reliability Applications vs. Techniques

Technique & Level of Detail	Qualitative			Quantitative		
	SPV[a]	Crit equip list (e.g. AP-913)	Crit equip list w/ FMEA	RBD[b]	Crit equip list GRA	Detailed model GRA
Applications			Failure modes	Failure modes Reliability	Failure modes; Reliability; Consequences	
Prioritization activities						
Capital spares procurement analysis and optimization			2	3	4	✓
Quality assurance audit prioritization	1	2	2	✓	✓	✓
Operating/maintenance procedure training prioritization	1	2	2	✓	✓	✓
Station major maintenance activity prioritization			2	✓	✓	✓
Project prioritization		2	2	3	4	✓
Component prioritization	1	2	2	✓	✓	✓
Preventive/Predictive/Corrective Maintenance prioritization		2	2	3	4	✓
Operating experience review			2	✓	✓	✓
Determination of risk tradeoff						
Trade offs between online and offline maintenance				3	4	✓

Technique & Level of Detail	Qualitative			Quantitative		
	SPV[a]	Crit equip list (e.g. AP-913)	Crit equip list w/ FMEA	RBD[b]	Crit equip list GRA	Detailed model GRA
Applications			Failure modes	Failure modes Reliability	Failure modes; Reliability; Consequences	
Major equipment refurbishment/replacement/repair decisions & optimization				3	4	✓
Refueling outage schedule and duration optimization					4	✓
Online/shutdown tradeoffs given equipment degraded performance					4	✓
Knowledge of absolute risk						
Trip monitor				✓		✓
Bulk power trading						5
Demonstrate cost-benefit						
Equipment design modification optimization				3	4	✓

Technique & Level of Detail	Qualitative			Quantitative		
	SPV[a]	Crit equip list (e.g. AP-913)	Crit equip list w/ FMEA	RBD[b]	Crit equip list GRA	Detailed model GRA
Applications			Failure modes	Failure modes Reliability	Failure modes; Reliability; Consequences	
Capital improvement assessment				3	4	✓
Procedures/training activities						
Treatment of risk from human errors				✓	4	✓
O&M procedure improvement				✓	4	✓
Life cycle management						
LCM planning at the plant level			2	3	4	✓
Component aging and aging management		2	2	3	4	✓
Component obsolescence management			2	3	4	✓
Corporate decision making						
Insurance			2	3	4	✓
Business plan optimization				3	4	✓

Technique & Level of Detail	Qualitative			Quantitative		
	SPV[a]	Crit equip list (e.g. AP-913)	Crit equip list w/ FMEA	RBD[b]	Crit equip list GRA	Detailed model GRA
Applications			Failure modes	Failure modes Reliability	Failure modes; Reliability; Consequences	
Mergers and acquisitions				3	4	✓

[a] Single Point Vulnerability analysis (SPV)
[b] Reliability Block Diagram (RBD)

Table 1-1 - Equipment Reliability Applications vs. Techniques
Key

✓ Method fully capable of supporting application including addressing uncertainties where needed
1 Can overestimate importance of passive component failure modes and miss relatively high failure rate active components multiple failures
2 Can overestimate importance of passive component failure modes
3 Frequency of occurrence can be assessed adequately. Cost-benefit analysis capability limited as some consequence information is unavailable (magnitude of load reduction, restoration repair times)
4 Qualitative and quantitative results available for all but non-Critical components
5 Requires precision in the failure data

2
COMPARISON OF AP-913 (QUALITATIVE) AND GENERATION RISK ASSESSMENT (QUANTITATIVE) COMPONENT CRITICALITY APPROACHES

As an example of one of the equipment reliability (ER) analysis methods discussed in the introduction, a single application is selected for evaluation: ER related component prioritization. As indicated in the introduction, both qualitative and quantitative techniques are available to perform ER component prioritization. In this report a comparison of several of these techniques is performed to ascertain the advantages and limitations of each. Application of the selected techniques and comparison of results obtained is presented for several representative systems important to plant generation. Data for these evaluations were obtained from the Nebraska Public Power District Cooper Nuclear Station.

To support implementation of the INPO AP-913 equipment reliability process [1], plant staffs are developing critical equipment lists for a variety of plant functions, including electrical generation and safety. AP-913 provides general guidance for establishing equipment criticality, but leaves the details of methods to the plant staff. To keep the process simple, the focus is often placed on qualitative methods such as identifying single point vulnerabilities or performing failure modes and effects analyses (FMEAs). Examples of AP-913 critical equipment identification programs being implemented by five U.S. utilities are described in an EPRI report, Critical Component Identification Process [3]. While the consideration of risk is presented for each of the five equipment reliability programs discussed in the EPRI report, the report recommends future work with respect to explicit consideration of both quantitative and qualitative information in component categorization.

Since publication of the Critical Component Identification report, EPRI has performed additional work in the area of Generation Risk Assessment (GRA). GRA is the process of projecting power plant generation loss (e.g. MWh/year) due to system or component failures over a future operating period, perhaps the entire remaining life of the plant (see EPRI's GRA Plant Implementation Guide [2]). The main motivation for developing GRA modeling was to provide utility business communities with a tool to support project evaluation and equipment long term planning (aka Life Cycle Management [4] and Risk Informed Asset Management [5]) A key element in RIAM is GRA which uses quantitative techniques to determine the degree to which a component failure affects generation. The EPRI GRA guide provides plants with methods that use PRA-like logic models to assess generation risk. A trial application of the GRA guide was performed in 2004-5 at NPPD's Cooper Nuclear Station (CNS) [6]. The trial application developed system models and produced component importance rankings for the selected systems as one of the products of a GRA, using lost production due to component unavailability as the classification metric.

Having developed these alternative approaches to determining generation criticality, questions exist in the industry about the relative benefits of GRA methods as compared to approaches that have been employed to assess component criticality to achieve the objectives of AP-913. Among these questions are:

- Are current techniques for identifying critical equipment adequate to support long term planning and business decisions?
- Do the additional insights from the results of a GRA application justify the greater resources perceived to be needed?
- Are GRA and the approaches used to assess component criticality to meet AP-913 compatible? Do they produce similar results with similar levels of effort?

Although AP-913 does not specify the methods to specify equipment criticality, as described in [3] and summarized in Section 3.5.1 of this report, most plants have employed qualitative methods to achieve this objective. Thus, for the purposes of this report, we will use the terminology AP-913 criticality analysis to signify use of these qualitative methods.

As part of its AP-913 program, the Cooper Nuclear Station has developed a "Power Critical" component list. In the study described in this report, the following three specific questions were developed with respect to the CNS's asset management efforts:

1. How do the inputs and outputs of the AP-913 criticality analysis compare to those for a GRA analysis?
2. What are the differences between the Power Critical list developed for AP-913 and the generation-important components identified by a GRA?
3. Can an AP-913 Power Critical list (in particular, a list of single point vulnerabilities) be used to generate quantitative results similar to those from a GRA?

We note here that the criticality specification approach employed at CNS separately analyzes the components impact on safety (designated Safety Critical) and other attributes (designated Other Critical). The maintenance program specified for the component is the result of the highest level classification for the three classes (e.g., the classification acts as a high value gate). For the purposes of this study, the results of GRA were compared only with the outcomes of the Power Critical evaluation since they evaluate the same end state (i.e., the potential impact on plant generation).

A summary of the similarities and differences between the inputs and outputs of an AP-913 criticality analysis and a GRA are provided in Section 3. In addition to the approach taken by Cooper in producing the Power Critical lists, those of seven other utilities were reviewed in comparing the inputs and outputs (PP&L, First Energy, PSE&G, Exelon, AmerenUE, SCE and PG&E).

A comparison of the AP-913 Power Critical list for four Cooper systems and the results of the GRA for these same systems was performed and is summarized in Section 4. The four systems compared are Instrument/Service Air, Service Water, Turbine Equipment Cooling (TEC) and Main Feedwater / Condensate.

An outline of what information from an AP-913 criticality analysis can be used in developing the results of a GRA is provided in Section 5. Also, a trial application of the guidance provided in this outline was performed to determine how closely GRA information generated from a critical equipment list reflects the quantitative information that would be derived from a more detailed GRA model. The Cooper instrument/service air system was used to perform this trial application.

Conclusions from the comparison of the AP-913 and GRA approaches are presented in Section 6.

The following terms will be used in the remainder of the report to define the various approaches to developing a generation-related equipment criticality list.

AP-913 component criticality approach (or AP-913 approach) - refers to methods for determining criticality referenced in AP-913. These methods are typically qualitative (although use of PRA is encouraged), include single point vulnerability assessments, with consideration of the effects of redundancy provided by plant components.

Single Point Vulnerability (SPV) approach - a subset of the AP-913 component criticality approach that involves identification of components that, by themselves, can lead to trips or derates were the components to become unavailable. SPV does not explicitly account for the failure of redundant components or systems.

GRA approach - refers to any quantitative method for determining the potential for future lost generation. Among the outputs of the GRA approach are quantification of system and component contribution to derates, trips and lost generation and the ranking of the components in order of importance to generation.

GRA fault tree approach - a subset of the GRA approach that refers to quantitative methods for determining the potential for future lost generation that use fault trees in a manner similar to those used for plant-specific PRAs.

ER component criticality approach - refers to any of the alternative methods for developing a critical equipment list (qualitative or quantitative)

Power Critical components - components that have been classified as other than 'run-to-failure' under an AP-913 criticality approach specific to generation impact (i.e, either AP-913 critical or non-critical components).

3
COMPARISON OF INPUTS AND OUTPUTS OF GRA AND AP-913 APPROACHES

The first of the three questions in Section 2 of this report was directed at identifying the similarities and differences between the inputs and outputs of component criticality classifications as in an AP-913 analysis and those in a GRA analysis. In addressing this question, it should be recognized that the purpose of GRA and AP-913 analyses may not be the same. To highlight this fact, this section will address the objectives of each approach, outline the applications for which each was intended, and then get into the details of comparing the inputs and outputs. Readers familiar with the AP-913 and GRA approaches may wish to skip the background information provided in this section and proceed to Section 4.

3.1 Objectives of GRA and ER Criticality Approaches

The AP-913 and GRA approaches have both been developed with specific objectives in mind. Those objectives are summarized here.

3.1.1 AP-913 Equipment Criticality Approach

The following statements of objectives are found in the Foreword and Equipment Reliability Process Objectives sections of AP-913 [1]:

- Assist utilities with the maintenance of high levels of safe and reliable plant operation in an efficient manner.
- Integrate and coordinate a broad range of equipment reliability activities into one process for plant personnel to evaluate important station equipment, develop and implement long-term equipment health plans, monitor equipment performance and condition, and make continuing adjustments to preventive maintenance tasks and frequencies based on equipment operating experience.

In addition, the Process Objectives section contains these specific objectives:

A.	The process is efficient, incorporates human factor considerations, and ensures effective performance during all phases of plant operations.
B.	A uniform process is used among all plants in an organization.
C.	Applicable in-house and industry lessons learned are incorporated into the process to improve adequacy and efficiency.
D.	Changes to the process are timely, responsive to user feedback, and implemented at all affected plants.

The scope of the AP-913 Equipment Reliability Process includes those “critical” components having importance to safety functions, safe shutdown capability, and power generation. The level of importance need not be quantified nor ranked. Insights from probabilistic assessment techniques can be considered in this determination of criticality.

3.1.2 GRA Equipment Importance Approach

Generation Risk Assessment (GRA) is the process of estimating the risk of generation loss during future operation given the probability and duration of plant trip or derate due to degradation or failure of equipment (systems, structures, and components – SSCs). GRA techniques described in [2] build on probabilistic assessment methods in the nuclear safety area in which the industry has invested over the last 30 years.

The primary reason for implementing GRA is to support the performance of applications that enhance plant operations and economic performance by improving reliability, reducing maintenance costs, or reducing future lost generation. Examples of supported applications are included in next section (Section 3.2).

3.1.3 Comparison of Objectives and Scope

The AP-913 process has a wider scope in that it includes nuclear safety criticality, whereas a GRA focuses solely on production (while safety issues may be inherently treated in some respects in the GRA, assessment of nuclear safety is deferred to the PRA). In addition, AP-913 has as an objective the development and integration of equipment reliability programs and strategies. The GRA does not specifically address strategies, but does develop insights as to where modifications or improvements might be warranted and provides information needed to perform a quantitative assessment of the benefits of implementing some of these strategies. Thus, the AP-913 process provides the capability to qualitatively classify SSCs into several broad classifications (e.g. critical / non-critical / run-to-failure); a GRA permits a quantitative ranking of SSCs.

3.2 Applications Supported by GRA and AP-913 Criticality Approaches

3.2.1 AP-913 Approach

The principal applications directly supported by the criticality categorizations derived from AP-913 [1, 3]:

- PM program implementation
- Equipment reliability improvement
- Performance monitoring
- Corrective action
- Life cycle management

3.2.2 GRA Approach

The inclusion of detailed quantitative information (including uncertainty distributions) in the GRA approach supports a potentially wider scope of applications [2], particularly those which require quantitative values and rankings. These applications include:

Prioritization activities

Capital spares procurement analysis and optimization

Quality assurance audit prioritization

Operating/maintenance procedure training prioritization

Station major maintenance activity prioritization

Project prioritization

Component prioritization

Preventive/Predictive/Corrective Maintenance prioritization

Operating experience review

Determination of risk tradeoff

Trade offs between online and offline maintenance

Major equipment refurbishment/replacement/repair decisions & optimization

Refueling outage schedule and duration optimization

Online/shutdown tradeoffs given equipment degraded performance

Knowledge of absolute risk

Trip monitor

Bulk power trading

Demonstration of cost-benefit

Equipment design modification optimization

Capital improvement assessment

Procedures/training activities

Treatment of risk from human errors

O&M procedure improvement

Life cycle management

LCM planning at the plant level

Component aging evaluation and management

Component obsolescence management

Corporate decision making

Insurance

Business plan optimization

Mergers and acquisitions

3.2.3 Comparison of Supported Applications

While there is overlap in the applications that can be performed with information from the AP-913 criticality list and a GRA, the inclusion of probabilistic information in a GRA allows the GRA to be used in applications requiring detailed quantitative results. Due to these differences, the AP-913 and GRA approaches should be viewed as complimentary in plant decision-making.

3.3 Inputs for GRA and AP-913 Criticality Approaches

Each of the approaches requires certain inputs in order to satisfy the stated objectives

3.3.1 AP-913 Approach

As a starting point, AP-913 was reviewed to determine the explicit inputs mentioned within the steps of that process. The following table summarizes those inputs, as they appear in AP-913. Items with asterisks also provide information relevant to power generation and GRA.

Table 3-1
AP-913 Inputs

Input	AP-913 Step
Insights from PRA	"Equipment Performance Objectives", Part B, and Step 1.1
Failure (experience) data*	Step 1.1, re: identify important functions
Safety related list	
Essential non-safety related list	
Maintenance Rule scoping criteria*	
License renewal scoping criteria	
Criteria for establishing equipment necessary for power generation*	
EQ criteria	
Appendix R safe shutdown criteria	
Station Blackout criteria	
Fire protection criteria	
ATWS criteria	
Pressurized thermal shock (PTS) criteria (for PWRs)	
Equipment Performance and Information Exchange (EPIX) Function and Device records*	
Design Basis Document*	

Table 3-2 (continued)
AP-913 Inputs

Input	AP-913 Step
EPRI PM Database*	Step 4.6, re: developing PM Templates
EPRI LCM Sourcebooks*	
Aging management guidance developed by EPRI, DOE, and NSSS vendors	
Industry operating experience from such sources as the EPIX database, INPO events, and just-in-time operating experience databases*	
Vendor manuals	
Maintenance craft experience and judgment	
System/component engineers' experience*	
License Renewal Aging Management Reviews	

Table 3-3 (continued)
AP-913 Inputs

Input	AP-913 Step
Insights from industry groups such as Snubber Utilities Group (SNUG), Nuclear Utility Obsolescence Group (NUOG), owners groups	Step 5.3 re: determination of aging or obsolescence concerns
Obsolete Item Replacement Database (OIRD) that is supported by NUOG	
Results of industry efforts such as EPRI LCM Planning and EPRI Lite*	
System health reports and continuing equipment reliability improvement reviews*	
Station procurement process*	
Vendor inquiries and notices*	
Review of planned EQ parts replacement	
Periodic review of approved ASME suppliers list to determine if any ASME material maintained in stock is traceable to a vendor not currently listed	
Periodic review of I&C technical specification equipment for sufficient inventory	
Reviews of aging effects for passive functions of SSCs*	
Long term reliability plan*	Step 5.5, re: integrating system plans with the station business plan
Business plan*	
* Provides information relevant to generation	

3.3.2 GRA Approach

The GRA Plant Implementation Guide [2] provides a comprehensive list of input sources for a GRA analysis. The following table is a summary of those inputs.

Table 3-2:
GRA Inputs

<table>
<tr><th>INPUT</th><th>SECTION OF GRA GUIDE</th></tr>
<tr><td>System design documentation (in terms of capacity of individual trains)</td><td rowspan="7">For determining derate categories - Section 2, Power Reductions from Postulated Failures; some inputs also helpful for selecting systems to be evaluated (Section 3, System Modeling and Analysis)</td></tr>
<tr><td>Plant power history data/records</td></tr>
<tr><td>System descriptions</td></tr>
<tr><td>System engineers and operators with their knowledge of system and plant operations</td></tr>
<tr><td>Maintenance Rule</td></tr>
<tr><td>North American Energy Research Council (NERC) data</td></tr>
<tr><td>Technical specifications/LCOs</td></tr>
<tr><td>Plant-specific PRA</td><td rowspan="4">Section 3, System Modeling and Analysis</td></tr>
<tr><td>Operating and Vendor Manuals</td></tr>
<tr><td>Piping and Instrumentation Drawings (P&IDs)</td></tr>
<tr><td>System notebooks</td></tr>
<tr><td>Computerized Maintenance Management Systems (CMMS)</td><td rowspan="4">Other plant-specific raw data sources (Appendix A, GRA Model Data Sources)</td></tr>
<tr><td>Corrective Action Documents</td></tr>
<tr><td>Control Room and System Logs</td></tr>
<tr><td>Surveillance, Testing, and Maintenance Procedures</td></tr>
<tr><td>NUREGs, WASH-1400, IEEE-500, and other sources of “generic” data</td><td>Appendix A, GRA Model Data Sources</td></tr>
<tr><td>Uncertainty parameters</td><td>Appendix A, GRA Model Data Sources</td></tr>
</table>

3.3.3 Comparison of Inputs

It is apparent that there is similarity between the inputs to the AP-913 process and a GRA. However, AP-913’s scope requires some non-production related inputs that are not necessary when focusing strictly on generation via a GRA. On the other hand, a GRA’s emphasis on quantitative results requires more inputs related to numerical information (failure rates, repair times, component and train capacities, etc.) than what appears to be needed for AP-913 implementation, which is primarily qualitative in nature.

3.4 Outputs of GRA and AP-913 Criticality Approaches

Each approach implemented using the inputs delineated above produces the set of outputs (results) listed below.

3.4.1 AP-913 Approach

The outputs of AP-913 are:

- List of SSC functions that are important to maintaining safety, reliability, and power generation (Step 1.1)
- List of "critical components" (Step 1.2)
- List of "non-critical components" (Step 1.3)
- List of "run-to-failure components" (Step 1.4)
- Performance criteria and monitoring parameters (Step 2.1)
- Dominant failure modes and effects (Steps 4.2 and 4.9)
- Maintenance strategies for critical and non-critical components (Steps 4.7-4.12)

By completing the steps of AP-913 the implementers, (i.e., the station staff) should not only produce a component categorization, but be able to generate (1) a list of PM activities for which an improvement in the frequency of performance is desired, based for example on industry operating experience, new predictive technologies, feedback from maintenance personnel, etc. (Step 4.1), (2) mitigating or compensatory strategies for dealing with components identified as critical to an important function or non-critical but should not be run to failure (Step 4.12), and ultimately (3) integrated and prioritized long-term reliability and business plans to ensure future station budgets support major equipment reliability plan activities (Step 5.5). These outcomes are not a direct output of the process, per se, but of the expertise of those using the process (in other words, AP-913 does not dictate strategies or business plan contents, but provides some general guidance for how to develop them).

3.4.2 GRA Approach

The outputs of GRA are:

- Listing of the combinations of failure events that result in plant shutdown or power derate
  - Single events resulting in plant shutdown or significant derate would be "single point vulnerabilities"
  - Combinations of component events that lead to trip or derate also are identified
- Frequency of occurrence of the failure events or combinations of failure events
- Consequences, in units of Megawatt-hours (MWh) lost or Equivalent Full Power Hours (EFPH) lost, associated with each failure event or combination of failure events
- Prioritized rankings of component failure events in terms of contribution to lost generation
- Uncertainty distributions for the frequencies and consequences of events for each system modeled.

3.4.3 Comparison of Outputs

The outputs of the two processes share a number of similarities in that both will produce a list of failure modes, effects and single point vulnerabilities. Both also provide information with respect to components that can contribute to lost generation from multiple failures, although the AP-913 list may be limited to components having a redundancy of two (e.g., it is possible that components that make up combinations of three or more may be classified as 'run-to-failure'). The GRA provides information supporting the ability to "risk rank" based on quantitative measures, e.g., frequencies or consequences as well as assessment of the significance of uncertainties. The criteria for classification of components as important in a GRA differ from those used in AP-913 to determine criticality. Section 4.2 expands on these differences for one of the Cooper Nuclear Station systems examined.

The output of a GRA does not provide strategies for maintaining or improving the reliability of important components. For that, a process similar to that described in AP-913 is still needed. By the same token, the results of AP-913 are not quantitative. For applications described previously that require quantitative information on equipment failure impact, the AP-913 approach will not provide sufficient information to support the application. For example, if the cost effectiveness of strategies to address equipment reliability is to be determined, processes and information similar to those found in a GRA analysis will be needed.

Information about failure modes and effects and criticality or importance is part of the output of both AP-913 and GRA approaches. However, it is interesting to note that there is a difference in the order in which information about failure modes and effects and criticality or functional importance becomes available. In GRA modeling, the failure modes and effects for a component must be known up front. In AP-913, determination of dominant failure modes and their effects are not needed until development of maintenance strategies in the equipment reliability process, which occurs after component criticality determination.

One also should note that these differences in outputs suggest that these approaches are complimentary and that for critical applications, the application of both may be beneficial. This use of both types of approaches (e.g. FMEAs for qualitative evaluations of component functional failure impact and importance and fault tree models for quantitative results) is often employed in critical applications in military, space and commercial aviation.

3.5 Utility-Specific Critical Component Identification Processes

In addition to the general AP-913 guidance, the processes used to identify critical equipment at several utilities were also reviewed, using the following sources:

- "Critical Component Identification Process – Licensee Examples *Scoping and Identification of Critical Components in Support of INPO AP-913,*" Report 1007935, EPRI, Technical Update December 2003. [3]
- AP-913 and Single Point Vulnerability Flowcharts from the San Onofre Nuclear Generating Station. [7]
- Plant priority assignment process and component classification matrix, from Pacific Gas and Electric. [8]

- "System engineering department, System engineer desktop guide, Section ii – identification of critical components," Cooper Nuclear Station, 98-03-02, Revision 4, 2004. [9]

EPRI Report 1007935 provides a detailed discussion of insights from utility criticality determinations obtained from application of AP-913. However, key points from this report are presented below to provide a convenient summary for the reader.

3.5.1 Critical Component Identification Process Report

The Critical Component Identification Process report [3] summarizes scoping and identification strategies at five nuclear power plant utilities in the U.S. They are:

- PP&L (Susquehanna)
- First Energy Nuclear Operating Company (FENOC)
- PSEG
- Exelon
- AmerenUE (Callaway)

The first several rows of the following table are extracted from Table 4-1 of EPRI's Critical Component Identification Process report. These summarize the approaches employed for critical component identification at these utilities. The last section of Table 3-3 (labeled Other Comments on Process) is not taken from Table 4-1 of the EPRI report but has been provided as additional information as a part of work performed for this report.

Table 3-3:
Comparison of Critical Component Identification Processes
(Portions extracted from Table 4-1 of EPRI Report 1007935)

INPO AP-913	PPL	FENOC	PSEG	Exelon	AmerenUE
Categorization Systems					
Critical	1	Critical 1	1 – Safety	Critical	Critical 1
	2	Critical 2	2a – Scram initiator 2b – Operational impact 2c – Support function		Critical 2
Non-Critical	3	Non-critical	3 - Non-critical economic impact	Non-critical	N
	4		4 – Scheduled maintenance		
Run to Failure	5	Run to Failure	5 – Run to Failure	Run to Failure	Not considered as a Criticality Categorization
	6				

Table 3-3: (continued)
Comparison of Critical Component Identification Processes
(Portions extracted from Table 4-1 of EPRI Report 1007935)

INPO AP-913	PPL	FENOC	PSEG	Exelon	AmerenUE
Consideration of Risk					
Not explicitly considered. Implicit, *qualitative* consideration in identification of "Important Functions."	*Qualitative* consideration in identification of Maintenance Rule functions and allocation of the component Maint Rule categorization (high or low safety significance)	*Quantitative* consideration in identification of Important Functions and impact on PRA model of loss of component	*Qualitative* consideration of impact of loss of Maintenance Rule function when determining critical components	*Qualitative* consideration of impact of loss of Maintenance Rule function when determining critical components	*Qualitative* consideration of impact of loss of Maintenance Rule function when determining component Functional Importance (FID)
- Observations on Process -					
	Explicitly includes performance of deterministic FMEA on each component being evaluated	Uses quantitative importance rankings derived from the plant specific PRA when considering criticality assignment: Risk Achievement Worth, threshold = 2, Fussel-Veseley, threshold = .005	Maintenance Rule information is used as part of the decision process for components in the highest sub-category within the "critical" category. PRA data is not explicitly used in the categorization process.	Process includes some questions outside of the AP-913 scope that establish the component operational environment and duty cycle. These then are used as direct input in support of Performance Centered Maintenance (PCM) templates, which are linked to criticality, environment, and duty cycle.	During the review process the impact of component failure on PRA results is reviewed as a means of confirming that categorization has been performed correctly.

3.5.2 San Onofre Nuclear Generating Station

Reference 7 provides information on categorization of components at San Onofre. Flowcharts are based on and similar to AP-913. This results in categorization into the same three categories as defined for AP-913.

Inputs and Outputs – This is very similar to AP-913. Explicitly include consideration of "security" and In-service Testing "IST" functions (these are not delineated explicitly in AP-913). Flowcharts also refer to results of reliability centered maintenance (RCM) evaluations.

Consideration of risk – Risk is considered through the use of Maintenance Rule data as one of the inputs for categorization. PRA results are not explicitly referenced in the process (although these results are implicitly accounted for via their use in maintenance rule classification of SSCs).

3.5.3 Pacific Gas & Electric

Reference 8 outlines the component classification process at Diablo Canyon. A component classification matrix lists criteria and strategies similar to those found in AP-913. The matrix has two "critical" sub-categories, one "non-critical," one "run-to-failure," and one "exempt."

Inputs and Outputs – Appear to be consistent with AP-913 for the component classification matrix. However, although not referred to in the matrix, PG&E has a "Plant Priority Assignment" process that assigns problem categories and level of degradation codes to components in order to specify action request priorities. It is likely that this process and results of its application can be (and are) used in component categorization for criticality purposes.

Consideration of risk – Risk is considered through the use of Maintenance Rule data as one of the inputs for categorization. PRA results are not referenced explicitly in the component classification matrix. However, the Plant Priority Assignment process, in its discussion of the assignment of the Risk Significant problem category mentions that "the magnitude of the effect on core damage or large early release frequency and trip risk should be considered…". In this same discussion, the PRA shutdown model also is mentioned. There is no explicit linkage to the component classification matrix, and therefore it is not clear whether one process feeds into the other.

3.5.4 Cooper Nuclear Station Desktop Guide

Although some of the terms and specific details are different, the approach described in the CNS guide [9] is similar to the Callaway approach described in the EPRI Critical Component Identification Process report. In other words, CNS establishes Functional Equipment Groups and specifies a Functional Importance Determination process. The categories into which components are binned are similar to those defined for Callaway.

Inputs and Outputs – See Table 3-3 column for AmerenUE (Callaway).

Consideration of risk – Risk is considered through the use of Maintenance Rule data as one of the inputs for categorization. PRA results are not referenced explicitly in the process (however, these results are implicitly accounted for via their use in maintenance rule classification of SSCs).

3.6 Summary

As indicated above, a review of the objectives, inputs, and outputs of a GRA and an AP-913 criticality analysis has revealed some overlap. However, there are important differences (e.g., AP-913's development of maintenance strategies, the GRA's ability to produce quantitative output). Because their objectives differ, specific differences in inputs and outputs exist, as do the types of applications supported by the results of the two approaches.

4

COMPARISON OF PLANT-SPECIFIC AP-913 CRITICALITY ANALYSES WITH GRA RESULTS

A key purpose of the research described in this report was to determine if the additional insights obtained from the quantitative results obtained from a GRA justify the resources perceived to be necessary to perform the analysis. To answer this question (i.e. the second question in the Introduction), a comparison was made of the Power Critical equipment lists generated as part of the implementation of AP-913 at the Cooper Nuclear Station with the lists of equipment modeled in the CNS GRA and their "importance to generation" determined as a part of risk ranking. The Cooper GRA was developed independently from the AP-913 implementation, as the latter was not yet complete at the time GRA activities were initiated. The comparison therefore provides an objective review of the similarities and differences between the two approaches. However, we note that although all US nuclear plants classify structures, systems and components for functional importance to satisfy AP-913 requirements, very few have conducted formal GRA type of analyses. Thus, in evaluating the results presented in this report, one should keep in mind that the comparison is based on a very limited sample of GRA output data.

4.1 Overview of Cooper AP-913 Criticality and GRA Criteria

Using the guidance in their desktop criticality guide [9], CNS staff developed lists of critical equipment in the general categories of "Nuclear Safety," "Production," and "Other." As stated in Section 1 of that guide, "This process is consistent with the key attributes for Scoping and Identification of Critical Components described in INPO AP-913, Rev. 1 'Equipment Reliability Process Description'…" The criteria used specifically for Production Criticality (PC) are shown in Table 4-1.

Table 4-1: Criteria for Production Critical Lists at CNS

Criteria for Functional Importance	
Level of Consequence	**Production Criticality** **(PC1, PC2, or PCN)**
1	Loss of a function of this component will cause: A reactor or turbine trip A down power >10% An LCO of ≤ 72 Hours Note: This includes Single Point Failure Components
2	Loss of a function of both redundant components could cause a reactor or turbine trip. Loss of a function of this component will cause: a down power less than listed above a loss of generation less than listed above significant economic consequences a plant down power by imposing a power limitation, either through automatic or operator action.
N	Loss of a function of this component will not cause a significant impact on production.

Given this guidance, the Cooper PC1 category can be expected to capture any single point vulnerabilities that by themselves could result in a plant trip, operator-initiated plant shutdown, or a significant power derate. The PC2 criteria referring to “loss of a function of both redundant components” will likely identify contributors to trips, derates and other plant shutdowns that could be initiated by simultaneous failure of two components.

The criteria used in a GRA to determine what components and failure modes should be included in the logic models is not limited to single or double failures and is discussed in detail in the GRA Implementation Guide [2]. Section 3.2 of the Guide suggests that the level of detail useful in the development of a GRA model depends on the application to be performed and the availability of data to quantify the component failure modes that may be included in the model.

Guidance is provided with respect to the treatment of

- "Critical Component Identification Process – Licensee Examples *Scoping and* Active and passive failures
- Common cause failure of multiple components
- Instrumentation and control (I&C)
- Sources of flow diversion
- Human errors
- Unavailability due to testing and maintenance

In general, modeling need not be performed for most applications at a level of detail more refined than the major component level as data for subcomponents is generally sparse.

It should be noted that the fact that a component is included in a GRA logic model does not necessarily mean that the component is "important to generation." It is the quantitative analysis of the GRA model from which component importance is determined. The concept of "important" is explained in the GRA Guide and in the Cooper GRA Trial Application report [6]. The importance of a component or group of components from a GRA perspective is a function of both the likelihood of its failure resulting in a plant derate and the consequences of the failure (magnitude of derate, length of time the plant may remain in the derated condition, cost of lost production due to equipment failure, etc.). Thus, low consequence (e.g., low derate) events that occur frequently may be more important on a relative scale than higher consequence (e.g., higher derate) events that occur less frequently. Additionally, multiple failures of moderate frequency or those that have long repair and restoration times may be more important than single failures with relatively low frequencies of occurrence and/or short mean times to repair.

In summary, a major difference between the criteria used in the development of the PC1 and PC2 lists at Cooper and the information provided by a GRA is the application of quantitative measures (probability of failure, magnitude of derate and restoration time) in the determination of importance using the GRA approach.

4.2 Comparison of Results, PC1/PC2 and GRA

For the purpose of comparing the AP-913 criticality lists to GRA fault tree results, the Power Critical lists of equipment were obtained from the CNS staff. [9, 10] By definition, these lists contain equipment that is important to production of electricity. Therefore no additional screening was required to eliminate equipment that may be important to nuclear safety or other functions but not to production. The Power Critical list contained two categories; PC1 corresponding to the AP-913 critical category and PC2 corresponding to the AP-913 non-critical category.

The PC1 and PC2 lists combined contain nearly 15,000 tag-level entries covering all systems at the plant. Four of the systems modeled in the GRA were selected for comparison of the GRA results to the power critical lists -- main feedwater / condensate, service water, instrument/service air, and turbine equipment cooling. The first step in the comparison, therefore, was to remove from the CNS lists entries not associated with those four systems.

The next step in the comparison process was to separate the PC1 and PC2 lists into system-specific lists, i.e., a combined PC1/PC2 list for main feedwater / condensate, another for service water, etc. This was accomplished by sorting the lists based on the tag identifier used in the lists for each entry. Each tag identifier (tag ID) uses two to three letters to designate the system to which the component is associated / assigned. Those designators are:

- Service water – SW
- Instrument/service air – IA/SA
- Main feedwater/condensate (e.g., power conversion system) – PCS
- Turbine equipment cooling – TEC.

Initial comparison of the number of components modeled in the GRA with the tag IDs on the PC1 and PC2 lists for the four selected systems revealed a great difference (94 GRA components vs 2471 PC1/PC2 tag ids - see Table 4-2). In the following Sections 4.2.1 and 4.2.2, we discuss two main causes for the difference:

- differences in system boundary definition between the AP-913 criticality analysis and the GRA, and
- GRA modeling at the component level vs. the use of tag IDs in the AP-913 criticality determination.

Table 4-2
Power Critical Tag IDs vs. Components Modeled in the GRA

	No. of tag IDs		**No. of components**	
	AP-913 Power Critical		**Explicitly Modeled in GRA**	
	PC1	PC2		
IA/SA	157	333	12	
SW	2	369	17	
TEC	210	177	10	
PCS	638	585	55	

4.2.1 Definition of System Boundaries

System boundaries for ER criticality and the GRA are defined differently. This difference in scope accounts for a significant fraction of the differences in results that were observed in the previous section.

For development of the Power Critical lists, the system boundaries are based on the tag IDs found in the equipment data base. For example, tag ids containing 'IA' or 'SA' are considered to be a part of the instrument or service air systems regardless of whether they can contribute to the failure of these systems. Given a list of functions for that system, the System Engineers are then responsible for developing functional equipment groups (FEG) and performing a functional importance determination (FID), establishing performance monitoring, and assigning appropriate maintenance activities to assure the reliability of components within their system.

For the GRA, a system function is defined (e.g., supply adequate pneumatic control pressure to plant systems) and a system model is created that supports that particular function (e.g., supporting sufficient pneumatic pressure from the instrument/service air systems to the plant air header). Components that contribute directly to a particular function are considered to be a part of the system that provides that function. Components that contribute only to the support of other functions but, if failed, do not contribute to the loss of the function being modeled are considered to be a part of the other systems they support. For example, main steam isolation valve (MSIV) air supply solenoid valves are classified as part of the instrument air system in the AP-913 criticality analysis; these same valves would be modeled as a part of the main steam system in the GRA.

Adjusting for system boundary differences, the number of PC1 or PC2 tag IDs directly supporting one of the given systems analyzed in this study (PCS, IA/SA, SW, or TEC) significantly reduced the original number of tag IDs for that system. This process permits a point by point comparison of results obtained via the two methods. For example, of the 157 PC1 tag IDs included in the original list for the instrument/service air system, only eight were found to directly support that system, the remaining 149 tag IDs supporting functions other than instrument air. For PC2 components, only 70 of the 333 tag IDs directly support the system. Table 4-3 compares the number of Power Critical tag IDs to the number of components modeled in the GRA after adjustment for system boundary differences.

Table 4-3
Power Critical Tag IDs vs. Components Modeled in the GRA
(after making the definition of system boundaries consistent)

	No. of tag IDs		No. of Components	
	Power Critical		GRA Model	
	PC1	PC2	Explicitly	
IA/SA	8	70	12	
SW	0	168	17	
TEC	33	87	10	
PCS(MFW)	567	*	55	

* Only PC1 Tag-ids reviewed for MFW due to plant and project resource constraints

4.2.2 Components vs Tag IDs

The level of detail included in PRA and GRA logic models generally stops at the major component failure mode level (e.g., pump fails to run, valve fails to remain open). This can result in grouping multiple tag IDs (as used in developing the AP-913 criticality lists) into single component failures representing loss of a major component. A logic model stops at the component level because failure data generally is not available at the tag ID level. As examples:

- For an MOV at Cooper, individual tag IDs are assigned to the motor, the operator (gear box, limit switches, etc.), and the valve itself. For the GRA, a single event name involves all the piece-parts of a "component."
- In the GRA, other components in series can be modeled as a single super-component failure (e.g., a pump basic event name in the GRA fault tree logic model may represent the pump and motor, as well as the breaker, discharge check valve, discharge and suction isolation valves, etc.). This results in multiple components (and their associated tag IDs) being represented by a single super-component in the model.

For situations in which multiple tag IDs are assigned in the PC1/PC2 list to components that are treated within the definition of a single major component within the GRA, the PC1/PC2 sub-components were recognized as being modeled "implicitly" in the GRA. In other words, consistency was considered to exist between the GRA and the Power Critical lists even without an explicit one-to-one match between a GRA logic model event identifier and the PC1/PC2 tag ID. To allow a meaningful comparison, implicitly modeled tag IDs were added to the list of components modeled in the GRA. We note that this situation is typical in the application of PRA modeling methods. The detail in a PRA model is generally only to the level at which data is readily available (often at the major component level, thereby only implicitly including the component piece parts). Effort to collect data at the piece part level (and, hence, support more detailed modeling) is considered to be cost prohibitive with limited benefit.

Reconciling the implicitly modeled GRA components with the PC1/PC2 tag IDs brought the two lists even closer together. For example, of the 78 Power Critical tag IDs in the instrument/service air system, 58 were considered to be included in the GRA either explicitly or implicitly. Table 4-4 provides a comparison between the number of tag IDs on the PC1/PC2 lists and the GRA after implicitly modeled tag IDs are taken into account. In general, the number of components on each list is now within a factor of 2 or 3, although the GRA list remains smaller for each of the four systems.

Table 4-4
Power Critical Tag IDs Compared vs. Components Modeled in the GRA
(after considering implicitly modeled components)

	No. of tag IDs		No. of tag IDs		Total No. of Tag IDs	
	Power Critical		GRA Model		Power Critical	GRA Model
	PC1	PC2	Implicitly	Explicitly		
IAS	8	70	46	12	78	58
SWS	0	168	40	17	168	57
TEC	33	87	28	10	120	38
PCS(MFW)	567	*	280	55	567+	335

* Only PC1 Tag-ids reviewed for MFW due to plant and project resource constraints

4.2.3 Distinction between Criticality in AP-913 & Important to Generation in GRA

Up to this point, reconciliation of the AP-913 Power Critical lists has considered whether a component is modeled in the GRA but has not yet considered which components in a GRA model are important to generation. Next, we examine the differences between definitions of criticality in AP-913 implementation at Cooper and what is important to generation in the GRA.

As previously noted, Cooper elected to create two qualitative levels of criticality for power generation purposes in the implementation of AP-913:

- PC1 includes any tag ID that failure of it alone could result in a plant trip, significant downpower, or entry into an LCO with a duration of less that or equal to 72 hours (essentially single point vulnerability to these events).
- PC2 includes any component that could lead to one of the above consequences should the failure of a redundant component also occur. This category also includes components such as those that can lead to minor derates or other non-generation related economic consequences (e.g., equipment damage) as a result of their failures.

The GRA, on the other hand, defines importance quantitatively. Two measures of importance are considered: how much does the component contribute to lost generation given its current reliability and how sensitive is future lost generation to changes in its reliability. PRA specialists will recognize these two measures of importance as being similar to Fussell-Vesely's measure (or Risk Reduction Worth) and Birnbaum's measure (or alternatively, Risk Achievement Worth). In order to use these two measures to identify a component's importance to generation, it was necessary to select thresholds above which components would be considered important and below which they would be candidates for categorization as low in importance. The following thresholds were selected for each of the two measures of importance in the work performed for this report:

Table 4-5:
GRA Importance Thresholds

Importance Measure	Cooper Threshold	Basis
Current contribution to lost generation (e.g., Fussell-Vesely)	0.004% lost capacity factor over life of plant	Translates to present value worth of $25,000 one time cost to completely eliminate risk (e.g., fixes to address components having lower risk may be difficult to cost justify)
Sensitivity to changes in component reliability (e.g, Birnbaum's measure)	0.02% capacity factor per unit change in failure probability (or slope)	Translates to $1,000,000 lost revenue over the course of a year if the component were always unavailable (of course, total potential for lost revenue is much less given that the component will not be unavailable all of the time)

We note that specification of component critically based on lost generation impact is somewhat subjective (i.e. management must balance the impact of a failure with its potential to occur against the costs associated with performing activities that could prevent it). Thus, it is expected that decision thresholds would vary based on the business objectives of the organization and the particular application being evaluated. In this regard, it is best if the plant staff selects appropriate thresholds based on factors important to running the business, such as cost-benefit or other recognized metric. It is also noted that both measures of importance generally are considered in determining component importance (exceeding either one will result in the component being considered important, and neither must be exceeded for the component to be considered low in importance and a candidate for 'run-to-failure'). This stipulation also is consistent with other applications of risk assessment results in nuclear power applications (e.g. component risk significance classification for plant maintenance rule program scoping.)

There are only loose relationships between the PC1/PC2 categories and the two importance thresholds provided in Table 4-5.

- As AP-913 is non-quantitative in nature, there is no Power Critical category that corresponds to the Fussell-Vesely measure of importance.
- There is an indirect relationship between the Power Critical categories and Birnbaum's measure of importance. The following observations can be made with respect to the sensitivity of the importance of a component to change in its reliability in this regard.
  - The collection of PC1 components (e,g., single point vulnerabilities) will likely be high in Birnbaum's measure of importance (generation risk will be sensitive to the reliability of these components).
  - Those components that are low in both measures of importance will be a mixture of PC2 components and those that are found to be 'run-to-failure'.

Application of these measures of importance of generation risk reduces the components on the GRA list from the number of those modeled to the number of those important to generation based on the selected criteria. For example, of the 58 generation related instrument/service air components modeled explicitly or implicitly in the GRA, the thresholds in the above table lead to 35 being classified as important to generation. Similarly, 4 of the 8 PC1 tag IDs in the instrument/service air system model are important to generation, as well as 28 of the 70 PC2 tag IDs. It is also noted that the GRA analysis identified 3 non-Power Critical components in instrument/service air as important. Examples of what components make up the difference between the AP-913 Power Critical list for instrument air and those found to be important to the GRA are provided in Table 4-6.   A summary of the comparison between the PC1/PC2 lists and the GRA results for all four systems is found in Table 4-7.

Table 4-6
Example Instrument/Service Air Power Critical tag IDs that differ from GRA Important Components

AP-913 Power Critical Category	Example Power Critical tag IDs	Description
PC1	CNS-0-SA-SOV-SSV611A	Dryer filter auto drain valves (not considered important to generation and therefore not modeled in the GRA)
	CNS-0-SA-SOV-SSV611B	
PC2		
	CNS-0-IA-SOV-SSV5A	Dryer repressurizer valves (not modeled)
	CNS-0-IA-PS-103A	Dryer pressure switch (not modeled)
	CNS-0-IA-REL-11CRA	Dryer temperature alarm relay (not modeled)
non-PC	Compressors 1A-1C	Air Compressors (explicitly modeled in the GRA)

Table 4-7
Number of Power Critical Components Compared to Important Components from GRA

	No. of tag IDs			Total No. Tag IDs	
	Power Critical		Important in GRA	Power Critical	Important in GRA
	PC1	PC2			
IAS	8	70	PC1(4), PC2(28), NPC(3)	78	35
SWS	0	168	PC2(50)	168	50
TEC	33	87	PC1(24)	120	24
PCS(MFW)	567	*	PC1(272), PC2(*)	567+	272

* Only PC1 Tag-ids reviewed for MFW due to plant and project resource constraints

Table 4-7 is the final result of the comparison. To help explain the differences, the experience of CNS system engineers was sought. The next section describes lessons learned from these interviews.

4.3 Lessons Learned from System Engineer Interviews

The last step in this process was to review the above results with system engineers at Cooper. The purpose of the interviews was to take advantage of their knowledge in explaining the remaining differences between the AP-913 Power Critical lists and the important components identified using the GRA. With the support of the CNS Risk Management and System Engineering groups, system engineers knowledgeable in the four systems being evaluated were contacted and interview schedules were arranged. Because of the numerous other duties requiring the system engineers' attention, only a limited amount of time (approximately two hours each) could be devoted to the interviews. To facilitate the reviews, the system engineers were provided in advance with the information provided in Attachment A to this report. Because of the limited interview time, the PC1 components were given priority and PC2 components discussed last. All components for the IAS and SWS systems were reviewed. The TEC and MFW/Condensate system reviews were limited to just the PC1 components. The interviews were conducted in a single day at the plant, in back-to-back sessions with the four responsible engineers.

Reviewing the responses and comments provided by the system engineers revealed the following:

- There were instances in which the system engineers questioned the original AP-913 categorization and recommend deleting a tag ID from the Power Critical list, or reclassifying it to a lower category, based in part upon the new information from the GRA regarding the tag IDs' importance to production.

Examples:

- CNS-0-TEC-V-425 PT-403 Shutoff (TEC HX Outlet)
  Reclassify from PC1 to PC2
- CNS-0-TEC-MVI-404 TEC HX Outlet Temp
  Reclassify from PC1 to PC2
- CNS-0-TEC-V-449 TEC-PRV500 Downstream Sensing Line Isol. Valve
  No production impact, should not be PC1 or PC2
- CNS-2-SW-DPIS-363B (and DPS-363B) SW PPS B&D STNR HI DP ALM
  Should not be PC2
- CNS-0-CD-LMS-BAV10A SJAE A Aftercooler TP Bypass V BAV10A LMS
  Not a concern, according to System Engineer, and should not be PC1 or PC2

- There were instances in which a tag ID not now on the Power Critical lists would be added to the PC1 or PC2 list based upon information and insights gained from the GRA.

Example:

– Instrument Air Compressors 1A, 1B, 1C
  Should be reclassified from 'run-to-failure' to PC2

- There were examples in which a tag ID classified as PC2 should be reclassified to PC1 based on additional system performance and other information.

Example:

- CNS-9-SW-V-54, 55, 56, 56   TEC HX inlet, outlet, backwash inlet and backwash outlet valves, respectively

  Should be reclassified to PC1 from PC2 until additional heat load calculations are completed

- There were examples of PC1 or PC2 components not now included in the GRA logic models that should be added to those models.

Examples:

- CNS-2-SW-CV-11CV   Service water pump B discharge valve

  PC2 Tag ID not now in SWS GRA model
- CNS-9-SW-V-54, 55, 56, 56   TEC HX inlet, outlet, backwash inlet and backwash outlet valves, respectively

  PC2 Tag IDs (possibly PC1 – see previous examples) – should be included in TEC and/or SWS model due to potential impact on derate
- CNS-0-CD-AO-LCV60A,B; 61A,B; 62A,B; 63A,B; 64; 65A,B; 66A,B; 67A,B; 68A,B; 69 – Heater A1,2,3,4,5, B1,2,3,4,5 Level Control Valves

  PC1 Tag IDs – should be included because controller failure may lead to valve failure. Valve failure floods heater. Reload analysis says plant has 2 hours to fix or must reduce power to 25%.   Since most problems can not be fixed within the 2 hour constraint, the GRA model should assume a controller failure results in derate to 25%.

- There were examples of PC1 components that, based on actual operating experience, were not correctly modeled in the GRA.

  - The plant design provides two redundant lube oil pumps for each reactor feed pump, only one of which is necessary to provide adequate lube oil. However, if the operating pump fails, the standby lube oil pump will not start fast enough to maintain lube oil pressure. Therefore, reactor feed pump lube oil pumps represent single failures in keeping the feed pumps operating.

4.4 Summary

Based upon the comparisons performed on four systems, the following general summary is provided:

- Some tag IDs that are important to production were not on the PC1 or PC2 critical component lists due to:

  – Redundant similar components that may be subject to common cause failure modes.

- Components that become single point vulnerabilities when system performance requirements change as a result of seasonal or environmental conditions.
  - For example, pumps or heat exchangers that are necessary during the hottest parts of the year, but are in standby the remainder of the year

- Tag IDs have been identified as candidates for removal to the PC1 & PC2 lists due to findings of the GRA:
  - Conservative classification of the Tag ID with respect to the effect on generation.
- Functions leading to plant shutdown or derate not considered in the GRA have been identified as candidates for future GRA modeling (e.g., administrative power reductions, design issues identified from operating experience and omissions resulting from simplification of the modeling).

5

COMPARISON OF PLANT-SPECIFIC AP-913 CRITICALITY ANALYSES WITH GRA RESULTS

The third question in the introduction essentially asks whether it may be possible to develop quantitative GRA results beginning with an AP-913 criticality list as a starting point, without the need to develop a fault tree or other specific quantitative model. Were this to be the case, the possible applications to which a criticality list could be applied are likely to be much broader than those listed in AP-913 (see Section 3.2). In addition, the results might be obtainable with less effort than required for the GRA fault tree analysis approach.

In this section, we discuss the results obtained in generating quantitative GRA results beginning with the AP-913 power critical list for the Cooper Instrument/Service Air System. The IA/SA power critical list used for this activity was that generated by the plant staff before adjustment to reflect insights from the GRA fault trees. In this alternative approach, the total frequency of plant trips was first estimated using the components listed on the PC1 list (largely made up of single point vulnerabilities). The exercise was then expanded to incorporate information from the PC2 list (containing information on components having redundancy in support of system operation). In each case, a comparison of the estimated trip frequency due to the Instrument/Service Air System derived from the power critical list with the GRA fault tree results is provided.

Based on the results of this analysis, general guidance was developed for the tasks needed to produce quantitative generation information using an AP-913 criticality list as input. This guidance is provided in Section 5.3.

5.1 Generation of IA/SA GRA Results Using Only the Cooper PC1 List

Table B-1 lists the components identified as PC1 for the Instrument/Service Air System (IA/SA). Recall that PC1 components are considered to be single point vulnerabilities with respect to power generation; they are those whose failure, by themselves, have been determined to lead to a plant shutdown, a derate of more than 10% rated power, or entry into an LCO within 72 hours. The original Cooper PC1 list contains many more components for Instrument Air than the six tag IDs in Table B-1. As described in Section 4.2, the tag IDs in Table B-1 have been screened to include only those that directly support IA/SA operation. For the purpose of this exercise, those components having IA/SA tag IDs but which support other systems and whose failure would not contribute to the loss of instrument air itself have not been included in the table.

An alternative way to pose the third question listed in the introduction is "Why can't GRA information be produced simply by estimating and summing the failure probability of each of the single failures that can lead to a trip or derate?" Table B-1 provides such an estimate for the PC1 components for the Cooper IA/SA system.

Before reviewing quantitative estimates provided in Table B-1 further, it should be noted that the only information provided in this table was obtained from the AP-913 criticality evaluation listing the PC1 tag ids and their descriptions. In the documentation provided to the researchers, there were no failure modes documented as a part of the PC1 list and no description of the effects of component failure. Also, since failure probabilities are not needed as a part of AP-913 implementation, they also were not provided. For the purpose of this exercise, this information was derived independently as follows.

It was assumed that the failure of the PC1 components listed in Table B-1 would contribute to a plant shutdown due to the loss of pneumatic pressure in the main plant instrument air header. This is the same top event as that modeled in the fault tree GRA. The failure mode of each component was determined either from the fault tree GRA or by examining the system description or P&IDs. By examining the fault tree, we are taking advantage of failure modes and effects analyses performed as a part of the GRA. Had the fault tree GRA not been available, a FMEA effectively would need to have been done to determine the applicable failure modes that would result in the sequence of events that would lead to a plant shutdown.

The PC1 component failure rates in Table B-1 are from the Cooper PRA database just as they were in the fault tree GRA analysis.

Table 5-1 summarizes the PC1 component quantitative results and compares them with failure probabilities from the fault tree GRA and industry averages from NERC (the % values representing the fraction of the total trip frequency value provided at the bottom of each column).

Table 5-1
Comparison of AP-913 PC1 Plant Trip Frequency with That from the Fault Tree GRA (Instrument/Service Air System)

Dominant Contributors	AP-913 PC1 List	Fault Tree GRA	NERC
Compressors		0.052/yr (61%)	0.002/yr (6%)
Dryers		0.012/yr (14%)	
Pre & Post Filters		0.006/yr (7%)	
Filter Drain Valves	0.105/yr (56%)		
Air Receivers	0.010/yr (6%)	0.010/yr (12%)	
Relief Valves	0.070/yr (37%)		
Miscellaneous			
Piping			0.014/yr (56%)
Valves			0.003/yr (12%)
Other			0.006/yr (25%)
Total	0.186/yr	0.086/yr	0.019/yr

The frequency of plant shutdowns derived from the PC1 list and the fault tree GRA are within roughly a factor of two of one another, but both are significantly greater than what industry experience would suggest. The following compares the dominant contributors to lost generation as identified from the AP-913 PC1 list for IA/SA, the IA/SA fault tree GRA and NERC industry data for instrument air systems.

AP-913 GRA dominant contributors. Table 5-1 indicates that the PC1 results are significantly greater than what industry experience would suggest. As indicated in Table 5-1, the dominant contributors from the PC1 list are the air receiver tank relief valves and the air dryer pre and post-filter drain valves. It is noted that dryer and air receiver tank related components are not significant contributors to lost generation risk in industry experience (in addition, neither air receiver tank relieve valves nor filter drain valves are modeled in the GRA fault tree analysis as being a contributor to the loss of the system).

In investigating the air receiver tank relief valves, it was determined that these valves are present as they are most likely required by code. As the air receiver tank is always open to the IA/SA providing flow, it is not expected that the valves would ever receive a demand. Additional failures causing pressure increases in the air system would be required before the relief valves would open and fail to reclose, thereby leading to a depressurization of the system. The low potential for this demand given the system configuration leads to the assumption that these valves can be included implicitly as a part of the air receiver tank boundary (and, hence, not modeled in the GRA). While the AP-913 criticality assessment recognizes these relief valves are critical in their function to remain closed, the GRA recognized that the potential for their failure is probably much less than generic PRA data would suggest for spurious operation of a relief valve.

With respect to the pre and post-filter drain valves, the system engineer was consulted and concluded that it was not clear why these valves should be on the PC1 list.

Removing both the air receiver tank relief valves and the air dryer filter drain valves from the table, the frequency of plant trip is now much closer to generic experience, within a factor of two.

Fault tree GRA dominant contributors. The fault tree GRA results are also significantly greater than industry experience would suggest. The most significant contributors to lost generation in the GRA are the air compressors (notably, these are not on the Power Critical list). This difference between the Cooper IA/SA GRA fault tree analysis results and the industry experience in NERC was investigated in [5]. It was noted that the performance of Cooper air compressors has been a focus of recent plant efforts and, as a result, replacement of the compressors is in progress. Assuming replacement of the compressors (0.052/year trip frequency) would bring the performance of the system back into alignment with industry experience (0.002/year trip frequency), this would address the dominant contributor to plant shutdowns from this system according to the GRA and could possibly bring the GRA results to within a factor of three of NERC.

Industry experience dominant contributors. The dominant contributor to loss of instrument air as indicated by NERC appears to be passive failures of instrument air piping. Passive piping failures are not explicitly considered either in the PC1 list or the GRA. However, passive failure of the air receiver tanks and air driers <u>are</u> considered and appear to have a similar frequency to that of the piping failures of NERC operating experience.

From a review of the PC1 list (single point vulnerabilities) for IA/SA, it is concluded that consideration of just single point vulnerabilities actually results in overestimation of the risk of plant trip and derate as the dominant contributors to lost generation (the air receiver tank SRVs) are not likely to receive a demand. At the same time it underestimates the risk by not considering the contribution from multiple relatively high failure rate failures (the air compressors). A review of the fault tree GRA results also shows it to overestimate the risk of plant trip as compared to industry experience. However, a large part of this difference can be attributed to the historical performance of the instrument air compressors.

5.2 Generation of Instrument/Service Air GRA Results Using Both the PC1 & PC2 Lists

Even with the total frequency of plant shutdowns from Instrument/Service Air failures for the PC1 list being similar to the GRA results and NERC information, the dominant contributors are not the same as industry experience would suggest. To investigate this difference further, the quantitative evaluation of the Cooper AP-913 list was expanded to include both PC1 and PC2 components. Table B-2 contains a summary of the 70 PC2 tag IDs for the Instrument/Service Air System. The PC2 list contains what AP-913 describes as 'non-critical' components and includes those for which system redundancy prevents failure of a single component from causing a trip or derate as well as components that may lead to long term equipment damage if they were to fail and not be repaired in a sufficient time frame.

Like the PC1 tag IDs, the list of PC2 components that was provided included no failure mode or effects associated with any of the components. Discussions with the system engineers were conducted to identify those that could contribute to generation losses if they failed versus those that were placed on the list to avoid other economic consequences from equipment failure. Twenty-eight of the components on the PC2 list were identified as having the potential to lead to a plant shutdown if redundant components also were to fail. Components on the list related to long term equipment damage are noted as such. Finally, in the conversations with the system engineer regarding the absence of the air compressors from either the PC1 or PC2 list, the importance of common cause failure of the compressors was discussed and it was elected to add them to the PC2 list even though there are three compressors and only one is needed to supply plant pneumatic loads. Note that even though the compressors were not identified as PC1 or PC2, they were not specified as run-to-failure components due to analysis of other characteristics (in this case “Nuclear Safety Critical” analysis of the Cooper equipment criticality evaluation process. This fact underscores the importance of conducting a complete and robust evaluation of component importance based on multiple criteria.

Table B-2 provides quantitative estimates of the frequency of plant shutdowns resulting from IA/SA PC2 components. As was the case for the PC1 tag IDs, the failure rates for each of the component types on the PC2 list are the same as that used in the database for the Cooper PRA. In generating the frequency of plant shutdowns for these components, an estimate of the potential for two or more components failing in a short period of time is necessary (representing common cause failure). Common cause failure estimates were made using guidance provided in the GRA guide [6].

As shown in Table 5-2, when both PC1 and PC2 components are considered, the AP-913 criticality lists and fault tree GRA result in a very similar event frequency. However, the results remain significantly higher than suggested by NERC in part, once again, due to plant specific performance of the air compressors.

It is noted that the dominant contributors to the Power Critical lists and the GRA are PC2 components (those for which multiple failures are required leading to plant shutdown) as opposed to single failures (PC1 components). This is a result of the failure rates of the PC2 components being significantly higher (e.g., active failures, such as compressors failing to run) relative to the PC1 components (which are dominated by passive failures, such as air receiver tank failure). (The % values representing the fraction of the total trip frequency value provided at the bottom of each column).

From this evaluation, it is concluded that quantitative estimates can be generated from the Power Critical lists of AP-913 that are similar to those that are obtained from a GRA. Where classification is performed in a conservative manner, it needs to be recognized that the estimate of lost generation also will be conservative. In addition, it is necessary to include the contribution from multiple failures that can lead to trips or derates (e.g., the PC2 list for Cooper) or an underestimate of lost generation due to the relatively high frequency failures of active components can occur.

Table 5-2
Comparison of IAS AP-913 PC1 & PC2 Plant Trip Frequency with that from the Fault Tree GRA

Dominant Contributors	AP-913 PC1 and PC2 List	Fault Tree GRA	NERC
Compressors (assume PC2)	0.022/yr (24%)	0.052/yr (61%)	0.002/yr (6%)
Dryers (PC2)	0.0005 /yr (<1%)	0.012/yr (14%)[1]	
Pre & Post Filters (PC2)	0.052/yr (57%)	0.006/yr (7%)[2]	
Filter Drain Valves (PC1)	*		
Chamber Iso Vlvs (PC2)	0.0004/yr (<1%)		
Chamber Iso SOVs (PC2)	0.003/yr (3%)		
Control Circuits (PC2)	0.0001/yr (<1%)		
Control Xfmr (PC2)	0.0005/yr (<1%)		
Repress Valves (PC2)	0.003/yr (3%)		
Air Receivers (PC1)	0.010/yr (11%)	0.010/yr (12%)	
Relief Valves (PC1)	*		
Miscellaneous			
Piping			0.014/yr (56%)
Valves			0.003/yr (12%)
Other			0.006/yr (25%)
Total	0.092/yr	0.086/yr	0.019/yr

* Filter drain valves and air receiver relief valve contribution deleted based on discussion at the end of Section 5.1

1 Fault tree GRA assumes that individual dryer leakage/rupture leads to loss of instrument air

2 Fault tree GRA model includes operator action recovery to open air dryer bypass line

5.3 Guidance for Producing Quantitative GRA Information from AP-913 Criticality List

The following general guidance is drawn from the lessons learned in the preceding section.

- Prior to attempting to generate quantitative information from AP-913 Power Critical lists, a review of each of the tag IDs is worthwhile to assure that its function in supporting power generation is understood. Any tag ID for which its function is not clear should be discussed with the system engineer. It is also necessary to understand the component's normal operating state (e.g., normally running or standby, normally open or closed) as well as the failure mode(s) that leads to loss of the component's function.
- Both critical (e.g., PC1 for Cooper) and non-critical (e.g., PC2) tag IDs should be considered, because the PC1 critical list alone may not include all dominant contributors to trips or derates (such as the Cooper air compressors).

With this information, the following structured procedure can be used to obtain quantitative estimates from a plant's AP-913 critical equipment list. These estimates of the potential for a plant shutdown or derate associated with the system in question should comparable to a fault tree GRA for the purposes of use in resource allocation and business decision-making.

1. Define the system function or functions to be quantified.
   In the case of the Cooper IA/SA, this was supply of pneumatic air pressure to the plant's main instrument air header. It is possible to define multiple functions for a given system. In the case of the Cooper IA/SA, this might include additional system functions of supplying air pressure to support specific plant loads (such as to AOVs in the condensate, CRD, and main steam systems).

2. Define the consequences of failure of the system and the system success criteria needed to avoid these consequences. In the case of the Cooper IA/SA the event to be modeled was the prevention of a plant shutdown should the system be lost. The success criterion for the compressors was 1 out of 3. For the air dryers, 1 out of 2 trains are needed to perform the required system function. For the air receiver tanks, rupture of any one tank was assumed to result in depressurization of the IA/SA.

3. Screen components from the critical (PC1) and non-critical (PC2) lists that do not directly support the functions of interest. These include:
   - Tag IDs that support other auxiliary functions of the system under investigation (such as TEC or REC for the Cooper IA/SA example above).
   - Tag IDs included on the list specifically for the purpose of preventing long term equipment damage (while important for this purpose, these components do not necessarily lead to a trip or derate as they often may be restored in sufficient time to prevent significant damage).

4. Screen components from the critical and non-critical lists that are not likely to be challenged or can be considered subcomponents of another major component on the list. Examples include:

- Passive components other than major equipment such as tanks and heat exchangers
- I&C components that support a single active major component that will dominate the failure probability
- Protective equipment requiring other conditions to occur before they would be called upon to perform their function (e.g., the air receiver tank SRVs for the Cooper IA/SA)

5. Identify the failure mode associated with each tag ID. From available sources of data, assign a failure rate to each tag ID. Such sources may include data used in the plant-specific PRA, LAMDA (EPRI) [12], DOE Savannah River Database [13], NUREG/CR-4550 [14], etc.

6. Calculate an annual frequency of trip or derate for each tag ID. In this calculation, methods accepted to address common cause failures in a PRA should be used. As an explicit example, one could use the following approach based on beta and gamma factors as suggested in Reference (2):

   - For critical (PC1) components

     P_f = Hourly failure rate * 8760h

   - For non-critical (PC2) components, consider only the common cause failure of multiple identical components

     P_f = Hourly failure rate * 8760h * 0.1 (for two redundant components)

     P_f = Hourly failure rate * 8760h * 0.1 * 0.5 (for three or more redundant components)

7. Sum the total frequency over all tag IDs for each trip and each magnitude of derate.

8. Compare the dominant contributors and contributions to each trip and derate level with those from NERC-GADS (or other data source such as plant specific history) to confirm the results and determine that there is a plant specific reason (i.e., either design or performance) for any significant differences.

6 SUMMARY / CONCLUSIONS

In the introduction to this report, it was noted that the objectives and results of an AP-913 criticality analysis and a fault tree GRA analysis overlap. AP-913 recommends at least a qualitative evaluation that includes the development of an equipment list of plant components critical for generation (as well as nuclear safety and other issues), and then calls for the identification of strategies to maintain the reliability and, hence, the safe economic performance of a nuclear generating facility. A GRA on the other hand, whether it is performed with a fault tree or some other modeling approach, produces a variety of quantitative results, among them a ranked list of components important to generation. The GRA ranking can support the resource allocation decisions that are part of both a plant's equipment reliability (ER) program and its nuclear asset management (NAM) program.

In comparing the AP-913 criticality and GRA fault tree approaches, this report addressed three questions associated with their respective qualitative vs. quantitative methods. This report examined application of both approaches on systems from the Cooper Nuclear Station. The following summarizes what was learned in addressing each of the questions posed in the Introduction:

1. How do the inputs and outputs of the AP-913 criticality analysis compare to those for a fault tree GRA?

   The answer to this question is influenced by the fact that the purpose of each of the two approaches may be different.

   - AP-913 is directed largely at equipment reliability and performance. The process includes activities involving not only the identification of critical power plant equipment, but definition of strategies to maintain or improve reliability and monitor equipment performance.
   - GRA fault trees are directed at providing quantitative information to identify not only the importance (criticality) of components but to estimate the overall performance of a generating facility. These estimates can be used by maintenance personnel, engineers and management in decision making with respect to investments in the facility and resource allocation. Note that the investments in question are to a large extent for improving reliability or assuring appropriate equipment performance as in AP-913.

   While there exists overlap in the form of a list of critical or important equipment, the objectives of each approach are broad and differ from one another. The AP-913 process emphasizes the development of strategies for the maintenance of the reliability of critical and non-critical equipment and monitoring its performance. The GRA cannot be used to develop these strategies. However, the AP-913 process, being qualitative, needs additional information (such as that obtained in a

GRA) if quantitative cost benefit analyses are to be performed. Since implementation of AP-913 predominantly has used qualitative analytical methods, it is not sufficient, by itself, to support activities where quantitative results are required in the decision-making process. Examples include optimizing on-line vs. offline maintenance or use as an operational indicator of the potential for a plant trip to occur (i.e. use as a trip meter). Conversely, the maintenance strategies developed as a part of the AP-913 process provide input to the reliability and availability values used by the GRA in performing these quantitative analyses.

That the inputs and outputs of the two processes have both similarities and differences is a fact, but is of minor importance. What is important is what is done with this list of critical or important equipment. In this regard, it would appear the two approaches are supportive of one another as opposed to alternatives in the overall objective of asset management. This conclusion is supported by the application of both approaches to analyze critical systems in other industries where failures may have unacceptable consequences and is particularly true within the defense and aerospace sectors.

2. Are there differences between the components identified on Power Critical lists for AP-913 and those identified as important in a fault tree GRA?

   Even after adjustment of the AP-913 criticality list to reflect differences in the definition of system boundaries and the GRA list of important components to include implicitly modeled components, the AP-913 criticality list remained larger than that for the fault tree GRA. These remaining differences between the AP-913 criticality lists and the GRA results precipitated conversations with the system engineers to assist in identifying the reasons for them. Two principal causes for the differences were noted. First, a number of tag IDs appear on the PC2 lists due to their role in avoiding equipment damage. Their failure does not necessarily cause power reductions or plant trips, but results in long term economic consequences. A second reason for the differences was that a number of tag IDs were found to be categorized conservatively. On discussion of the functions and failure modes of these components with plant system engineers, a number were considered candidates for lower classification or elimination from the PC1 and PC2 lists. It was importantly pointed out, however, that there were several critical components that should be modeled in the GRA but were not. These components were often found in plant administrative procedures as requiring a plant derate if they were unavailable, generally to maintain plant operating conditions within the assumptions of the accident analysis in the FSAR.

   It can be seen that, as with most applications requiring engineering judgment, there was give and take as a result of the discussions with system engineers, with some components being candidates for lower criticality classification while others were newly found to be added to the GRA model. The AP-913 criticality analysis and the fault tree GRA appear to have provided a check on one another, improving the results of both efforts. This further supports the conclusions provided in (1) above.

3. Can an AP-913 Power Critical list (in particular, a list of single point vulnerabilities) be used to generate the models for a fault tree GRA?

   The answer to this question appears to be 'Yes' if a complete and robust qualitative classification process is used; however, it is not possible if only single point vulnerabilities are considered. The PC1 list by itself (corrected for the differences identified under question 2 above) appears to underestimate the risk of lost generation when the components on the list are assigned failure rates and then summed. When contributors from the PC2 list are incorporated into the analysis, there is much closer agreement with the GRA model estimates and historical data from industry databases. It is notable for the system examined in this exercise (Instrument / Service Air) that the dominant contributors to a plant shutdown were PC2 components (active components having relatively high failure rates) as opposed to the PC1 components (passive components with relatively low failure rates).

While the conclusions of this analysis are based on the comparison of qualitative and quantitative results for only four systems, a number of observations may be made regarding the consistency of the results between the two approaches. First, 'the 'accuracy' of the results will be system design dependent. Systems largely made up of single point vulnerabilities can be quantified either way with results that are comparable. Systems with significant or partial redundancy have a greater chance of being either over or underestimated in terms of quantitative results depending on the degree of conservatism and the manner in which common cause failures are treated. Second, the criticality or importance of components using the two approaches may differ for reasons that are relatively easy to understand. As shown for the instrument air system example, it should not be surprising that single point vulnerabilities that are relatively passive in terms of their failure modes do not have the potential to contribute as much to generation loss as multiple, redundant components that have active failure modes. It is interesting that many practitioners inherently believe the reliability of production related systems is driven by single point vulnerabilities. With the exercises performed for the Cooper Nuclear Station presented in this report, we have found this is not necessarily the case.

A final observation coming out of this study is that the level of detailed information provided along with the AP-913 equipment reliability list plays a significant role in the amount of work needed to compare the criticality lists with GRA results or in using a criticality list to produce quantitative results. A criticality list that consists only of tag IDs requires significant work to generate quantitative results. This is because the analyst is missing information regarding function, failure modes and consequences as well as the basis for component classification. This information must be generated from other sources such as system descriptions and P&IDs, and discussions with the system engineers. The effort to obtain this information can be on the order of that required to build a fault tree GRA model independently. On the other hand, an AP-913 criticality list that is accompanied by FMEA information (as appears may be available with the PP&L approach noted in Table 3-3) is much more likely to provide sufficient information to perform follow-on quantitative analyses with reasonable effort.

The conclusions of this study are that the objectives and application of the AP-913 component criticality evaluation and a GRA differ. In comparing the two approaches, it was found that information from both might not only be useful in applying the results but could enhance one another in the overall implementation of an asset management program.

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A
SYSTEM ENGINEER INTERVIEW

Attachment A presents background information provided to system engineers in the comparison of GRA results with AP-913 Power Critical lists.

The system engineers for each of four systems - Instrument/Service Air, Service Water, Turbine Equipment Cooling and Main Feedwater / Condensate - also were provided with a table containing a list of the power critical tag IDs for their system as compared to the components important to generation identified using the GRA. These tables contained the tag ID and description as taken from the CNS database and an indication of whether the tag ID is a PC1 or PC2 component identifier. The tables next indicated if a basic event could be found in the GRA logic models that corresponded with the tag ID. Whether the tag ID was assumed to be modeled explicitly in the GRA or implicitly through the modeling of another component also was indicated. Finally, comments or questions for discussion with the responsible system engineers was provided, particularly where there was a difference between the criticality classification from the power critical list and the important components from the GRA.

The following describes the System Engineer Interviews that were conducted.

<u>Purpose of meeting:</u>

- To discuss the results of the comparison of the Cooper PC1 and PC2 lists to lists of important generation-related components from the GRA.
- To identify possible changes to the GRA models and / or potential opportunities for focused attention within the PC1 / PC2 lists.
- To identify possible revisions to the PC1 / PC2 lists if the opportunity for changes arises in the future.

<u>Approach for discussion:</u>

1. Provide a quick tutorial that outlined the GRA approach to each system engineer.
2. Provide a quick outline to each system engineer of the approach taken for comparison (e.g., “start with PC1/PC2 lists as provided to us by the station; use P&IDs, system documentation, etc., to match tag ID to event ID in the GRA model…”)
3. Conduct detailed discussion of system-specific results of comparison, for each individual system / system engineer

<u>Questions for / information needs of each system engineer:</u>

1. For the components on the PC1 and PC2 lists (that are not on the GRA list): describe the function of the component.

2. For those components: describe the rationale used for placing the component on PC1 or PC2 lists (e.g., the failure mode of interest, the impact on shutdown or derate, the impact on LCO, etc.).

3. For those same components, describe their normal operating position. (So that one may correctly model these components.).

The above questions will help understand the plant better, and possibly identify components / failure modes that should be added to the GRA models.

4. For components on the GRA list but not on the PC1 / PC2 list: what was the rationale for considering these as non-Power Critical components?

This discussion may result in (a) addition of components from the GRA model or (b) provide additional information to the system engineers for consideration in determining appropriate performance criteria and preventive maintenance for components appearing on the PC1 / PC2 lists.

Useful: resources

1. P&IDs

2. FEG descriptions

3. System operating procedures

4. System lesson plans

B

PC1/PC2 IA/SA QUANTIFICATION

Tables B-1 and B-2 provide the quantification of the contribution of each PC1 and PC2 tag ID in the instrument / service air system to the frequency of plant shutdown. The tag IDs have been screened to eliminate those that support functions other than the operation of instrument / service air itself. Those tag IDs that are in the tables for the purpose of avoiding equipment damage are noted.

For each tag ID, a failure rate per hour is provided along with a reference for the source of the data. The failure rate is then converted to a frequency (1/operating year). For PC1 components (which represent single point vulnerabilities), the frequency is simply the product of the hourly failure rate and 8760 hr/year (i.e. the number of hours in one year). For PC2 components (which require multiple failures before a plant shutdown would occur), common cause factors are applied to the product, per the GRA Guide (Ref 6) $\beta = 0.1$ if there are only two redundant components and $\beta = 0.1$ and $\gamma = 0.5$ if there are three or more redundant components. The sum of the Frequency column yields an estimate of the frequency of plant shutdowns for the system.

Table B-1
Cooper AP-913 PC1 Components (Instrument/Service Air System)

Tag ID	Description	Rate (per hour)	Freq (per year)	Data Source	Comment
CNS-0-SA-RCVR-A	Air Receiver A	6.0E-07	5.3E-03	Accumulator Ruptures IEEE-500	
CNS-0-SA-RCVR-B	Air Receiver B	6.0E-07	5.3E-03	"	
CNS-0-SA-RV-14RV	Air Reciever A RV	4.0E-06	3.5E-02	Pressure Relief Valve FTRC IEEE-500	
CNS-0-SA-RV-15RV	Air Reciever A RV	4.0E-06	3.5E-02	"	
CNS-0-SA-SOV-SSV611A	B DRY PREFILTER LWR AUTO DR	3.0E-06	2.6E-02	Solenoid valve FTRO (Savannah River)	
CNS-0-SA-SOV-SSV611B	B DRY PREFILTER UPR AUTO DR	3.0E-06	2.6E-02	"	
CNS-0-SA-SOV-SSV614A	A DRY PREFILTER LWR AUTO DR	3.0E-06	2.6E-02	"	
CNS-0-SA-SOV-SSV614B	A DRY PREFILTER UPR AUTO DR	3.0E-06	2.6E-02	"	

Table B-2
Cooper AP-913 PC2 Components (Instrument/Service Air System)

Tag ID	Description	Rate (per hour)	Freq (per year)	Data Source	Comment
	Compressor 1A	5.0E-05	2.2E-02	Compressor FTR NUREG/CR-4550	Common cause failure of all 3 compressors to run
	Compressor 1B				
	Compressor 1C				
CNS-0-SA-HX-ACA	SA CPSR A AFTERCOOLER				Prevent long term equipment damage
CNS-0-SA-HX-ACB	SA CPSR B AFTERCOOLER				Prevent long term equipment damage
CNS-0-SA-HX-ACC	SA CPSR C AFTERCOOLER				Prevent long term equipment damage
CNS-0-SA-MSEP-A	SA CPSR A DISCH MSEP				Prevent long term equipment damage
CNS-0-SA-MSEP-B	SA CPSR B DISCH MSEP				Prevent long term equipment damage
CNS-0-SA-MSEP-C	SA CPSR C DISCH MSEP				Prevent long term equipment damage
CNS-9-IA-DRY-A	Dryer 1A	6.0E-07	5.3E-04	Accumulator Ruptures IEEE-500	Common cause failure of both dryers
CNS-9-IA-DRY-B	Dryer 1B				

CNS-9-IA-F-PAA	Dryer 1A pilot air filter	3.0E-05	2.6E-02	Filter Plugging NUREG/CR-2728	Common cause failure of both filters
CNS-9-IA-F-PAB	Dryer 1B pilot air filter				
CNS-9-IA-F-PFA	Dryer 1A post particulate filter	3.0E-05	2.6E-02	Filter Plugging NUREG/CR-2728	Common cause failure of both filters
CNS-9-IA-F-PFB	Dryer 1B post particulate filter				
CNS-0-IA-CV-10CV	AIR DRY A CHAMBER A AIR OUTLET	1.0E-07	8.8E-05	Normally open AOV FTRO NUREG/CR-4550	Common cause failure of both control valves
CNS-0-IA-CV-11CV	AIR DRY A CHAMBER B AIR OUTLET				
CNS-0-IA-CV-12CV	AIR DRY A CHAMBER A DRY AIR INLET	1.0E-07	8.8E-05	Normally open AOV FTRO NUREG/CR-4550	Common cause failure of both control valves
CNS-0-IA-CV-13CV	AIR DRY A CHAMBER B DRY AIR INLET				
CNS-0-IA-CV-24CV	AIR DRY B CHAMBER A AIR OUTLET	1.0E-07	8.8E-05	Normally open AOV FTRO NUREG/CR-4550	Common cause failure of both control valves
CNS-0-IA-CV-25CV	AIR DRY B CHAMBER B AIR OUTLET				
CNS-0-IA-CV-26CV	AIR DRY B CHAMBER A DRY AIR INLET	1.0E-07	8.8E-05	Normally open AOV FTRO NUREG/CR-4550	Common cause failure of both control valves
CNS-0-IA-CV-27CV	AIR DRY B CHAMBER B AIR				

	INLET				
CNS-0-IA-PS-101A	A DRY SWITCHING FAILURE, PSW1				Prevent long term equipment damage
CNS-0-IA-PS-101B	B DRY SWITCHING FAILURE; PSW1				Prevent long term equipment damage
CNS-0-IA-PS-102A	A DRY SWITCHING FAILURE, PSW2				Prevent long term equipment damage
CNS-0-IA-PS-102B	B DRY SWITCHING FAILURE; PSW2				Prevent long term equipment damage
CNS-0-IA-CPU-101A	A DRY PC	1.1E-07	9.6E-05	Relay inadvertent signal IEEE-500; PIS	Common cause failure of both control circuits
CNS-0-IA-CPU-101B	B DRY				
CNS-0-IA-SOV-SSV5A	A DRY REPRESSURIZER V	3.0E-06	2.6E-03	Solenoid valve FTRO (Savannah River)	Common cause failure of both solenoid valves
CNS-0-IA-SOV-SSV5B	B DRY REPRESSURIZER V				
CNS-0-IA-PS-103A	A DRY LO LINE PRESS PSW3				Prevent long term equipment damage
CNS-0-IA-PS-103B	B DRY LO LINE PRESS				Prevent long term equipment damage
CNS-0-IA-REL-11CRA	A DRY OVER TEMP ALM R1				Prevent long term equipment damage
CNS-0-IA-REL-11CRB	B DRY OVER TEMP ALM R1				Prevent long term equipment damage
CNS-0-IA-REL-12CRA	A DRY SWITCHING FAILURE R2				Prevent long term equipment damage

CNS-0-IA-REL-12CRB	B DRY HI OUTLET TEMP R2	Prevent long term equipment damage
CNS-0-IA-REL-13CRA	A DRY HI OUTLET TEMP R3	Prevent long term equipment damage
CNS-0-IA-REL-13CRB	B DRY HI OUTLET TEMP R3	Prevent long term equipment damage
CNS-0-IA-REL-14CRA	A DRY COMMON TROUBLE; R4	Prevent long term equipment damage
CNS-0-IA-REL-14CRB	B DRY COMMON TROUBLE; R4	Prevent long term equipment damage
CNS-0-IA-REL-1CRA	AIR DRY A HTR CONTACT	Prevent long term equipment damage
CNS-0-IA-REL-1CRB	AIR DRY B HTR CONTACT	Prevent long term equipment damage
CNS-0-IA-REL-5CRA	A DRY HTR LOCKOUT PWR M	Prevent long term equipment damage
CNS-0-IA-REL-5CRB	B DRY HTR LOCKOUT PWR M	Prevent long term equipment damage
CNS-0-IA-RO-A	IA DRY A PURGE INLET	Prevent long term equipment damage
CNS-0-IA-RO-B	IA DRYER B PURGE INLET	Prevent long term equipment damage
CNS-0-IA-RV-10RV	AIR DRY A CHAMBER A RELIEF	Prevent long term equipment damage
CNS-0-IA-RV-11RV	AIR DRY A CHAMBER B RELIEF	Prevent long term equipment damage
CNS-0-IA-RV-12RV	AIR DRY B CHAMBER A	Prevent long term

	RELIEF				equipment damage
CNS-0-IA-RV-13RV	AIR DRY B CHAMBER B RELIEF				Prevent long term equipment damage
CNS-0-IA-SOV-SSV1A	A DRY EXH PILOT V 1, SOL #1	3.0E-06	1.3E-03	Solenoid valve FTRO (Savannah River)	Common cause failure of 4 solenoid valves
CNS-0-IA-SOV-SSV1B	B DRY EXH PILOT V SOL. #1				
CNS-0-IA-SOV-SSV2A	A DRY INLET PILOT V 1; SOL #2	3.0E-06	1.3E-03	Solenoid valve FTRO (Savannah River)	Common cause failure of 4 solenoid valves
CNS-0-IA-SOV-SSV2B	B DRY INLET PILOT V 1; SOL #2				
CNS-0-IA-SOV-SSV3A	A DRY INLET PILOT V 2; SOL #3				
CNS-0-IA-SOV-SSV3B	B DRY INLET PILOT V 2; SOL. #3				
CNS-0-IA-SOV-SSV4A	A DRY EXH PILOT V 2; SOL #4				
CNS-0-IA-SOV-SSV4B	B DRY EXH PILOT V 2; SOL #4				
CNS-0-IA-SW-5A	A DRY HTR LOCKOUT RESET SW				Prevent long term equipment damage
CNS-0-IA-SW-5B	B DRY HTR LOCKOUT RESET SW				Prevent long term equipment damage
CNS-0-IA-TC-102A	A DRY HTR OVER TEMP CONTR TSW3				Prevent long term equipment damage

CNS-0-IA-TC-102B	B DRY HTR OVER TEMP CONTR TSW3				Prevent long term equipment damage
CNS-0-IA-TE-2A	A DRY HTR OVER TEMP E				Prevent long term equipment damage
CNS-0-IA-TE-2B	B DRY HTR OVER TEMP E				Prevent long term equipment damage
CNS-0-IA-TIC-101A	A DRY HTR TEMP IND. C				Prevent long term equipment damage
CNS-0-IA-TIC-101B	B DRY HTR TEMP IND. C				Prevent long term equipment damage
CNS-0-IA-TE-1A	A DRY HTR TE				Prevent long term equipment damage
CNS-0-IA-TE-1B	B DRY HTR TE				Prevent long term equipment damage
CNS-0-IA-TS-103A	A DRY OUTLET OVER TEMP SW TSW5				Prevent long term equipment damage
CNS-0-IA-TS-103B	B DRY OUTLET OVER TEMP SW TSW5				Prevent long term equipment damage
CNS-0-IA-XFMR-1TA	AIR DRY A CONTR XFMR	5.2E-07	4.6E-04	Transformer fails to function NERC GADS code 3600	Common cause failure of both transformers
CNS-0-IA-XFMR-1TB	AIR DRY B CONTR XFMR				

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