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HVAC Equipment Aging and Reliability Issues At Commercial Nuclear Power Plants

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ABSTRACT

The Heating Ventilating Air-Conditioning (HVAC) equipment at nuclear power plants in the US age with passing time, and even with programs to maintain the systems and increase their reliability and continued operation into the next decade, the true span of the HVAC useful service life is indeterminate. Utilities are beginning to address whether or not to continue repairing the HVAC equipment when they fail or replace them. HVAC equipment is no different than any other mechanical devices as they all have finite service life which is influenced by the environment they are located in, the service they perform and maintenance activities performed on them.

The reliability issues associated with HVAC equipment center on the preventative maintenance and the design of the HVAC systems. Aging is typically associated with the sub-components of an equipment (for example, relays) due to its failure mechanism or obsolescence. However, the reliability of chillers can often be traced back to chillers being improperly sized for the application and utilization of outdated controls. Oversized chillers are often subjected a cycling condition which accelerates the aging process whereas undersized chillers defeat the system redundancy by requiring the redundant chiller to operate as well to meet the cooling load. In addition, the outdated controls are unable to control oversized chillers during the wide variance in the condenser water (employing the plant service water) temperature as seen at nuclear power plants. The commercial chillers on the contrary have a narrow temperature band for condenser water as they use cooling towers for the condenser water source.

Based on this paper the commercial nuclear industry should:

- Investigate chiller aging and reliability issues, and develop guidance for the replacement of aging safety and non safety related chillers
- Promote retention of knowledge of the HVAC system design, and utilize the lessons learned experience into new plant designs
- Prevent current design flaws in HVAC systems from propagating into designs of next generation of plants
- Promote continued preventive and predictive maintenance of simple components such as fans, dampers, and coils with the issued industry guidance
- Promote adoption of reliability improvement programs of HVAC equipment

INTRODUCTION AND BACKGROUND

The initial design life of a nuclear power plant is 40 years. The current average operating age, of a US nuclear power plant is approximately 25 years with about one third of the 65 sites approaching or having approached the 30-year mark. This time frame does not include the design and construction period which took on average 10 years. Most of the major HVAC equipment at nuclear power plants was selected with the intention that they will last through the length of the plant life. However, considering that HVAC equipment on most sites was the first equipment installed and placed in service, results in this equipment being in operation longer than the operating life of the site.

Since HVAC systems are expected to be in operation through the decommissioning of plants (up to 40 to 60 years when including the plant design life), aging of HVAC equipment becomes a factor. Aging is the term used for equipment degradation due to factors such as time, environmental factors, and variation in duty cycle. The aging (or age) of a component is thus an input into the component's reliability. Various studies have been done to address aging issues of HVAC equipment, but none have been adopted since studies were done on different products and no two products are the same.

Aging is also an input to HVAC equipment reliability consideration. Proper maintenance, metal fatigue, and replacement of obsolescent parts are some of the other elements that affect reliability. Commercial nuclear power plants, in an effort to become more efficient and cost effective, are trying to optimize the maintenance activities. The maintenance optimization process includes, for example, reviews of the maintenance being performed, frequency of periodic preventive maintenance activities, the cost of replacement parts, and impact of component failure on plant operation. Optimization generally means less maintenance on non-critical items. This optimization program is supposed to offset the reduction in workforce at the power plants (that is, less work results in a smaller workforce). In some instances, the US commercial nuclear industry has addressed maintenance issues for certain nuclear HVAC equipment with the generation of Electric Power Research Institute (EPRI) Nuclear Applications Maintenance Center (NMAC) documents (References 1-6).

A complete discussion of the science of reliability is beyond the scope of this paper however the concept of a bathtub curve is useful at this point. The bathtub curve, shown in Figure 1, depicts what is considered the failure rate for HVAC equipment. The bathtub curve is a graphical representation typically used to describe the reliability of an item or system. The bathtub curve consists of three periods (References 7 and 21):

- First Part - an early failure period (infant mortality and typically occurring during initial startup and commissioning process) with a decreasing failure rate,
- Second Part - a normal life period (known as intrinsic failure period and represents the useful service life of the component or system) with a low, relatively constant failure rate, and
- Third Part - a wear-out period that exhibits an increasing failure rate and represents the end of life period of the component.

For example, the three different parts of the bathtub curve can be thought of as identification and correction of problem or malfunctioning components for the first level; continued operation with replacements of consumable parts for the second level; and identification of problems associated with structural and pressure boundary components such as mounting frame, condenser and evaporator shell and tubing, compressor, etc. for the third level.

Some individual parts will fail relatively early (infant mortality failures), while others will last until wear-out. Some will fail during the relatively long period typically called normal life. Wear-out is a fact of life due to fatigue or depletion of materials (such as lubrication depletion in bearings). A product's useful life is limited by its shortest-lived component and it can be extended by the care and preventive maintenance that component receives. This bathtub curve is being used as a visual model to illustrate the three key periods of failure as it applies to HVAC equipment. The graph is based on the subjective experience gained to date for the HVAC systems at commercial nuclear power plants and is included here for illustration. The length of the intrinsic failure period is impacted by maintenance and equipment upgrades.

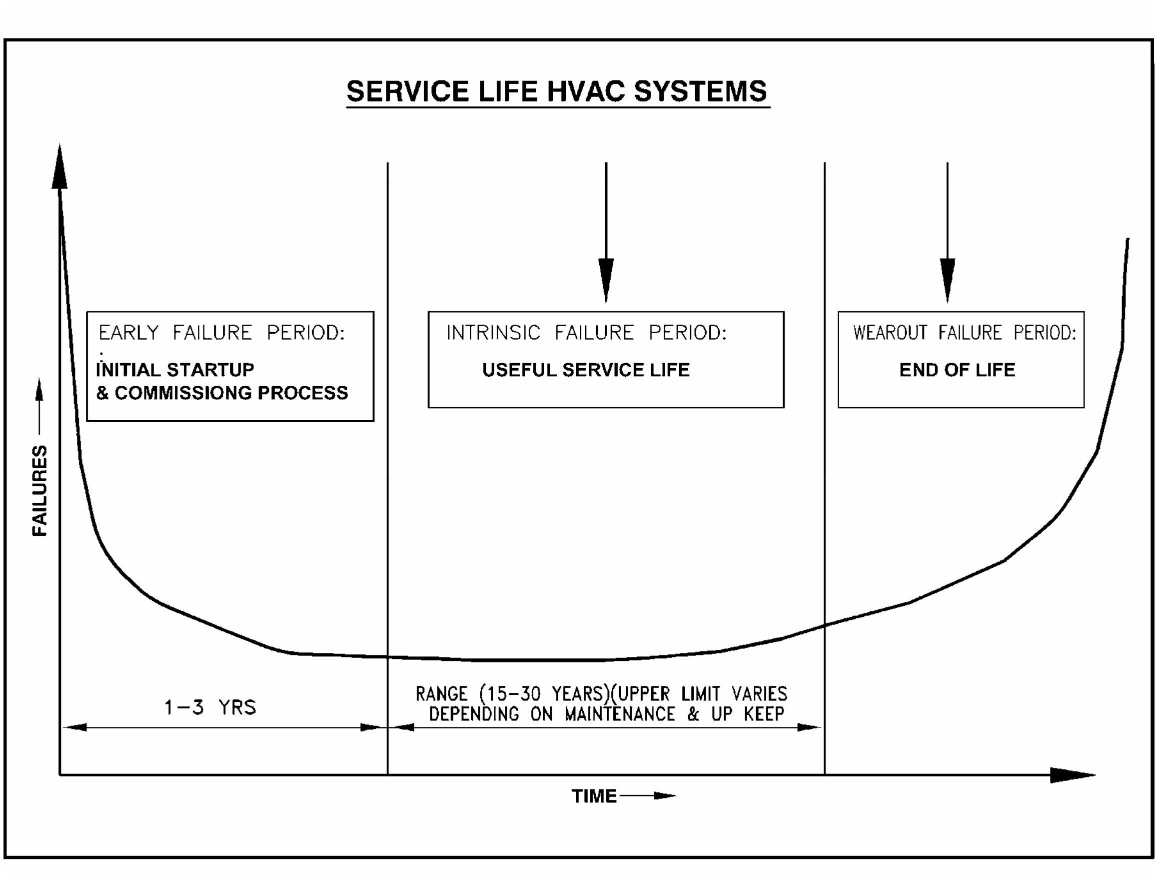

Figure 1: The Bathtub Curve

Figure 2 indicates a curve showing the availability of parts for HVAC systems. Again this curve is based on the subjective experience gained to date for the HVAC systems at commercial nuclear power plants and is included here for illustration. By using this curve with that of the bathtub curve, it is apparent that as time passes the availability of parts and the reliability of the systems occur in the same period. With the availability of replacement parts, the flat part of the curve (intrinsic failure period) may be extended, but eventually the end of the curve would be reached and failures (and thus unreliability) would increase. Initially, replacement parts are not a problem however as time progresses parts availability does become an issue. Additionally the life may not be defined by the wearing of major components, but by the availability of smaller replacement parts such as solenoids and relays. As time progresses, replacement parts become unavailable or difficult to find. . Manufacturers simply stop manufacturing outdated parts, as market demand changes and remanufacturing of those parts require expensive tooling setups. It is inferred that each site will experience different issues associated with parts availability and thus this will have to be addressed on a case-by-case basis.

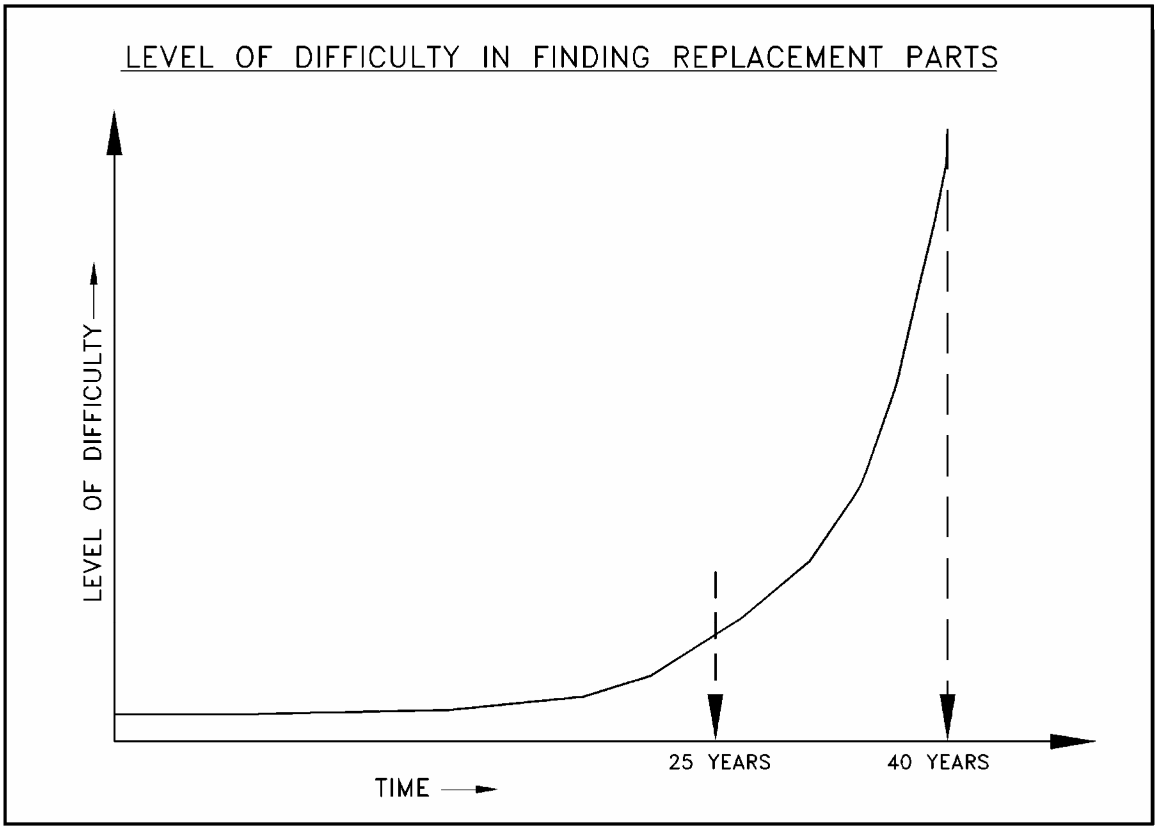

Figure 2: Parts Availability Curve

Maintenance activities on HVAC equipment at commercial nuclear power plants are typically performed by plant maintenance staff. This staff maintains a large variety of equipment from HVAC systems to items such as reactor coolant pumps. The maintenance staff also receives training on items such as configuration control, system interactions, and plant impact. This is unlike commercial HVAC systems where specialized personnel provide the necessary services, and they do not have to consider configuration control, system interactions, and plant impact. Because commercial HVAC systems and components are maintained by personnel experienced and trained exclusively for HVAC services, specific equipment problems are typically more readily identified and corrected before they escalate. The level of knowledge of the maintenance staff is a function of the training they receive and the experience they gain on the job. Lack of training and experience transforms into human error issues, also affecting the reliability of the equipment being serviced.

A second issue is the aging workforce of the current group of US nuclear plants. In certain instances, the aging work force currently maintains equipment based on knowledge and experience gained on the job which is typically referred to as "tribal knowledge." This knowledge may not be reflected in procedures or other plant documents and concerns the operating and care of equipment and systems. As the workforce retires, this knowledge can be expected to be lost. For simple items this not a concern, but for more complicated areas loss of tribal knowledge may be critical for ensuring equipment reliability.

With the increase in the number of nuclear power plants in the US seeking a 20 year life extension, questions arise concerning the HVAC equipment age and reliability for the extended life. Nuclear industry guidance/requirements such as the Maintenance Rule (Reference 18) and Institute Of Nuclear Power Operations document (INPO) AP 913 form the basis for maintenance programs. These programs then provide the avenue for appropriate management attention to equipment via vehicles such as periodic system health reports. Note that the attention individual equipment gets depends on its relative importance as compared to equipment in other systems, availability of funds, and manpower to perform the necessary tasks. HVAC systems do not directly contribute to power production, and often do not get the needed attention until they have completely failed or about to fail. Though, some plants have tried to adopt the principles of predictive maintenance to identify problems before they occur, this method can only be applied in limited scope to only some of the components in a complex system. Passive components in HVAC systems such as ductwork and piping system are expected to last through the original 40 year life of the plant, and hence their life expectancy credits inspections to be performed as part of the Aging Management Review (AMR) process to identify weaknesses and implementation of corrective action. Utilities are expected to use their best judgment in deciding when to repair or replace aging/unreliable equipment.

Therefore there are numerous issues facing a utility concerning the HVAC equipment aging and reliability. Two of these issues are the replace versus repair option and training of the maintenance staff. For this paper, discussions are limited to active HVAC equipment such as fans, room coolers (coils), dampers, and chillers and how aging issues impact reliability. The filter aspects of the HVAC systems are already well documented for charcoal, high efficiency particulate air (HEPA), and other filters and as such are not discussed in this paper (References 9-11, 24).

INVESTIGATION

General

The technical expertise of the commercial HVAC industry lies primarily in American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE). Even though ASHRAE has not clearly defined the service life issue, it is a general understanding in the HVAC industry that the service life of a chiller[1] such that in use at a residential building is about 15-20 year and that in a commercial building it is about 20-25 years[2]. Since the design life of a nuclear power plant is 40 years, the HVAC equipment was expected to last through the life of the plant. Since no plant in the US has been operating for that length of time, it is difficult to validate the expected service life. Current operating experience has indicated that some HVAC equipment may not last through the original life of the plant and definitely not through the extended life.

The nuclear HVAC industry has not established any specific replacement guidelines for HVAC equipment (Appendix 1). However, generic guidelines (Reference 8) can be used to determine if the equipment needs to be replaced or repaired when it fail.

Additionally the cost of upgrades to increase reliability can be significant. The upgrades have to include consideration of redundancy, seismic qualification, environmental qualification, procedure and document changes, and emergency power

A nuclear power plant chiller replacement can cost between $2 and $4 million (reference 22) depending on complexity even though the cost of the chiller itself is usually small. At other non-nuclear industrial facilities, the chiller replacement cost is justified by cost benefit analysis taking credit of energy cost of savings following the replacement. In the past, energy usage of chillers was in the order of 1.0 to 0.81 KW/ton of cooling. Currently, chillers have become more efficient and energy usage has dropped off to about 0.60 to 0.51 kw/ton of cooling. As an example, for a cooling requirement (assumed constant throughout the year) of 1275 tons, the energy cost savings (based solely on chiller operation) would be 0.31 kw/ton of cooling or a total of approximately 395 kW.

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[1] **Chiller is referred to as a generic refrigeration machine representing air conditioners, direct expansion units, and water chillers**

[2] **ASHRAE HVAC Applications Handbook 2003Table 36-3, "Estimates of Service Lives of Various System Components" for package chillers. Note that with today's efficiency improvements many companies (other than power companies) replace chillers sooner due to cost savings in energy alone.**

For an industrial facility, the energy cost savings can be computed assuming electricity cost of $0.05/kwh:

Energy Cost Savings = 0.31 kw-hour/ton X 1275 ton * 24 hours X 365 days X $0.05 dollars/KW-hour

Energy Cost Savings = $171,119.50 or approximately $170,000 year

The above example illustrates how a commercial entity (other than a nuclear utility) would approach replacing a chiller. The cost of a new chiller can run from $250,000 to $500,000. The total cost savings would also include cost associated in the reduction of maintenance man-hour savings as a result of usage of a newer machine. The total savings could then pay for a new chiller (outside the nuclear industry) in a relatively short period of time with the added benefit that the company has a new chiller that will operate reliably and require less maintenance.

However, due to high costs of chiller replacements at nuclear power plants and utilities cannot take credit for energy cost saving to justify chiller replacement costs, many chillers are maintained rather than replaced.

Fans/Dampers

The expected service life of a fan is expected to be longer than that of a chiller as it is a simpler machine, provided it is routinely maintained. The service life of a fan can be anywhere from 15 to 25 years in a commercial installation (Reference 12). The service life of a damper is not very different of that of a fan (reference 6). However, catastrophic failures of fans have occurred at nuclear power plants, and the failures can be attributed to those in systems with little or no maintenance. In some instance, a fan failure can be attributed to the cascading effect of a failing fabric duct connector, which is a passive component in a system. Due to cyclic loading of fan, failures of fan blades are often attributed to metal fatigue.

Fans can fail catastrophically and a number of occurrences in the commercial nuclear industry have been documented. Commercial nuclear sites may have as many as 300 fans operating at any one time related to power production. Thus the number of fans operating in the US commercial nuclear plants is approximately greater than 19,000 fans. This is a large number of components and the failure rate is very low (less than 0.015%/year based on existing data). The common cause for these failures is due to fan operation in either a stall condition (that is, little airflow) or outside its class rating. This type of operation leads to vibrations being induced in the fans. The vibration problem may not be evident to plant maintenance staff as past vibration historical data indicated normal vibration levels. A reason vibration measurement may not reveal such problems since fan balancing problem can mask a vibration issue. As a result, over a period of time, the vibration can result in the failure of the fan bearing causing the fan to seize up and the fan motor to trip on overload or simply burn up. Vibration can also result in the fan blades or fan hub to crack and subsequently resulting in catastrophic failure of the fan assembly. Methods to prevent this are known, and well documented but requires the maintenance and engineering staff be knowledgeable of these techniques (Reference 6). Fans can also fail due to outside influences (such as breakers and inlet or outlet damper failure).

Thus increasing the reliability of a fan can be a simple task. After determining the critical function of the fan, an experienced system or maintenance engineer can recommend the appropriate periodic preventative maintenance. For example, flow and pressure measurements can be made to assure the fan is either not operating in a stall or outside it class rating. Periodic vibration measurements can provide the assurance that the fan is running smoothly. Trending of vibration data can be used to determine if field balancing will be necessary to resolve the vibration issues. If field balancing of a fan does not resolve high vibration issues, this may be an indication of other issues with the fan (that is, operating in a stall).

Catastrophic failure of dampers is not common. There is no readily available documentation for a complete damper failure. However, damper failures do occur and can be attributed to many causes. The most common are:

- Binding of the damper linkage or blades (misalignment, excessive flow, or bearing failures)
- Damper actuator issues (either not opening or closing completely)
- Relays and switches not operating properly
- Damper seals non-existent or degraded
- Damper blocked open due to foreign material of maintenance

Of the above items, the binding of the damper linkage and degradation of damper seals are most easily addressed and can be remedied by periodic maintenance. Damper actuators are considered as a separate subcomponent, and, when problems occur with the actuator, its replacement can allow the damper to function reliably. Damper failures can also be impacted by the airflow through the damper inducing vibration. Though adequate documentation does not exist in this regard anecdotal evidence suggests that keeping air velocity through dampers to those recommended by manufacturers can reduce or eliminate this type of failure. Thus damper aging can be slowed through proper maintenance of its seals, alignment checks of its linkage, and periodic lubrication of its bearing. Reliability of a damper can be increased via periodic actuator maintenance and routine damper control checks.

The maintenance staff can be easily trained in the care and maintenance of dampers and fans. Knowledge and adequate training of the above issues for example would prevent future catastrophic failures of fans. Additionally dampers are simple devices and the function of the dampers changes little over time. Thus the dampers and fans can be maintained to reduce the impact of aging and increase reliability.

<u>Room Coolers/Coils)\</u>
The room cooler consists of a fan and a cooling coil, and the aging concern is with the cooling coil in the room cooler. . The service life of cooling coils in room coolers served by the plant service water system continue to be questionable, as service life tends to vary with the quality of service water, location of the room coolers and frequency of the maintenance activities performed on them (see Appendix 1 for survey summary). Failure of a cooling coil is measured by number of leaks in the cooling coil. Even though efforts are made to repair those leaks, there is often a finite number of tubes that can be plugged without affecting its expected cooling capacity. Thus the service life of a service water cooling coil is limited by the amount of repairable leaks and needed cooling capacity, and generally varies between 13-18 years. In contrast, the cooling coils in the closed loop chilled water system have not experienced similar failure mechanisms and hence, it can be concluded that their life expectancy will match that of the plant.

The failure of a cooling coil is usually classified as tube leaks as a result of MIC or tube thinning due flow accelerated erosion or failed brazed joints or permanently fouled tubes. Even though airside tube failure is not a common occurrence, fouling of the airside tube fins is a maintenance challenge in ensuring their cleanliness. Improper cooling coil fin cleaning technique can sometime cause permanent damage to the fragile fins and render them unrepairable (Reference 4).

Cooling coils are typically a passive component but need to function reliably for heat removal. The aging is primarily dependent on the condition/velocity of the water flowing through the coils. However, site-specific data are needed to determine the appropriate coil material to prolong expected coil life. Improved controls on both water and air sides of the coils will prevent problems with the coils even though the airside problems are not the overriding factors in determining coil aging or reliability.

Replacement of cooling coils is labor intensive; however it has been performed at many plants as a result of cooling coil failures. Issues impacting replacement is procuring coils that fit dimensionally into the space provided or material changes that lessen the impact of either corrosion or erosion. Common occurring problems (identified above) can also be addressed and corrected when replacing the coils through design changes.

The maintenance staff can also be easily trained in the maintenance of coils. Routine cooling coil inspection data can be trended to predict when coils replacements can be expected. Thus the aging of the coils and their reliability can be addressed through proper care and replacement.

Chillers

Chillers are the primary cooling media for conditioned spaces and often necessary for maintaining a plant online (Reference 16). Since a chiller is essentially a complex machine utilizing a lot of plant resources in its upkeep (mechanical maintenance staff, electrical maintenance staff, Operations personnel, engineering staff, Technical Specification (TS) considerations, etc.) the discussion addresses the chiller aging issue in some details, how it may affect reliability, and what constitutes a failure as the existing Maintenance Rule (MR) criteria do not adequately define it in relationship to chillers.

According to Title 10 of the US Code of Federal Regulations, the maintenance rule (MR) (reference 18) requires plants to monitor the effectiveness of the maintenance being performed on the plant. The rule applies to both safety related and non-safety related equipment[3]. Chillers have been identified as equipment that is a problem within the MR (Reference 19). This implies that chillers are reliability problems for most commercial nuclear power plants. Thus plants are addressing chiller reliability through either replacing equipment or addressing the maintenance aspects of the equipment in order to increase reliability. Finally, industry data indicates that there is a 5% probability per year of a redundant chiller failure for a potential loss of $2.6 million over a 20 year period if timely actions are not taken to increase chiller reliability (Appendix 2). Thus improving chiller reliability is a focus for many utilities.

Some nuclear power plants have started to replace their chillers after about 25-30 years of operation (Reference 15). The outcome of such chiller replacements is reliable operation with more efficient machines and up-to-date controls. As a result of the 1990 clean Air Act, the CFC refrigerants (R11, R12, R113, R114, R115 and R500) commonly used in US commercial nuclear power plant chillers were phased out in 1996 (Reference 20). However, the nuclear industry continues to embrace the use of CFC refrigerant based chillers in the pretext to save on replacement costs (Appendix 1). Plants have stockpiled such refrigerants to ensure continued operation of their CFC chillers. Since the CFC phase-out did not trigger an exodus of chiller modification or replacement, the service life of a chiller at a nuclear power plant can be tied solely to its performance criteria and availability of replacement parts. Commercial chillers in the vintage of late 1950 and early 1960 are still in operation, but these are unusual and are generally exceptions to the rule. These vintage refrigeration machines are outdated and not as efficient as compared to those presently available, and users of such chillers may have some unusual justifications and outlying reasons to continue operation of those machines.

There are different types of chillers, and the ones commonly in use at a nuclear power plant are limited to the electric motor driven water cooled centrifugal chillers and air cooled reciprocating and screw chillers. The cooling water source for the water cooled chillers is usually the plant raw service water. The plant raw service water for the chiller condenser cooling is not ideal as the water tends to have lots of suspended solids and organisms besides the extreme temperature swing between the summer and winter months. The quality of the service water can accelerate chiller aging while affecting its reliability. This results in the same issues as can be seen in those for room coolers.

The other factors that result in chiller aging are vibration, cycling of pressures due to temperature changes, breakdown of chemicals, and the ambient environment. The refrigerant side of a chiller is

[3] **Non-safety related equipment whose function may be in an emergency operating procedure, whose failure could result in a reactor SCRAM, or whose failure could prevent a safety related component from operating.**

usually not a problem unless the refrigerant has high moisture content. A high moisture content promotes accelerated corrosion and chiller aging. Moisture can enter a chiller through the condenser side of the chiller due to the issues discussed. The chiller controls in older machines usually employ relay logic, and high rate of chiller failures are often attributed to malfunction or failure of the chiller controls. The chiller compressor usually does not pose problems provided the refrigerant and oil qualities are maintained and is periodically overhauled. Routine oil analysis can also provide indication of potential failure. Failure to perform critical maintenance activities or not understand the system design or the limitation of chiller component is often a precursor of a human error related to chiller failure. Whatever the failure mechanism, a combination of routine and predictive maintenance and trending of daily operating data can prevent unpredicted failure (Reference 2).

The chiller in some cases is grossly over designed for its application (Reference 14), and this may cause the chiller to operate mostly at reduced load condition with the inlet vanes partially closed. Even though a chiller can operate down to 10% of its design capacity, operating a chiller under low load condition for a prolonged time period can subject the chiller to increased fatigue loading. Similar phenomenon also happens when the cooling water temperature varies from the summer to the winter months when the cooling requirement is also considerably less (Reference 2). All of factors can cause chiller to cycling. Cycling differs from loading and unloading for which the chiller is designed (i.e., example going from 80% load to 60% load and back). Cycling can be viewed as the machine turning on and off. This then requires components (relays, controls, motors, etc.) to cycle on and off thus increasing the wear on the component. Chillers are designed to operate continuously and this cycling is typically not included in the design.

Lastly the maintenance staff at plants is aging as the equipment ages. Future staff will be familiar with digital controls and logic and not the controls developed in the 1960's or 1970's. Additionally some chiller manufacturers either no longer make parts or are out of business entirely, further complicating the issue. Chillers are complicated thermodynamic machines and require years of experience and training to maintain effectively. With parts and equipment no longer being manufactured and maintenance information knowledge potentially being lost as maintenance and engineering staff ages it is crucial that plants consider how they will address chillers to avoid costly issues such as a plant shutdown.

Summarizing the above discussion, chillers are complicated machines that require a significant amount of plant attention to maintain them reliable. Chillers typically are replaced at the 20-25 year interval but their life may be extended. Extension of life depends on factors such as maintenance and availability of parts. Reliability can be attributed such factors as (but not limited to):

- Being oversized – resulting in constant cycling of a machine designed not to cycle (this is a major factor)
- Inadequate controls – most chillers have controls intended for steady state operation
- Aging issues – examples are bearings and coils/tubes erosion corrosion
- Refrigerant issues – plants were considering stockpiling discontinued refrigerants, however these plant may now have to consider replacement or upgrades due to plant life extensions

The maintenance/engineering staff knowledge is also a factor in the aging and reliability of chillers. Well trained and experienced staff can contribute to prolonging service life and maintaining the reliability of the chillers.

RESULTS

The HVAC equipment on most sites has or will be in operation longer than the operating life of the site. This equipment is subject to aging and increasing unreliability. Proper maintenance can slow the aging process and increase reliability, and plants have started to optimize their maintenance programs. However, the reliability of the HVAC systems/components will decrease over time as components wear and the end of life is approached. The workforce knowledge and training will also impact the quality of the maintenance and thus reliability of HVAC systems. Adequate information for the care and upkeep of HVAC components also exist, and needs to be documented if not already done so. This information in many instances is invaluable to diagnosing and correcting problems.

HVAC components can be simple (e.g. Damper) or complicated (e.g. Chiller). These components can also be arranged in either simple or complicated systems. These systems can function reliably with the proper attention. However, the information on when to replace components and when they begin to become unreliable is scarce. With the equipment in many sites approaching or having already exceeded their design life (25-40 years) decisions on repair or replacement are becoming more important. This would require the engineering work force to develop necessary justifications for either repair or replace without adequate industry guidance. For complicated systems, training and experience gained on the job are also important as no new plants are being built in the US in which to gain experience.

Decision on replacing dampers, fans and cooling coils is a simple matter whereas for a chiller the decision is more involved. Chillers are expensive equipment and are typically in large complicated systems sometimes with TS considerations involved. Often the cost savings associated with a chiller replacement may not justify the replacement cost, but it may be necessary to ensure system reliability.

Maintenance staff knowledge of simpler HVAC equipment can be enhanced by proper training and this can be used to increase reliability of those equipment regardless of age. The training on chillers is more rigorous but for older chillers training becomes more important and finding training people will be getting difficult with time.

CONCLUSIONS

Based on the above discussions the commercial nuclear industry should

- Develop guidance and long range plan for the replacement of chillers
    - Develop guidelines that can reduce the cost of replacement
    - Should consider the use of digital controls
    - Consider the cost of power savings
    - Training staff in the maintenance of the chillers (including controls)
- Maintain the level of knowledge of HVAC system design and utilize the lessons learned experience into new plant designs
- Continue to maintain simple components such as fans, dampers, and coils with the current industry guidance
- Promote adoption of reliability improvement programs of HVAC equipment

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Appendix 1
Survey Information[4]

NHUG Survey 1
Query. Which sites have defined criteria for replacement versus repair of HVAC equipment?
Response Summary: 16 US sites responded to the query. This represents 25% of the operating sites in the US. All 16 sites responded indicated that there is no formal criteria set for determining when HVAC equipment should be replaced versus repaired. However, some sites (50%) are developing criteria based on life cycle costs. This life cycle cost is a function of recurring maintenance cost, initial cost, anticipated out of service time, life expectancy (or remaining life expectancy), etc. Additionally, three sites (19%) do take into account factors such as parts availability, reliability, and costs when making a decision. These decisions are made typically be Engineering.

NHUG Survey 2
Query: How is air/water coils monitored for replacement.
Response Summary: 10 US sites responded to the query (15% of operating sites). 80% of the respondents indicated that coils were replaced when leaks were observed. 20% of the respondents did not have coils leaks. Those that did not have coil leaks had closed systems with the water chemistry controlled to prevent corrosion. Additionally the following information was obtained from the respondents in addition to the response to the query.
Coil life maximum (raw water) can be expected to be 27-30 years before failing. (Note ASHRAE in Reference 6 gives a 20 year life on coils but makes no distinction on if the coil is using raw or treated water)

- *Coils can fail between two and 15 years depending on the condition of the raw water*
- *CuNi coils hold up better for erosion*
- *Coil headers work best for cleaning coils*
- *Closed system coils will last indefinitely (due to water chemistry control)*

NHUG Survey 3
Query: Due to refrigerant phase-outs how is this impacting chiller replacement.
Response Summary: 14 US sites responded to the query. This represents 21% of the operating sites in the US.
5 sites will retrofit to new refrigerants (36%)
5 sites will stockpile refrigerants (36%)
4 sites will replace equipment, at end of life (28%)

[4] **Summaries of the information are presented here. The individual data is presented in this format to show it as Industry data and not individual plant data.**

Appendix 2
Cost of Chiller Loss

Conclusion:
Data indicates that there is a 5% probability per year over a 20 year period of a redundant chiller failure for a potential loss of $2.6 million.

Data on Potential Shutdown
Industry Data related to potential shutdown of plants due to loss of control room chillers. Data was collected from the daily reports of plant notifications to NRC. Between 1997 and 2000 there were nine events in which the loss of two trains of control building chillers resulted in entry (or potential entry) into LCO 3.0.3 since. There were no shutdowns, but down powers were initiated in some instances. In each case a train of cooling was restored to an Operable status within the LCO AOT and the unit returned to full power. In no case was a unit shutdown commenced due to a loss of one train of equipment.

The data represents about 350 years of operation within the US nuclear industry. This is one event for every 38.9 years of operation. Knowing that only half the sites in the US had implemented TS for control room chillers this then equates to potentially one event for every 19.5 years of reactor operation for those plants with chiller TS. The plants that initiated the 3.0.3 entries were aware of the safety significance of the chillers due to the new standard TS as evidenced by either their implementation of the new specifications or planned implementation. Based on the NRC information only, half the US operating plants have implemented the new TS.

A reasonable rate for the possibility of a unit entry into LCO 3.0.3 is thus estimated to be about 5% (based on industry data) for a plant that has implemented a TS for control room chillers. 5% equates to approximately one LCO 3.0.3 entry/potential shutdown once every 19.5 years.

As chillers have not always been treated as true SR equipment by other plants in the industry (that is chillers have not been given the same attention as say a diesel-generator) then the industry could possibly see a few plant shutdowns before the condition is addressed and steps are taken to assure that chillers are CORRECTLY addressed. Note that the industry also has some generic issues concerning chillers. These issues are large differences between the normal operational loads (low) and the accident loads (high) of chillers making them difficult to maintain (constant cycling and wearing out of components), utility modifications to chiller controls adding automatic starts (idle chillers - if not properly designed - do not easily start automatically), and control problems during cold weather operation (TCV's on water cooled chillers). The industry is slowly addressing these issues but has not made a concerted effort. The problems are solvable, but require the necessary resources to solve them.

Conclusion:
There is an approximate possibility of unit shutdown once every 19.5 years due to loss of both trains (or more appropriately loss all cooling) of cooling to the control room. Should this happen then it is estimated that the unit would be down at least one week (considered reasonable) returning BOTH trains of cooling (chillers) to OPERABLE status.
The revenue loss due to unit shutdown for a week (based on an average 945 megawatt unit) is estimated as::

[16.19[5] dollars/mw-hour (lost) X 945 mw X 24 hours/day X 7 days] = $2,570,314.50 or $2.6 million

[5] **Nucleonics Week Dated August 7, 2003; U.S. nuclear plants report continuing efficiency gains (reference 17)**