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Short-Term Shutdown Guidance for Steam Turbine-Generators and Auxiliary Systems

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PRODUCT DESCRIPTION

This report provides guidelines on the methods that utilities should consider to protect operating equipment when it is removed from service for short periods of time. The equipment and systems considered in this report include the steam turbine, generator, exciter, feedwater heaters, and related auxiliaries. The timeframe for this report includes outage periods from a weekend to six months.

Improper layup can cause long-term equipment damage and premature failure. Increased shutdown frequency and duration due to change of operating mode (such as to cyclic operation) and varying system load demands have increased the challenges to planners, operators, and chemists in providing equipment protection during shutdowns. Compounding these problems is the uncertainty of outage durations.

Results and Findings

The guidelines in this report have been developed to provide direction in selecting the appropriate layup procedures for steam turbine-generators and related equipment. This report provides guidance on layup methodology and selection criteria for short-duration shutdowns.

Challenges and Objectives

Layup procedures depend on the shutdown conditions and requirements. Depending on these conditions and requirements, equipment and units must be maintained in varying states of readiness. No matter what the operating requirements, attention must be paid to protecting the assets and enhancing availability. Plant personnel must be able to choose an appropriate layup procedure for each shutdown condition.

Application, Value, and Use

These guidelines consider various factors (such as design, materials, and site conditions) for each set of equipment, the operating mode and reason for the shutdown (such as maintenance, dispatch, outage duration, and return-to-service requirements), and the capabilities of each facility to appropriately implement different layup procedures.

EPRI Perspective

These guidelines will help utilities to enhance equipment availability and reliability. They are based on the three guiding principles for equipment protection defined in the Electric Power Research Institute (EPRI) report *Cycling, Startup, Shutdown, and Layup Fossil Plant Cycle Chemistry Guidelines for Operators and Chemists* (1015657). By applying those principles and the layup procedure options outlined in this report, utilities can select and customize layup practices that will meet the unique needs of their units.

Approach

EPRI and EPRI consultants, with the assistance of a Technical Advisory Group, were tasked with developing a guideline for practices and procedures on short-term layup of fossil turbine, generator, condenser, exciter, and auxiliary systems. Researchers reviewed existing material and conducted discussions with industry personnel, and the Technical Advisory Group reviewed the materials. The report defines layup periods and applicable layup requirements and procedures for components and systems and describes how to react to changing outage conditions.

Keywords

Dry layup
Layup
Shutdown
Steam turbine-generator
Wet layup

ABSTRACT

Several documents describe long-term layup of units; however, little has been done to review these layup procedures for their proper applicability to shorter-duration outages. It is well understood that corrosion and contamination of equipment occurs whenever it is shut down and exposed to air and moisture. Many units are experiencing short-term outages due to age and cycling, as well as reduced or seasonal dispatch demands.

It is important that proper storage criteria be followed to protect the equipment and systems from corrosion and contamination. The shutdown and layup periods should be viewed as a continuation of the good practices used during operations.

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1
INTRODUCTION

1.1 Introduction

Improper layup can cause long-term equipment damage and premature failure. Utility planners, operators, and chemists face the challenges of providing equipment protection during unit outages and shutdowns. Compounding these challenges are the aging of the equipment and conversion from base-loaded to cycling or peaking operation.

Materials used in steam and water systems readily corrode or pit when exposed to air and moisture, a condition that is often created by poor layup procedures. Thus, without perceiving what is taking place, a plant can unwittingly experience loss of unit performance, impaired serviceability, extended startup, or after-startup failure. Proper layup procedures can extend the useful life of a unit; reduce repair, replacement, and maintenance costs; and prevent costly outages [1].

The objective of proper layup and equipment storage is to eliminate pitting and general surface corrosion and maintain the stability of protective metal oxides formed during normal operation. Successful implementation of equipment protection serves the broader purpose of minimizing damage by other mechanisms that are active when the unit is in service.

Plant outages for repairs or maintenance can be as short as a few days to as long as several months, depending on the reason for and the nature of the outage. It is quite common to have many plant systems and components open for inspections, maintenance, and repairs during an outage. Depending on the precautions that are taken by the plant staff, the internal surfaces of these systems and components will be exposed to air or moisture for various periods of time. A source of oxygen is required for most corrosion mechanisms that have been observed in power plants; oxygen greatly accelerates certain corrosion mechanisms, even at ambient temperature.

Changing outage or shutdown durations present additional challenges. The unit that was shut down due to economic conditions might have to be activated sooner or later than initially specified. Technical as well financial implications of this uncertainty can be profound.

Proper layup practices must consider the entire unit. Protection strategies will take into account site-specific factors, operational requirements, and unit design, as well as a seamless transition from service, through shutdown, into the out-of-service or layup period, and through the subsequent startup and return to service of the unit. The proper storage of all major unit components or systems should be incorporated into a comprehensive layup procedure for a unit. This guideline focuses on steam turbine-generators and their related systems.

1.2 Equipment Covered in This Guideline

The following equipment types are covered in this guideline:

- Turbine (high-, intermediate-, and low-pressure)
  - Extraction lines
  - Drain lines
  - Lubricating oil system
  - Main stop and control valve internals
  - Turning gear
  - Seal oil system
  - Hydraulic controls
- Condenser (steam side and hotwell)
- Feedwater heaters (tube and shell side)
- Deareator and storage tank
- Exciter
- Generator
  - Rotor
  - Stator
  - Seal oil
  - Cooling system
  - Hydrogen supply
  - Carbon dioxide supply
  - Stator water cooling

The steam turbine, turbine condenser, and reheater are often considered as a unit because they are typically interconnected, with no reasonable means of isolation from each other. Many auxiliary components are not typically subjects of either short- or long-term layup procedures, except under special circumstances such as mothballing, including the following:

- Generators
- Motors
- Air receivers, inert gas tanks, and other similar tanks
- Tanks
- Piping
- Pumps

- Switchgear
- Circuit breakers
- Control and relay cabinets

Although protecting the auxiliary components of a power plant during standby is equally as important as protecting the boilers and turbines, it might be impractical to protect all auxiliary equipment during a shutdown. For example, the time required to protect some auxiliary parts might be longer than the length of the shutdown. In other cases, the cost of the treatment can approach the cost of replacement and, therefore, not be cost effective [1].

1.3 Layup of Systems

When unit components are not in service, they are subject to deterioration and contamination due to exposure to the elements and physical damage due to maintenance, inspections, or other ongoing activities at the plant. Depending on the precautions taken by the plant staff, the internal surfaces of these systems or components can be exposed to air for various periods of time. A source of oxygen is required for most corrosion mechanisms, even at ambient temperatures.

The shutdown and layup periods should be viewed as a continuation of the good practices used during operation. The primary purpose of the cycle chemistry is to provide protective oxide surfaces on all components throughout the steam and water circuits. The primary purpose of the shutdown and layup practice should be to maintain those protective surfaces [2].

Steam turbines are particularly susceptible to corrosion damage because air is drawn into the turbine during cooldown. The oxygen in the air combines with the steam that has condensed in low spots and cavities that are not drainable, thus providing the ingredients for corrosion to quickly develop [3]. Three guiding principles should govern all layup decisions and practices [3]:

1. **Keep the chemical oxidation-reduction potential (ORP) of the water in the cycle the same during all operating conditions.** This refers not only to excluding air but also to maintaining chemical residuals that exist during operation. If reducing agents (such as hydrazine) are used during normal operation, they should be used during layup; if they are not, they should not be introduced for layup. Guidelines include the following:
   - Do not add reducing agents during shutdown, layup, or startup, when using oxidizing all-volatile treatment or oxygenated treatment as the feedwater treatment.
   - Maintain a negative ORP by excluding oxygen and keeping a constant level of reducing agent in the water during shutdown when using reducing all-volatile treatment treatment as the feedwater treatment. (The ORP should be verified as negative because the presence of a reducing agent alone does not ensure a negative potential.)
   - Do this while actively complying with guiding principle 2.

2. **Keep water from becoming oxygenated by the surrounding environment.** Regardless of the chemistry during operation, water in the steam cycle should never be allowed to become saturated with oxygen by unrestricted contact with air because it will cause corrosion. Guidelines include the following:
   - Maintain pressure on the boiler and deaerator and maintain vacuum on the condenser as long as possible.
   - Introduce nitrogen to the equipment to exclude oxygen all the time that the unit is not pressurized. The nitrogen blanketing system should have multiple entry points to ensure that all equipment that contains water is blanketed.
   - Avoid adding oxygenated water to a cold unit to replace water lost due to leaks. Instead, use one of the recommendations for drained equipment to minimize the dissolved oxygen added to the unit.
   - If equipment has been drained, use treated, deaerated (<100 ppb), high-purity water to fill equipment before startup and as cycle makeup during the startup. This can be accomplished in several ways, including the following:
     - Sparging oxygenated water with steam or nitrogen in the condenser, deaerator, or boiler.
     - Using gas transfer membranes to remove oxygen before adding water to the unit.
     - Heating the water while in the feedwater piping and recirculating it to the condenser while it is under vacuum (cleanup loop).
     - Using auxiliary steam to prevent air ingress at deaerators during startup.
3. **Keep water and moisture out of steam-touched components and any water-touched surface that is to be maintained dry during the shutdown period.** Any successful layup practice will require consideration of all the water- and steam-touched equipment in the steam cycle and should begin when the equipment is being removed from service. The partial layup of the system or layup of only some of the equipment (boiler) will not produce the desired results or provide adequate corrosion protection. Guidelines include the following:
   - Rapidly drain water-touched components and evacuate the reheat steam lines (using the vacuum in the condenser) while the piping is still hot to promote complete drying before applying dehumidified air.
   - Use dehumidified air to dry out the deareator, turbine, condenser, and other piping that would typically be wet and exposed to air.
   - Maintain the relative humidity inside the boiler, deaerator, condenser, and related equipment at less than 35%.

In all cases, it is important that proper storage criteria be followed to protect the equipment and systems from corrosion and contamination. The proper layup will depend on the equipment condition, the materials of construction and design considerations, the duration of the layup, the local site conditions, and the safety of personnel who might perform maintenance on the equipment.

1.4 Definition of Short-Term Layup Period

The duration of a short-term layup can be from 2 days to 26 weeks. Short-term layups, therefore, include weekend shutdowns for cycling and maintenance, scheduled maintenance shutdowns that can last several weeks, longer unit shutdowns due to major plant retrofits and improvements, or units placed in cold standby due to other power system requirements. EPRI defines shutdown periods as follows [2]:

- **Short-term shutdown.** Periods extending overnight or through a weekend. It is typical of cycling operation and utilizes a wet layup approach.
- **Intermediate shutdown.** Periods extending more than a weekend and up to one week. This could typify a shutdown for equipment repair of a modest nature. Either wet or dry approaches can apply.
- **Long-term shutdown.** Periods extending for more than one week. This could include major equipment repair, planned outage, or a long-term layup due to system load requirements, which could include mothballing. Both wet and dry approaches can apply.

Although placing a unit in layup might seem to be a simple process, the unit must be maintained to protect the equipment and personnel and to allow for maintenance, testing, and other activities. The length of shutdown plays a major role in the type of layup procedure selected. The rapidity with which plant personnel need to and are able to return the unit to service can place constraints on how the units are shut down or the procedures used for layup.

Although it is simpler to choose a layup approach based solely on the length of the shutdown, plants should consider a number of additional factors. In addition to the anticipated duration of the outage, plants should consider the purpose and conditions surrounding the outage. Criteria to be considered in selecting the proper layup practice are described in Section 1.5.

1.5 Factors Involving Selection of Layup Method

Most short-term outages, if not due to lack of demand, are due to some form of plant maintenance. The duration of the maintenance activities can range from a few days to many weeks. In many cases, it might not be possible to provide the appropriate layup because the equipment is opened for inspection and repair.

The selection of the layup methods for the various plant systems and components should begin when the planning is initiated for the next outage. Some of the factors involved in choosing a layup method are fairly obvious, whereas others might be less obvious. These factors are described in the remainder of this section [4].

1.5.1 Outage Duration Versus Maintenance Activity

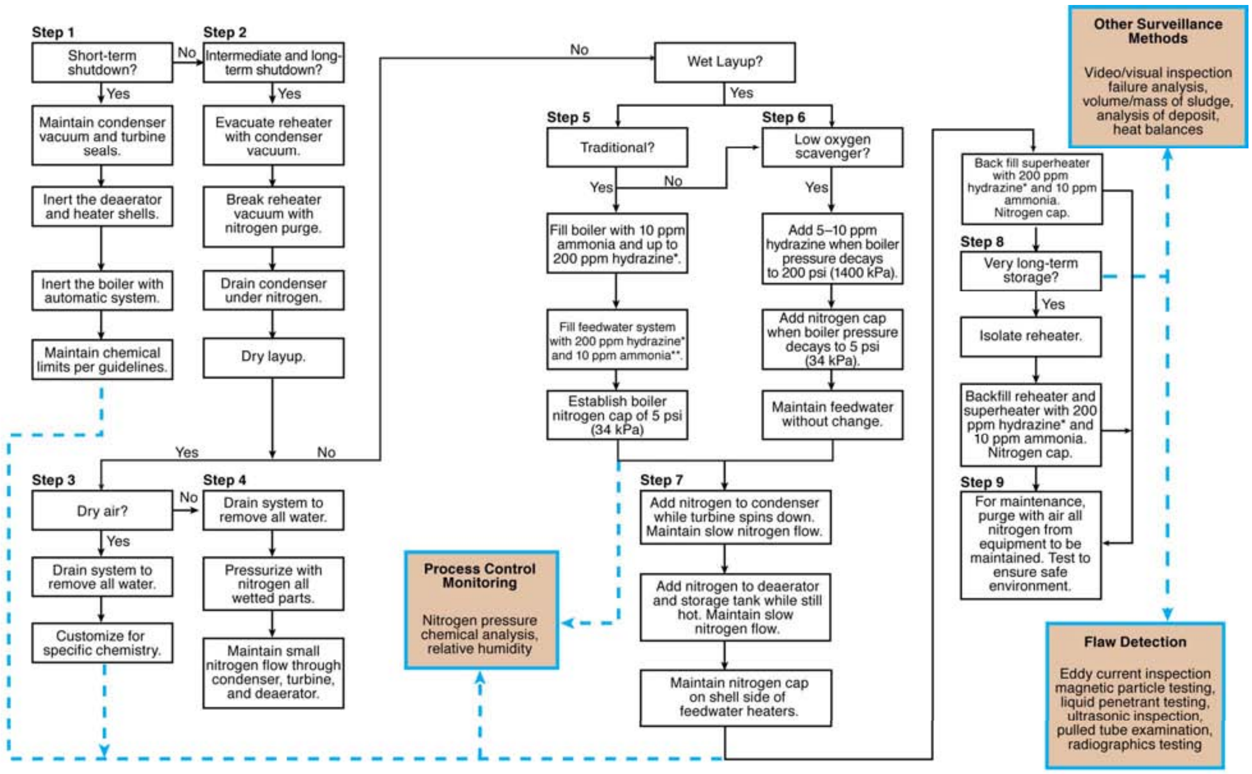
The duration of the outage and the repair or maintenance scheduled for the system or component can directly affect the choice for the layup method. If maintenance on a given component will require the entire outage to complete, obviously little can be done to place that component in layup. If it takes one month to place a system in dry, dehumidified layup and one month to return the system to service after layup, it would not be practical to use this layup method if the outage duration were only two months. Thus, the time required to place the component or system in layup with the selected method must be compatible with the scheduled maintenance activity. In addition, the maintenance activity should be scheduled in a manner that will minimize the time that the equipment will not be in proper layup or the number of times that a component or system must be taken into and out of layup. Strong consideration should be given to the anticipated maintenance that will be required during the outage. This might impact how equipment is drained or cooled and where the staff will be required to enter the equipment.

1.5.2 Convenience

The layup method used must be easily implemented in a timely manner. For example, if it takes a week or longer to implement layup for a typical outage of six to seven weeks and another week or longer to prepare the system or component for plant startup, the method might be too complex and, in all probability, it will be avoided by the plant personnel. For instance, if dry layup is to be used, it must be convenient to connect temporary drying equipment and to circulate the dried air through the system, a portion of a system, or a component. It is clear that the system access points (such as vents, drains, handholds, and manways) and flow paths must provide easy access to the component or system.

1.5.3 Organization

Plants that appear to have the most effective layup programs are those that develop flowcharts similar to that illustrated in Figure 1-1. In addition, plants that have dedicated layup teams with layup coordinators can facilitate timely and routine plant layup of selected components and systems. The layup coordinator uses a logic diagram to select the layup methods for the various plant systems and components based on the outage duration, scheduled maintenance activity, applicable layup methods for the given system or component, and so on, and provides this information to the outage planner.



Notes:
* No hydrazine for oxygenated treatment units.
** Limit pH to 9.0–9.2. If units have copper alloys in cycle, maintain hydrazine at 40–50 ppm.

Figure 1-1
Shutdown and Layup Flowchart

1.5.4 Plant Design

The design of the plant can affect the selection of the layup method for certain systems. For example, the piping supports for the main steam lines are not generally designed to carry the load if these lines were filled with water. Therefore, wet layup cannot be applied to plant piping that usually contains steam unless the piping supports are modified to carry the additional load or temporary supports are put in place. It is essential, therefore, that someone knowledgeable regarding the plant design review the appropriateness of the various layup methods to each plant system. If wet layup is to be used, it must be possible to circulate the water to prevent stagnant locations, to thoroughly mix additions of water treatment chemicals, and to obtain representative samples for analysis and control of the layup conditions.

1.5.5 Planned Versus Unplanned Shutdown

Many shutdowns are elective. They typically occur with some advance notice and usually offer at least some flexibility in timing; they are thus controllable by unit operators. Therefore, the shutdown can be initiated with equipment protection in mind, even if the duration is uncertain. Unplanned outages due to mechanical problems, severe water chemistry excursions, loss of connection to the grid, or other causes occur with little or no advance notice and might restrict the ability of the operator to control the shutdown. Circumstances will determine the nature of the outage. Residual pressure on the boiler and other pressurized equipment or vacuum in the condenser can provide time to take appropriate steps for equipment protection.

1.5.6 Environmental Conditions

The most obvious environmental condition that should be taken into account is the potential for freezing and the resulting damage. This can be mitigated by temporary enclosures, heat tracing, or localized sources of heat. Other environmental conditions that can damage equipment can include dust, salt spray (including cooling tower drift), and high humidity. These can be mitigated by using temporary, environmentally controlled structures (such as tents or canopies) and controlling humidity and dust with air handling systems that have filters.

1.5.7 Return-to-Service Requirements

The choice of layout practice will be driven by how quickly the unit is expected to return to service. For example, it takes longer to return a unit to service that has been in dry layup than one that is full of water (generally due to activities such as disconnecting piping, removing blanks, realigning valves, filling with treated water, and so on).

Regardless of whether the shutdown was planned or an emergency trip, plant personnel have time to decide on their layup practice while the boiler, feedwater heater (shell side), and deaerator are still pressurized and the vacuum is still on the condenser. The plant should have a written action plan describing the type of layup that will be used in each situation.

2
LAYUP OF PLANT EQUIPMENT

2.1 Layup Methods

Successful protection strategies should always consider the guiding principles for equipment protection. These strategies should take into account the purpose of the outage and the expected duration. The objective of proper layup and equipment storage is to eliminate corrosion and fatigue and minimize damage by other mechanisms that are active when the unit is in service. The predominantly used layup methods are described in the remainder of this section [4].

2.1.1 Wet Layup

Wet layup generally means that the water chemistry conditions are similar to the conditions during plant operation. Wet layup in the feedwater and condensate system equipment generally consists of filling the components and connecting piping with demineralized water that contains the proper chemicals for the metallurgy of the system (all-ferrous or mixed metal). With this method, the equipment should be filled completely with the treated water to avoid pockets of trapped air, and should not generally be open to the atmosphere. This method is used in feedwater heaters (tube and shell sides), feedwater and condensate piping, condensers (tube and shell sides), and auxiliary boilers.

2.1.2 Wet Layup with Nitrogen Blanket

Plants can use the wet layup method with the addition of a nitrogen gas blanket above the liquid level in the component or piping. This method is used for the duration of the outage, after all maintenance work has been completed. The wet layup method that includes the use of a nitrogen gas blanket above the liquid level can be used on the tube side of the feedwater heaters, the feedwater and condensate piping, and the shell side of the condenser.

The main advantage of wet layup with nitrogen blanket is that it provides a more positive method for protecting equipment than some other methods do. The main disadvantage of this method is that it requires more work by the operations and maintenance personnel to ensure that the nitrogen cap is not lost and that the chemical concentrations remain at the proper level. This method would be optimum for some of the equipment if the layup period were short (six months or less) and a full operating and maintenance crew were available.

2.1.3 Drained

Some systems are drained for the outage without maintaining any control of the layup environment, which exposes them to air throughout most of the outage. This practice will not typically cause serious harm if the system materials are corrosion-resistant, unless deposits or crevices are present.

Some plants drain portions of the feedwater and condensate systems with no control of the layup environment. These portions of the systems are exposed to air throughout most of the outage. This is not considered to be a good practice, especially if deposits or sludge are present. Plants can use draining as a layup method for the service water cooling system, the component cooling water system, the closed cooling water system, and the emergency cooling water system. Draining would typically be used only if maintenance is to be performed or to prevent freezing and the system would be refilled as soon as the maintenance work was completed.

2.1.4 Drained with Nitrogen Blanket

This method uses nitrogen gas to assist in draining the system or component and to maintain an inert gas environment during layup. This layup method involves draining the system or component with a nitrogen cover gas, which prevents the ingress of air into the system or component during draining and maintains an inert gas environment during the layup period. Some plants might use this technique for the shell side of the high- and low-pressure feedwater heaters, the main steam piping, and the feedwater and condensate piping.

2.1.5 Dry Layup

Dry layup is an alternative for protecting closed-in equipment, such as pressure vessels, piping, and so on. This is an especially effective method when the equipment being protected must be opened and inspected periodically.

Two options can be used for dry layup: one uses nitrogen gas to blanket the internals of the equipment, and the other uses dry air. Nitrogen blanketing is not used for long-term layup due to maintenance and operational requirements to keep the gas in the systems. The nitrogen blanketing method is more effective when protecting an air-tight vessel for short periods. Dry or dehumidified air offers the same advantages as nitrogen gas plus others. The dry condition can be maintained even while the equipment is opened for routine inspections. This allows routine inspections and repairs to take place without the loss of costly gas or possible corrosion taking place during the inspection or repair. Dehumidified air systems are also less costly to maintain over the long term.

2.1.6 Dry Layup with Forced Air

This layup method uses large fans to circulate air from the building through the component or system to displace the residual moisture. It can enhance the dry layup process by assisting in the removal of residual moisture in the system or components. This method is used on both sides of the feedwater heaters, the feedwater and condensate piping, and both sides of the condenser.

2.1.7 Dry Layup with Dehumidified Air

This layup method involves drying the air within a system or a component by circulating air through a dehumidification device to lower the relative humidity to less than 40%. This method has been used in both sides of feedwater heaters, main steam piping, feedwater and condensate piping, turbines, and both sides of the condenser. If the climate at the plant location is arid or semiarid, it might not be necessary to consider this layup method because it is not likely to be cost effective. If the air in the plant is dry (that is, it has a relative humidity of less than 40% during the entire outage) the use of forced, dehumidified air should not be necessary. The ambient plant air could be circulated through the systems at substantially less cost.

2.1.8 As Is

In the as-is layup condition, the system or component remains in the shutdown condition with no special treatment. If the system or component is filled with water during plant operation, it remains filled with water with no additional chemical treatment. The water environment will generally degrade due to the ingress of air. If a system contains steam during power operation, the steam is replaced by air and residual condensate, which is essentially equivalent to the drained layup method. This method can be used on both sides of the feedwater heaters; feedwater and condensate piping; tube side of the condenser; turbine; turbine lubricating oil, seal oil and control fluid systems; and cooling water systems.

2.1.9 Keep in Service

Keeping selected equipment and systems in operation, instead of shutting them down, is another method used. Such systems as the turbine lubricating oil and fuel oil transfer systems contain fluids that provide a natural protection. The closed cooling water system can be left in operation because the cooling water has been treated with a corrosion inhibitor to give it protection. This system is also used during the layup period. Many systems can be left running during the layup period. The only disadvantage is the energy cost and the minor maintenance required to keep them operating. However, these costs can be minor when compared to the alternatives to protect the same equipment for an extended period.

2.1.10 Maintain Circulation

Many plants have found that the best form of layup for cooling water systems is to continuously circulate the water. Several forms of localized corrosion are more likely to occur when a cooling water system is left stagnant or is drained during the outage. The latter is not significant if the system is drained for only a short-term maintenance activity (one week or less) and is immediately refilled with treated water when the maintenance work is completed.

2.1.11 External Preservative Coatings

Primers, paints, or preservative coatings can be used to protect most surfaces. Proper coatings can offer protection from corrosion, rot, and deterioration from causes such as corrosive vapors, sunlight (ultraviolet radiation), marine growth, and galvanic action. These methods can be used during the layup period to protect external surfaces such as structures and other equipment that can be exposed to the elements of the weather.

The main disadvantage of this method it that it requires extensive effort to prepare the surfaces and applying the proper coatings. The maintenance crew must periodically monitor the condition of the coatings during the layup period and recoat them as necessary. However, this can be the only practical method for protecting exteriors of equipment exposed to the weather. Keeping up with this activity requires the most maintenance effort during the shutdown.

2.2 The Two Predominant Approaches

The procedures for layup of idle equipment generally fall into two categories—the wet and the dry procedures. In general, with the exception of units on oxygenated treatment, wet layup requires filling most of the system with an alkaline-reducing solution (ammonia and hydrazine) and preventing air ingress by pressurizing it with an inert gas (nitrogen). Dry layup requires drainage while the equipment is hot, removal of all water, and pressurization with a moisture-free inert gas or the use of dehumidified air to maintain a low-moisture environment. In selecting the proper layup procedure for equipment, plants should consider the following [2]:

- Compatibility between the chemistry required for layup and that used during operation
- Maintenance of the protective oxides formed during operation
- The possibility that the equipment might be required for operation on short notice
- Facilities for proper disposal of layup solutions
- The possibility of freezing
- The practicality of maintaining all the required conditions of a given procedure
- Local atmospheric conditions (such as a salt air environment)
- The availability of sufficient, high-quality condensate; deaerated, demineralized water; nitrogen; or dehumidified air during a unit outage

2.3 Wet Layup

Wet layup is a popular method of protecting equipment when it might have to be returned to service on relatively short notice or when makeup water capacity is limited. Wet layup consists of maintaining water in the boiler, deaerator, and hotwell and excluding oxygen from the equipment to prevent corrosion. Traditionally, wet layup has been used for relatively short layup periods (usually less than two weeks), but if the nitrogen blanket and chemistry are maintained, there is no reason that a system cannot remain in wet layup for six months or longer [2].

Extensive use of nitrogen blanketing is recommended in conjunction with wet storage. The purpose of using nitrogen during a wet layup is to exclude oxygen-containing air as the unit comes off line. Because the air is excluded, the water will not contain the oxygen necessary for corrosion. With any wet layup, the potential exists for water to freeze in the piping, and precautions against freezing must be taken.

2.3.1 Nitrogen Systems

Properly designed and maintained systems have been used by many utilities for years. Although each nitrogen system is unique to the plant site, important design characteristics common to all nitrogen systems can be summarized as follows [3]:

- Multiple injection points must be available to allow capping of any components or circuits to be maintained wet. Typically, the injection points should be located to blanket steam out of all the piping and equipment as quickly as possible.
- For nitrogen purging (draining under nitrogen) procedures, the flow rate should be sufficient to match drain rates while maintaining a positive pressure to continually exclude air ingress.
- Vacuum breakers must be provided on closed tanks and other equipment in case the nitrogen supply could be cut off or run out.
- Check valves and other provisions must be made to prevent steam or water from pressurizing the nitrogen system.
- Flow meters allow a controlled flow of nitrogen into systems that have open vents or seals that leak by. As long as there is a continuous flow of nitrogen to the equipment, it will remain blanketed.
- Proper signage should be available and provisions should be made for mounting this signage to warn personnel when the equipment is under a nitrogen blanket and, therefore, is not permissible for entry.
- Provisions must be made to quickly and totally isolate the nitrogen supply from the equipment, so that it is impossible for nitrogen to be accidently added to equipment when personnel will enter it. This is often done by removing a spool piece in the nitrogen supply piping to the unit. Another option is to have a section of flexible piping containing a quick disconnect that can be easily separated.
- When nitrogen is to be introduced to high-pressure vessels and components, double isolation valves with check valves are typically used to prevent pressurizing the nitrogen piping system with steam in case a valve could be accidently left open.

Nitrogen source and purity are important design factors for careful consideration. The purpose of applying nitrogen is to exclude the ingress of oxygen from ambient air; therefore, the purity is important. Purity levels of at least 99.5% are considered suitable for plant use. Nitrogen from a cylinder or liquid source is 99.995% pure.

There are three primary methods of obtaining nitrogen: compressed gas storage, liquid-gas systems, and on-site generation, as follows [3]:

- High-pressure gas storage in individual or ganged cylinders are generally the most expensive and operator intensive. These systems are simple to operate but require frequent inspection and cylinder replacement.
- Cryogenic, liquid-nitrogen storage systems can be less expensive and require less frequent replacement.
- On-site production with membrane separation equipment is potentially the least expensive. The purity of gas resulting from on-site generation depends on design and operating conditions.

Liquid nitrogen can have other uses at a plant, and this fact should be taken into account when designing a system.

A nitrogen cap has the following characteristics:

- It allows feedwater equipment to remain full.
- It requires no excessive addition of chemicals.
- It permits nitrogen to rush in when steam collapses, preventing oxygen from entering the system.

The following procedures are used with a bulk nitrogen system [2]:

- Main condenser and turbine
  - Nitrogen addition starts while the turbine is spinning down.
  - Nitrogen is added quickly at first, then slowly as the vacuum approaches zero. When nitrogen has filled the condenser, it can be shut off completely or a minimal flow (20 scfh [0.57 m^3/hr]) can be maintained to replace any nitrogen that leaks out of the steam seals.
  - Nitrogen is added to the condenser and turbine to prevent absorption of oxygen at the air–water interface and prevents wetted surfaces in the turbine from becoming oxygen saturated. At no time is the condenser to be pressurized with nitrogen because this could damage the atmospheric seals on the turbine.
  - Nitrogen can be added through the reheater vents to supply nitrogen to all parts of the reheater and turbine set, as well as to assist in the removal of moist steam from the reheater.
- Deaerator and storage tank
  - Nitrogen is added when the deaerator is still hot, as the steam supply is shut off, through a connection in the deaerator or storage tank.
  - Nitrogen is purged for about 20 minutes, and then a small positive nitrogen flow is maintained. Most deaerators will hold a positive nitrogen pressure (2–5 psig [13.7–34 kPa]) with the vents closed; if it is preferable to keep the vents open, a small positive flow of nitrogen can be maintained.

- Feedwater heaters
  - Nitrogen is supplied through a shell-side vent line to each heater, or through other piping such as the reheater by way of the turbine extraction lines.
  - Maintain a small positive flow to prevent air from leaking in after the heaters have cooled to ambient temperature.
  - If the heater drains or vents are connected to the condenser, applying nitrogen to the feedwater heaters may be sufficient to blanket the condenser also.

Wet layup, particularly with nitrogen, must be maintained and monitored. If wet layup practices do not exclude oxygen at all times, corrosion in the form of pitting will result. The use of a nitrogen cap improves startup chemistry, reduces layup corrosion, reduces deposits, and lengthens the time between chemical cleanings.

Because nitrogen does not support human life, safety issues are highly important. Before any equipment that has been in nitrogen layup can be entered by personnel, all nitrogen supply lines must be disconnected, the equipment must be purged with air, and oxygen levels must be verified safe by proper oxygen test procedures.

2.3.2 Chemical Treatment for Wet Layup

Before shutdown, care must be taken to ensure that the feedwater and boiler water pH levels (and hydrazine or ORP levels, if appropriate for system metallurgy) are within normal operating ranges. This is especially applicable to short-term layups, particularly when immediate return to service is required.

Elevating the chemical concentrations in the feedwater and boiler water chemistry, particularly for longer layup periods, has also demonstrated success. This typically involves the use of parts-per-million levels of hydrazine and sufficient ammonia to elevate the pH above 9.5. When using these chemical layup practices, the chemicals in the boiler should be circulated by an external pump. It is preferred that these chemical layup treatments be used in addition to nitrogen to blanket the deaerator and condenser, as well as the steam drum, superheater, and reheater. Reducing chemicals alone cannot provide adequate protection for steam-touched surfaces that are vented and distant from the treated water.

The levels of pH control with 10 ppm of ammonia and 200 ppm of hydrazine were established many years ago. In the interim, utilities have found that lower levels of hydrazine can also produce the desired results. Some of these approaches are summarized in Table 2-1 [2].

Table 2-1
Normal and Elevated Layup Chemistry Conditions

Layup Duration	Feedwater System		Boiler Water	
	All Ferrous	Mixed Metallurgy*	All Ferrous	Mixed Metallurgy*
Short Term	pH, 9.5–10.0	pH, 9.0–9.3 Hydrazine, 2–10 ppm	pH, 9.5–10.0	pH, 9.3–9.6 Hydrazine, 2–10 ppm
Intermediate or Long Term	pH, 9.5–10.0	pH, 9.0–9.3 Hydrazine, 200–250 ppm	pH, 10.0–10.3	pH, 9.3–9.6 Hydrazine, 200–250 ppm

* It is recommended that the ORP be verified as reducing (<< -100 mV) in the layup and throughout the subsequent startup of the unit.

If the boiler is fired with excessive amounts of hydrazine in the boiler water, it will produce a high concentration of ammonia in the steam. These high ammonia concentrations, in combination with oxygen and carbon dioxide, will increase the corrosion rate of copper in the condenser and feedwater heaters.

Although the concentrations of hydrazine differ in the different procedures, the desired results are the same: 1) that the boiler and feedwater conditions maintain a strong ORP during the outage and 2) that copper corrosion due to ammonia, either from direct addition of ammonia or from the degradation of hydrazine, is minimized either by draining and refilling the boiler with water that approximates feedwater quality or by venting the ammonia before it comes in contact with copper alloys.

The EPRI report *Cycling, Startup, Shutdown, and Layup Fossil Plant Cycle Chemistry Guidelines for Operators and Chemists* (1015657) presents specific recommendations regarding the chemistry in the steam cycle before layup (if the unit will be stored wet) and during the subsequent startup [3]. These recommendations vary depending on the normal operating chemistry of the unit. Each EPRI chemistry regime—phosphate, all-volatile treatment, and oxygenated treatment—is described.

2.4 Dry Layup

Two options can be used for dry layup: one uses nitrogen gas to blanket the internals of equipment, and the other uses dry air. Dehumidified air can be used to continuously remove moisture from the equipment and from the air to the level at which corrosion does not form, or nitrogen can be used to blanket drained equipment, preventing oxygen from reacting with any remaining water. Nitrogen blanketing is not generally used for long-term layup due to maintenance and operational requirements to keep the gas in the systems. This method is more effective when protecting an air-tight vessel for short periods.

Dry or dehumidified air offers the same advantages as nitrogen plus many more. The main advantages of the dry air concept include no chemicals and no wastewater or resultant disposal problem (ammonia and hydrazine solutions) and no personnel hazards (nitrogen blanketing). The dry condition can be maintained even while the equipment is opened for routine inspections. This allows routine inspections and repairs to take place without the loss of costly gas or possible corrosion taking place during the inspection or repair. These systems are generally less costly to maintain over time.

The justification for using dehumidified air to protect ferrous surfaces is shown in Figure 2-1. The graph illustrates that corrosion can be mitigated by maintaining air in contact with corrosion-prone surfaces at a relative humidity of 60% or less. If the equipment is drained hot, air passing through the equipment will quickly be heated to match the metal temperature. Even air that is humid—for example, 90% relative humidity at 77°F (25°C)—will be less than 40% relative humidity when the air is heated above 104°F (40°C) by the metal. Weather conditions in many regions of the United States can produce air that is close to or even below 40% relative humidity during certain times of the year. In addition, compressed air that is used for plant equipment or instruments can be dried well below 40% relative humidity.

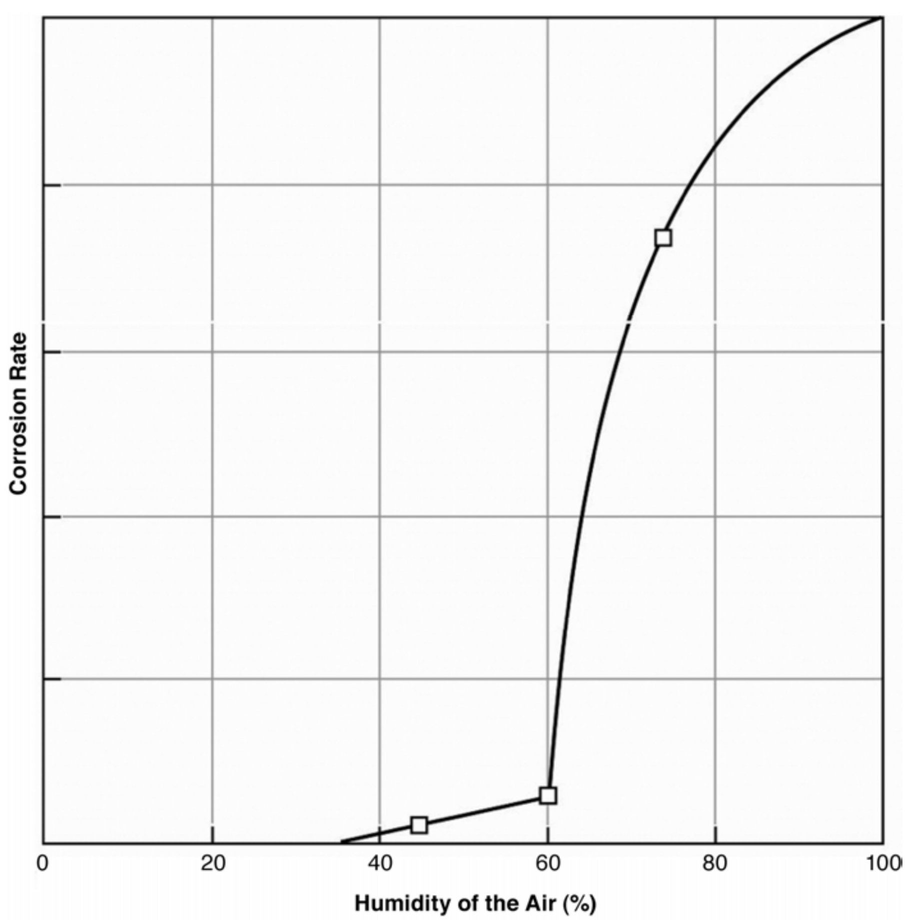


Figure 2-1
Corrosion Rate of Steel Versus Humidity of Air [3]

2.4.1 Dehumidified Air Layup

Desiccant-type dehumidification machines are a practical means of preserving materials by continuously removing moisture. The dehumidification machine is similar to a regenerative air preheater, although on a much smaller scale. The wheel is a nonmetallic (such as a ceramic), inert structure that is impregnated with an inorganic desiccant, which absorbs moisture from the air. As the wheel turns (approximately 6 to 20 rpm), humid air passing through the flutes in the wheel is dried. At the same time, a counter-flowing hot reactivation air stream, passing through the reactivation sector of the wheel, removes the moisture that was picked up by the desiccant. This allows for continuous, controlled drying. The dried process air is circulated by a blower fan. Figure 2-2 shows a schematic of a dehumidifier system.

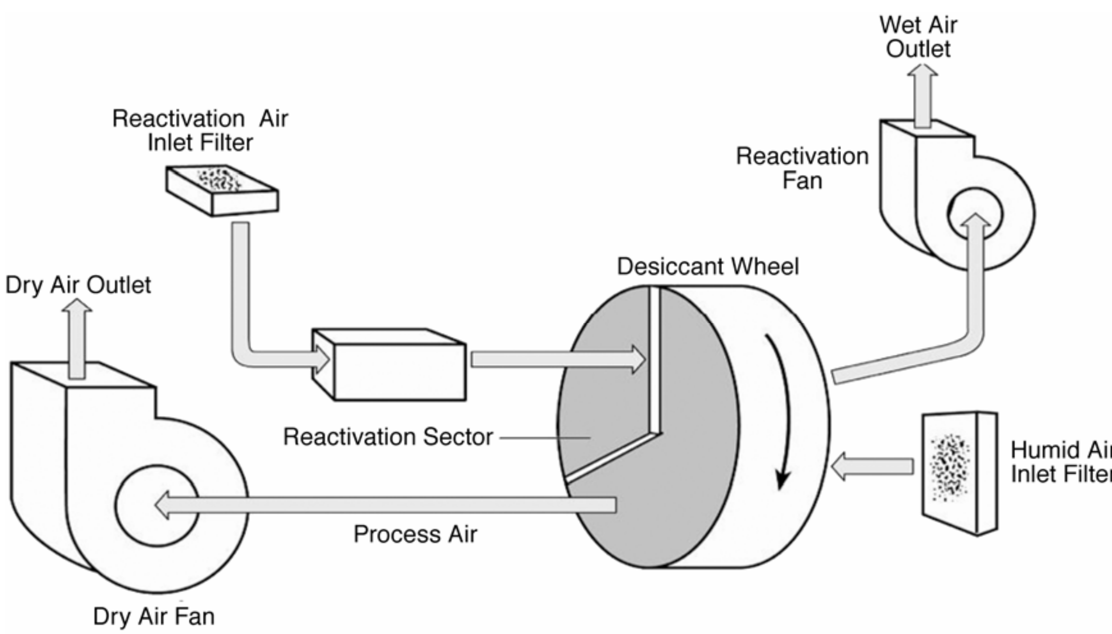


Figure 2-2
Rotary Dessicant Dehumidifier

Establishing flow paths for layup with dehumidified air depends on the following [3]:

- What equipment is to be included. Flow paths for protecting the turbine will differ from flow paths that involve the boiler, superheater, deaerator, and so on.
- Whether dehumidified air will be used in a recirculating mode (back to the dehumidification equipment) or in a once-through mode (out to the atmosphere).
- Available connection points.
- Whether the hotwell will be drained or left full of water.
- Return-to-service needs. For example, some flow paths will require blocking open turbine stop valves. This will impact the time required to return the system to service.

In many cases, several dehumidification units will be needed to protect a given flow path. The number of dehumidification units needed and the capacity of those units is a function of the volume of the equipment to be protected. The EPRI report *Shutdown Protection of Steam Turbines Using Dehumidified Air* (1014195) provides guidance on selecting the number and size of dehumidification units [5]. The dry air circulation systems are sized to provide adequate refreshment of dehumidified air to the component being protected. Typical rule of thumb values for sizing are 5–10 air changes per hour for generating equipment and 10 air changes per hour for all water and steam side components, including steam turbines, feedwater system components, and condensers [3]. If the installation does not allow the systems to be air tight, larger values for sizing are used.

Short dry air circuits—those that limit the amount of equipment included in the circuit to just a few, closely coupled components—are recommended for short-term dry air layup (normal outages). For long-term layup (such as mothballing), longer circuits—which can include many components with additional fans in the circuit—can be used. For applications using temporary connections, dehumidification equipment can be ordered on wheels and just wheeled into position for the layup.

Dehumidification equipment can be applied with manual installation or automatic installation and operation features. Frequent layup requirements, coupled with limited availability of operating and maintenance personnel, tend to indicate that the system should be installed with permanent connection and automatic valves. Long-term storage (mothballing) does not support an automated system based on installation and setup requirements, but it will support an automated monitoring system [5].

The dehumidified air process allows the system and equipment being protected to be preserved in an as-is condition. No special or complicated procedures are necessary. No special coatings or preservatives are needed and no major disassembly of the equipment is required. The dehumidified air and a tight system are all that is required. The equipment is substantially left intact. This makes the process economical in layup, monitoring, and return to service [5].

Dehumidified air is typically injected on the high-pressure end of the turbine and uses the remaining heat of the turbine metal to heat the air and hasten drying. Keeping the turbine on turning gear after the cooldown helps air to circulate, as the turbine itself creates air flow. The gland seal system blowers continue to operate through the cooldown period to prevent condensation in the seals. Depending on the length of the outage, advanced notice on restarting, and the capacity of the plant to produce demineralized water, the hotwell might or might not be drained. If it is not drained, some corrosion products will form in the hotwell and must be removed during startup (such as circulation through a polisher). Care must be taken not to thermally quench the turbine during any dehumidification process. Dehumidified air should be applied after the turbine has been shut down for 24 hours and no later than 72 hours after shutdown [3]. (See the manufacturer's recommendations for specific times and temperatures to start the dehumidified air.)

A number of flow paths are possible, depending on the equipment to be protected and whether the system is once through or recirculates the dehumidified air. One possible flow path is the following (see Figure 2-3) [3]:

1. Dry air is discharged from the dehumidifier into the hotwell, flows through the low-pressure turbine, and continues through all turbine sections to the boiler, backward with respect to steam flow.
2. Dry air flows through the feedwater heaters and is discharged from the system, back to the dehumidifier.
3. Condensate pumps receive dry air from the hotwell and discharge it back to the dehumidifier from the discharge check valves.
4. Extractions are left open so that dry air can reach the feedwater heaters, from which air is returned to the dehumidifier.
5. Drip pumps and crossover heaters are protected in the same manner. Dry air is extracted from each waterwall header and returned to the dehumidifier. (Additional configurations are illustrated in Appendix A).

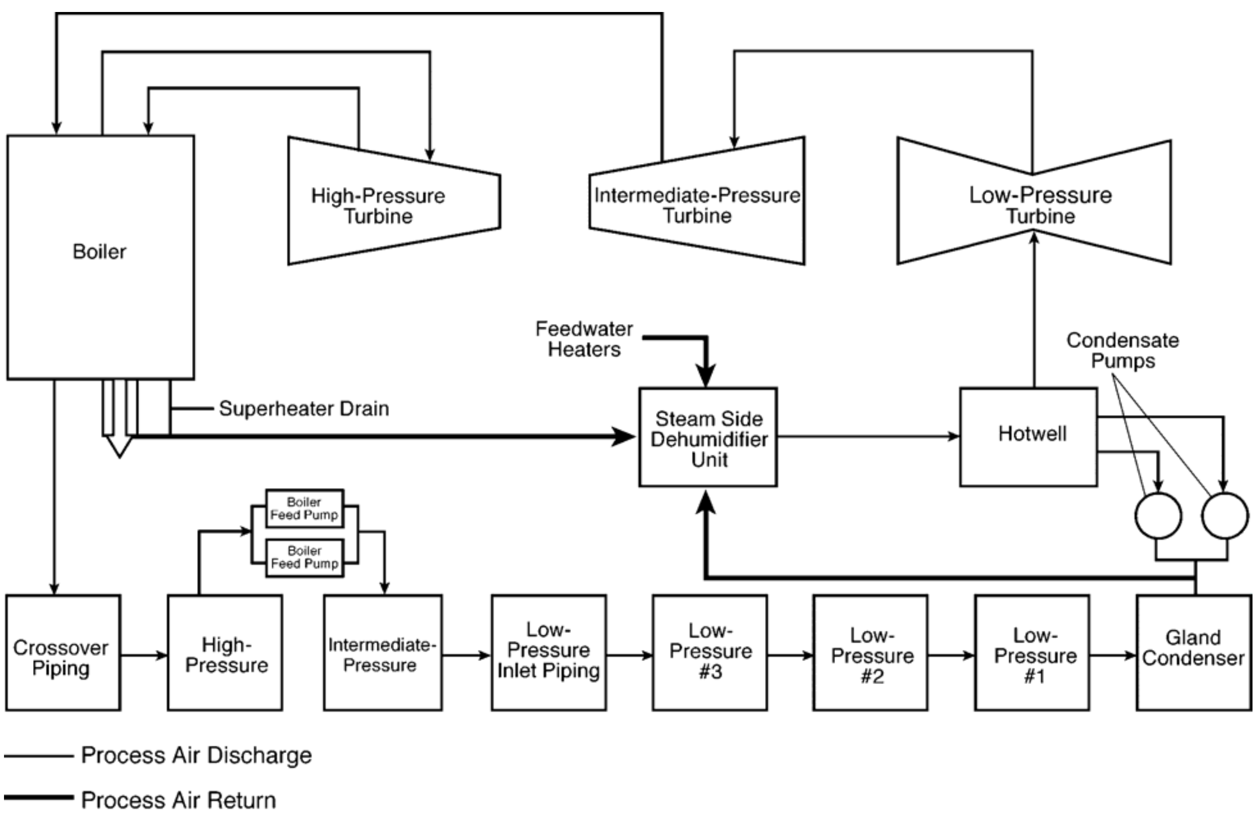


Figure 2-3
Dehumidification Flow Path

After the dehumidified air flow is established, the process should be monitored to ensure that a relative humidity of 40% is quickly achieved. Several humidity sensors can be set up in areas in any discharge that leads to the outside air or back to the dehumidifier and also just downstream of the dehumidifier. Operators should routinely monitor the equipment, air ducts, and connections where the air enters the equipment to ensure that the circuit is intact and that the equipment is operating. Depending on the tightness of the system and the amount of recycled air, the dehumidifier might not need to be operated continuously.

Entering the dehumidified air areas for inspections is easily done by opening the normal accesses and entering. The dehumidification equipment can be kept operational during the inspection, and afterward, the systems can be closed up and the drying process continued. (Remember to follow all confined-space entry procedures).

The use of dehumidified air to purge equipment during layup periods is routinely practiced internationally and is becoming more common in the United States. When the metal of the water- or steam-touched component is cool (<140°F [<60°C]), the movement of ambient air through the unit and the changes in daytime and nighttime temperatures can result in condensation and corrosion of the equipment in any high-humidity areas (>40% relative humidity). Any deposits on the equipment that are hydroscopic (salts and caustic) will attract moisture and allow concentrated electrolytic solutions to develop on the metal surfaces and accelerate pitting corrosion. The continuous flow of dehumidified air through the equipment can minimize or eliminate this corrosion.

2.4.2 Dry Layup with Nitrogen Cap or Blanket

Nitrogen can also be used to meet the essential purpose of preventing oxygen ingress during layup. Nitrogen is used either to cap components that are to be maintained wet or for dry protection when applied to purge and blanket systems as they drain to prevent the entry of ambient air. In order to produce an effective nitrogen cap or blanket to exclude oxygen from components, both the appropriate nitrogen supply and delivery system and the appropriate application procedures are required.

Because nitrogen is not circulated like dehumidified air, it is likely that even if equipment is drained hot, there can still be some water present in the piping. Draining under nitrogen and maintaining a nitrogen blanket precludes the need to ensure that the equipment is completely dry. Therefore, the following guidelines can be applied whether the equipment will be drained under nitrogen (dry) or left full of water.

Comprehensive operating procedures should be developed for the nitrogen system to cover all situations. The application of a nitrogen cap to various pressurized circuits and other components should consider the fact that the gas must be applied before the pressure has decayed to atmospheric. Use of nitrogen to purge any components under vacuum requires a higher priority and should be done earlier in the shutdown.

The needs of the unit during each shutdown must be considered in the context of the protection strategy to be implemented and the associated needs for nitrogen. Key actions required include the following [3]:

- Select which parts of the system will be protected with nitrogen and how nitrogen will be applied (for wet or dry protection).
- Establish a hookup and valve list that will accommodate nitrogen injection.
- Select an order in which systems or equipment will be blanketed with nitrogen.
- Develop a short, sequential procedure that follows the order of placing equipment in layup.
- Delineate the system conditions that should exist for starting to apply nitrogen to each part of the system.
- Train personnel on the procedure and included equipment.

The initiation of nitrogen application to specified systems should be consistent with the unit shutdown procedures and anticipated outage activities.

2.5 Comparison of Two Main Approaches

Table 2-2 shows a comparison of the advantages and disadvantages of wet and dry storage procedures [5].

Table 2-2
Shutdown and Layup Alternatives Showing Advantages and Disadvantages for Each Alternative

Alternative	Advantages	Disadvantages
Wet storage with ammonia or hydrazine solution*	No concern about relative humidity. Easily maintained. Easily tested. With proper installation, leaks can be easily detected. Superheaters and reheaters can be stored safely. If facilities are installed, solution can be reused.	Possible pollution when draining. Need to recirculate regularly. Hydrazine is a possible carcinogen. High water consumption before startup; solution must be drained and possibly rinsed. Requires regular monitoring. Excessive ammonia must not be added if copper or copper alloys are present in the system. Tight isolations are prerequisite. Not recommended if freezing might occur. Requires draining if work is to be carried out. Pure water (demineralized) must be used.

Table 2-2 (continued)
Shutdown and Layup Alternatives Showing Advantages and Disadvantages for Each Alternative

Alternative	Advantages	Disadvantages
Nitrogen	System need not be completely dry. Completely independent of climatic conditions. Can be used as a capping of normal operating fluid during outages.	Quite dangerous; asphyxiation of workers can occur if the system is not properly vented before access. Preferably carried out while system is being drained.
Dry air	Readily available, basic constituent. Maintenance on plant can be performed without problems. Easy monitoring. No risk to personnel. Whole plant can be stored dry if drainable or dryable. Independent of ambient temperature if air is dry enough, Residual heat in boiler steelwork used for drying.	Drying equipment and blowers are required. Climatic conditions can cause rapid deterioration in storage conditions. Hermetic sealing might be required to prevent deterioration caused by climatic conditions. System must be completely dry. Sediment may cause corrosion if hygroscopic. Sulfur dioxide and dust must be excluded from the air used. If work is to be carried out on part of the dried system, that part of the system must be isolated and redried afterward. Even draining hot and under pressure does not ensure complete water removal.

* Requires nitrogen blanket.

2.6 Barrier Film Technology

The most effective approach to equipment protection typically is to provide dry conditions. Some treatments provide equipment protection by establishing a barrier between the oxide surface and any water or moisture that might be present. Among these barrier treatments are vapor phase corrosion inhibitors, also known as *vapor phase inhibitors (VPI)* and filming amines, also referred to as *polyamines*.

These products have a chemical structure which contains both hydrophilic and hydrophobic sites. These features of the molecule provide an attachment of the hydrophilic site essentially to the surface of the metal (or metal oxide) in a monomolecular layer. The non-attached hydrophobic site of the molecule repels the moisture, and as the molecules accumulate the surface becomes non-wettable effectively providing a protective barrier to contaminants such as oxygen, water and corrosive vapors. Since the molecules repel each other, there is not a tendency for the accumulation of multiple molecular layers or thick films.

Use of these treatments appear to meet many of the guiding principles of equipment protection, possibly in ways that could be simpler and more cost effective than the traditional wet and dry methods. However, the properties of the chemicals used are not fully understood and experience with their use for equipment protection in operating plants is limited. Further research would be needed to improve the understanding of the materials with respect to their suitability for routine use in protection of steam and water touched surfaces.

2.6.1 Vapor Phase Inhibitors

The basic premise of all VPI products is the same. The chemicals volatilize, and the vapor condenses on the metal, forming a thin, protective barrier. This barrier keeps the metal surface dry by blocking water access to the metal, thus preventing corrosion [3].

One concern with the application of VPI is the adequacy of distribution of the product to all areas. This concern applies to major components such as the turbine, in which access and inspection is limited and completeness of coverage can be questionable. Both quantity and distribution of the VPI chemical are important to achieve successful results. Because the chemicals are proprietary, plants must rely on the vendor to determine the proper quantity. Monitoring is important to confirm the coverage and effectiveness of the VPI treatment.

VPI technology is used in many applications to protect metal surfaces from corrosion while in storage. Application of this technology to operating equipment has been primarily to smaller package boilers. The VPI powder is applied by fogging into the steam drum. Sufficient volatilization will occur to protect surfaces throughout the boiler. Fossil-fired utility boilers are much larger and have more complex circuitry. This complexity can affect complete coverage.

It is important that any VPI considered for use in a utility boiler be low in silica, chlorides, and sulfate. Silica is sometimes added to the VPI to prevent clumping and to keep the material flowing. Silica residues in the unit could result in extended periods of elevated silica in the steam. Chloride and sulfate contamination also present turbine corrosion concerns.

Personnel working inside an environment protected with VPI should use respiratory protection to avoid inhaling the dust. Because dusts can create explosive mixtures with air, possible ignition sources must be avoided, including the possible discharge of static electricity. Metal probes or lances used for spraying VPI should be grounded.

Information on the impact of VPIs on chemistry after startup is limited, and the impact on downstream equipment and potential for startup delays have not been well documented. Based on currently available information, these molecules should break down to amines, carbon dioxide, and volatile organic acids as the unit is fired or turbine parts are heated before operation. Any organic acids or carbon dioxide that become entrained in the feedwater would be expected to increase cation conductivity [3].

2.6.2 Filming Amines

Filming (or film-forming) amines are typically used to counter the effects of oxygen corrosion and have been used as a means of equipment protection during both operational and idle conditions. *Filming amines*, often referred to as *polyamines* or *fatty amines*, are long-chain hydrocarbons that have one hydrophilic end and one hydrophobic end. Filming amines form a monomolecular film on the metal surface, creating a physical barrier that prevents water, oxygen, or other corrosive agents from reaching the steel surface.

Filming amines protect against oxygen and carbon dioxide corrosion by replacing the loose oxide scale on metal surfaces with a thin amine film barrier. During the period of initial film formation, old, loosely adherent corrosion products are lifted off the metal surface due to the strong surface affinity of the amine. The metal can be cleansed of oxides, which normally cling quite tightly; however, excessive initial filming amine treatment of old, untreated, or poorly treated condensate systems can cause large amounts of iron oxide to be sloughed off, resulting in plugging of traps and return lines. Therefore, treatment must be increased gradually for old systems.

The dosing of filming amines is usually adjusted so that a small amount of the filming amines can be detected in the condensate, feedwater, and boiler water. In most cases, the presence of the smallest reliably detectable amount of amine suffices. Amines can usually be detected quantitatively at concentrations as low as 0.5 ppm (0.5 mg/kg). The two most common filming amines are octadecylamine (ODA) and ethoxylated soya amine (ESA).

ODA volatilizes in a boiler above 425 psig (2930 kPa). Therefore, ODA (as well as other filming amines) is applied to the cycle during operation, in advance of shutdown for layup protection. Excessive or too-rapid feed will cause the system to plug with iron oxide removed from the metals. Incomplete film formation will cause localized corrosion. Extreme care and monitoring are required when using ODA.

ESA is another type of filming amine. The major difference between ODA and ESA is that ODA has one hydrophilic attachment, whereas ESA has three. This increases the solubility of the molecule, resulting in a lower sludging tendency. Therefore, ESA is easier to apply and maintain, but again, extreme care and monitoring are required.

Newer formulations of filming amines are currently being developed. These proprietary products are typically blended with a neutralizing amine to facilitate feeding of the moderately soluble product to the feedwater. These newer formulations might provide equivalent or superior barrier protection and might be less problematic with regard to sloughing oxides and other concerns. EPRI is investigating this technology for use in equipment layup.

3
LAYUP PROGRAM

3.1 Introduction

Each plant should develop a good layup program with detailed procedures for the specific application of appropriate layup approaches. These must include the plant's standard procedures, including safety procedures that are appropriate to the equipment and systems affected.

3.2 Key Elements of a Good Layup Program

The plants that seemed to have effective layup programs were those whose programs included the following key elements [4]:

- Written procedures to delineate the actions to be taken and the person or organization responsible for placing the plant systems into layup
- Scheduling of layup for the various plant systems during the outage planning for the next outage
- Development of a plant-specific logic diagram to provide the basis for layup method selection
- Designation of a plant layup coordinator responsible for placing the appropriate systems and components into the proper layup conditions
- Assignment of a layup team to assist the layup coordinator in accomplishing the assigned responsibilities

These elements helped to ensure that appropriate layup methods were selected based on the described selection factors; that the performance of layup was properly scheduled for the outage; that the personnel were committed to perform the necessary layup steps; and that the layup would be performed properly, using documented procedures.

3.3 Tools to Assist in Selecting and Implementing Proper Layup Procedures

This section provides examples of two tools that personnel can use in selection of the appropriate layup procedure (decision matrix) and in the proper implementation of layup procedures (road map). Although these examples are representative of conditions and practices common to many units, each plant should review and adapt them to their individual requirements.

It is important that plant personnel have enough information to make good decisions on how to best perform system or unit layup each time a shutdown occurs. Proper review of plant equipment, systems, and expected operating requirements will enable the creation of tools to aid operating personnel in properly protecting plant equipment.

Figure 3-1 is a decision matrix that lists criteria affecting which layup practice is best for a particular set of circumstances [3]; an additional decision matrix is presented in Appendix C. It is not necessary that the entire steam cycle be stored with the same procedure. For example, the boiler can be stored wet with nitrogen and the turbine can be stored dry with dehumidified air.

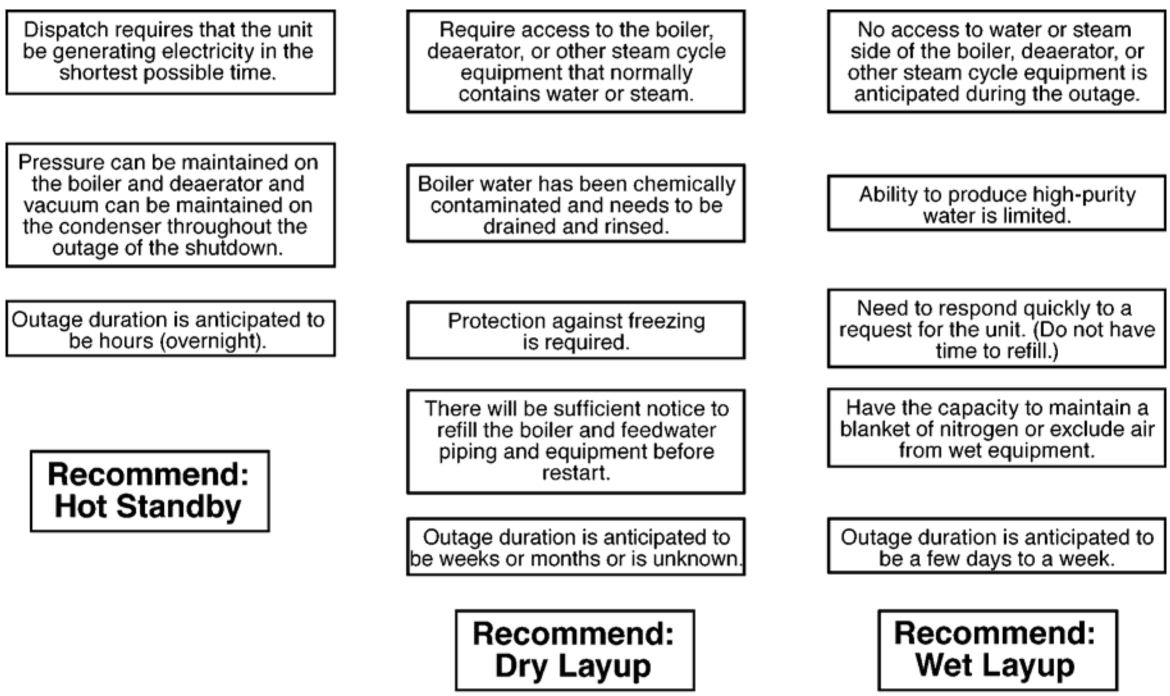
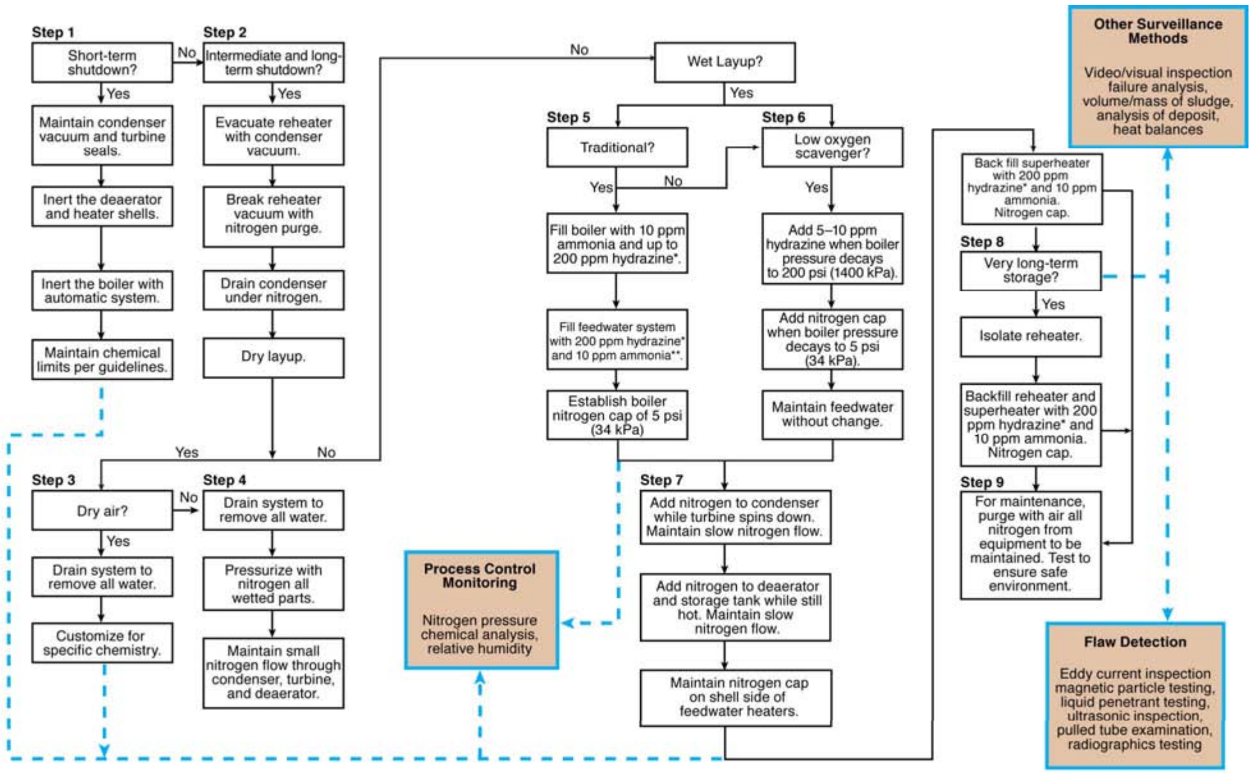


Figure 3-1
Decision Matrix

Figure 3-2 provides a flowchart for shutdown and layup procedures common to most units [5]. Due to variations in design and operation, some customizations might be required to adapt to a particular plant’s needs.



Notes:
* No hydrazine for oxygenated treatment units.
** Limit pH to 9.0–9.2. If units have copper alloys in cycle, maintain hydrazine at 40–50 ppm.

Figure 3-2
Shutdown and Layup Flowchart

3.4 Benefits of Good Layup Practices

Based on an EPRI survey of member utilities, some of the benefits perceived by the utilities of using layup during plant outages include the following [4]:

- Shorter cleanup periods during plant startups to remove corrosion products after outages. This translates into generating greater revenue.
- Less corrosion product fouling of condensate polishers during plant startups. This translates into fewer regenerations or resin replacements and lower operating costs.
- Fewer premature failures of plant components requiring repair, replacement, or plugging of feedwater and condenser tubes. This translates into lower operating costs.
- Fewer unscheduled, forced outages due to premature failures. This translates into greater revenue and lower operating costs.

Currently, most of the utilities participating in the survey have not performed a cost–benefit analysis for layup of systems or components in their plants. On the cost side, most of the required data for implementation are available for the costs associated with layup, such as the following:

- Materials and equipment
- Engineering
- Planning
- Installation labor
- Restoration labor
- Operations

It is considerably more difficult to obtain the necessary data on benefits because the benefits have not been quantified at most plants. For example, the shorter times required for cleanup of the system water before power generation have not been quantified. These data are generally not documented, and in fact, hold times during startup are often related to other operating requirements rather than the chemistry of the feedwater. In addition, the reason for regeneration or replacement of the condensate polisher resins is not always documented.

3.5 Effects of Deficient Practices

Failure to establish and follow good layup procedures during shutdown and entering a layup state can lead to a number of detrimental conditions within the equipment and systems to be protected. This will lead to reduced availability and reliability and increased operating costs. Some of the main undesirable results of poor adherence to established procedures, deficient control of chemistry, or poor housekeeping are the following:

- Contamination due to maintenance and inspection activities (abrasives such as grit blast media, dirt, paints, and solvents)
- Contamination by dissolved solids and gases (such as oxygen and carbon dioxide)
- Pitting and general corrosion of unprotected surfaces
- Stress corrosion cracking
- Plugging of hollow copper conductors in water-cooled generators
- Deposition onto turbine blade surfaces, reducing efficiency and capacity
- Loss of the protective oxide structure formed on water- and steam-touched surfaces
- Increased outages and outage duration
- Increased startup periods and costs (chemicals and loss of generation)
- Need to prematurely replace components

3.6 General Rules and Good Practices Based on Utility Experience

Although every plant is unique in some way, some general rules or good practices have evolved from industry experience. Following are some general rules or good practices derived from an EPRI survey of member utilities. These are general rules that might not apply to plant-specific conditions. Some of these rules or good practices will not apply to all plants. Although the list is not all-inclusive, some of the more prominent rules are the following [4]:

- If a plant has an unexpected forced outage, determine the duration that will be required to make the necessary repairs and use the layup method or methods that can be accomplished quickly enough to provide corrosion protection for the plant systems and components. In outages requiring only seven days or less, it might be best to leave the systems normally filled with water as is, while continuing to circulate the water. The chemistry should be monitored and maintained in the normal ranges or limits as much as possible. Other systems that normally contain steam should remain in an essentially drained condition. If a system or component must be opened to perform repairs, steps should be taken to exclude or minimize the ingress of air. This can be accomplished by using temporary manway and handhold covers when personnel access is not required and by avoiding opening several access points at the same time, particularly at different elevations. For longer forced outages (seven days or more), the layup methods that are typically used for outages should be implemented.
- For more extended outages, dry layup is the preferred method for most of the balance-of-plant components and piping, because the materials of construction are primarily carbon steel or low-alloy steels. Carbon steel will begin to rust in a short period in a moist, oxygenated environment. Therefore, it is prudent to exclude the moisture, because it is often difficult to exclude air (oxygen) from a system, particularly if repair work is scheduled. If moisture can be excluded from carbon steel surfaces by reducing the relative humidity to 40% or less, rusting will be less severe, and it will take longer for the first traces to appear. This practice should be used for the steam side of the condenser, both sides of the high- and low-pressure feedwater heaters, the turbine, the condensate and feedwater piping, and the main steam and extraction steam piping.
- If dry layup is being contemplated for any system or component during the outage, draining will be facilitated if it is initiated while the plant temperature is still above 200°F (93°C). Implementation of dry layup after wet layup is almost impossible when the system is cold. Although flashing the water to steam should be avoided, more moisture will be removed from the system and less condensation will occur as the plant continues to cool down.
- Some form of layup is desirable compared to no layup, because the latter results in an uncontrolled environment. The typical wet and dry layup methods are directed toward controlling the environment in the systems and components during the plant outage. Although it may be difficult to quantify the benefits of exercising control of the layup environment, numerous incidents of material failure have occurred in plants that have not routinely and systematically controlled the layup environments.
- When no work is being performed on a component or system, all openings should be sealed with temporary covers. If work is not being done for long periods (five days or more), it is desirable to purge the system or component with nitrogen.

- The main concern during a maintenance and repair outage is that there is a tendency to be somewhat lax with regard to these systems, which often results in inadvertent contamination from the plant atmosphere or improper use of consumable materials. Therefore, care should be exercised in any operation of an auxiliary system to reduce the occurrence of contamination. It is also desirable to exercise portions of systems, where possible, to reduce stagnant conditions, which are conducive to some forms of corrosion.
- If the climate at the plant location is arid or semiarid, it is not necessary to consider the use of forced, dehumidified dry layup because it is not likely to be cost-effective. Likewise, if the air in the plant is dry (that is, the relative humidity less than 40%) during the entire period of the outage, the use of forced, dehumidified air should not be necessary. The ambient plant air could be circulated through some of the systems at a cost savings.
- When a system or component is drained and left as is, considerable moisture remains in pockets of water that cannot be drained (for example, in crevices or under deposits), and droplets of water adhere to the metal surfaces, causing local corrosion. Additional effort should be made to remove the moisture from the system by blowing compressed air or nitrogen gas through areas that retain moisture. Depending on the size and area that is retaining moisture, wiping with clean, dry cloths should be considered.

The practice of layup in a power plant requires planning and the commitment of resources. Although it might be difficult to determine the actual financial impacts and benefits, experienced plant personnel recognize that proper layup is essential to the realization of the design life of plant components and systems. Although the utilities participating in the survey did not provide information on the ranking of systems and components with respect to the importance of layup, plants might consider the following in establishing a layup program [4]:

- The cost of replacing a component should guide the plant in placing the priority for layup. On this basis, one component that merits a top priority is the steam turbine.
- Components having large carbon steel surface areas (such as the feedwater system) should be given a high priority.
- Heaters should also receive a high priority for layup. These components can contribute a large amount of corrosion products to other systems.
- The components that have caused the most trouble in the past should be given greater attention and priority for layup.

This list is not intended to be all-inclusive, but it should provide a basis for each utility to establish some order and organization into the process for deciding which components or systems should receive the higher priority for implementation of layup.

3.7 Review of Equipment for Layup

An approach for reviewing equipment and systems for the appropriate layup procedures for a given set of operating requirements should include the following actions:

- Select the equipment for layup consideration, taking into account related equipment that also must be considered in conjunction with it (for example, consider whether the turbine can undergo layup without affecting the reheater or feedwater heaters). Although the scope of this guideline is focused on turbines, generators, exciters, feedwater heaters, and related auxiliary equipment, the majority of the unit or plant must be considered in many facilities. Also consider, for any component or system, whether the replacement cost of the equipment merits the actions and expense of the layup procedure.
- Each facility will need to develop a set of procedures covering its specific equipment and potential operating requirements. In addition, personnel (operations, maintenance, chemistry, and design groups) should be dedicated to each of the planning, procedure development, and execution activities. These procedures should incorporate logic diagrams and basic instructions for establishing, monitoring, and maintaining the proper layup conditions.
- These procedures should have the following characteristics:
  - Be written
  - Be sequential
  - Delineate system conditions to start or continue layup procedures
  - Designate the responsible groups or individuals
  - Include resource-loaded activity schedules, as appropriate
  - Include hookup or valve lists, as appropriate
  - Include checklists, as appropriate
  - Include required monitoring to ensure that all lockout, tag-out, and safety procedures are followed
  - Be reviewed periodically to ensure that each procedure is still accurate for each system and operating condition and that all operating scenarios are covered

Development and selection of the acceptable layup processes to be used by the plant, depending on the operating requirements, should take into account the following:

- Plant design and materials used in construction (all-ferrous or mixed metal)
- Normal cycle chemistry regimes (all-volatile treatment or oxygenated treatment)
- Environmental conditions (temperatures, dust, or spray from nearby sources such as cooling towers or the ocean)
- Expected outage durations (procedures are needed for each of the potential durations—overnight, weekend, one to two weeks, and longer)
- Expected maintenance activities and requirements, including the following:

  - Whether the equipment will be opened or entered
  - Whether maintenance activity will consume the entire outage or occur early or late in the outage
  - Whether the area under maintenance can be reasonably isolated from the other components in the circuit
  - Whether auxiliary systems will be operated during the outage (cooling water, lubricating oil, turning gear, and so on)
- The existing constraints at the facility that limit the possible layup approaches that can be implemented, including the following:
  - Makeup water capability
  - Chemical solution disposal capability
  - Availability of layup equipment, including nitrogen injection system or dehumidification machines
  - Ability to provide proper isolation to accomplish the following:
    - Prevent air ingress
    - Prevent water or moisture ingress
    - Prevent chemical ingress
    - Maintain nitrogen pressure
    - Maintain dry dehumidified air pressure
  - Existence of adequate connection points to maintain the following:
    - Chemical concentrations
    - Nitrogen pressure
    - Dehumidified airflow (whether reasonable flow paths exist based on design and number of available dehumidification machines)
  - Monitoring capabilities, taking into account the following:
    - Available equipment
    - Sampling required
    - Outage duration
    - Any specific equipment concerns that might necessitate a more thorough examination and monitoring
    - Determination of whether it is justified to leave the equipment unprotected to accommodate the monitoring activity
  - Return-to-service requirements (whether the expected outcome is known)
  - Ease or difficulty of going from one layup process to another, such as wet to dry or dry to wet. This could be required due to something as simple as a seasonal weather change in which freezing might be a concern.

3.8 Factors to Consider for Optimizing Equipment Layup

The determination of the most suitable approach for equipment protection should be made at the plant level. Each layup decision will be based on the current conditions and information at hand. Each unit is composed of many different sets of equipment and systems, which need not use the same layup procedure. Some equipment can use a wet layup with nitrogen blanket approach, while others are maintained with dry, dehumidified air, and others are kept in operation.

Each component or system to be to be protected should be reviewed for its condition, function, and the current operating constraints. Optimizing the layup approach for each system will assist in providing the best protection for the unit. Successful protection strategies should take into account the following:

- The type and purpose of the outage
  - Economic dispatch
  - Forced outage
  - Scheduled outage for maintenance
- The expected duration
  - Short
  - Intermediate
  - Long
- Return-to-service requirements
  - As soon as possible
  - Scheduled
- Maintenance or testing to be performed
  - On the equipment or system
  - On related equipment or systems
  - On other unit equipment
  - When the maintenance or testing activities are to occur (early or late in the outage)
- Impact on unit status
  - Whether the equipment must be operated to support other systems (for example, the lubricating oil system, seal oil system, or cooling system)
  - Whether a time commitment is required for maintenance or testing activity (whether there is sufficient time and schedule flexibility to complete a repair after a commitment is made to do so)
  - Whether the layup procedure can be implemented in the timeframe available (for example, draining equipment and implementing a dehumidified air procedure for a short outage might not provide the best protection because drying equipment with air can be slow)

The following are scenarios and possible layup practices that consider the reason for the outage and how quickly the unit must be returned to service [3]:

- Forced outage for a boiler tube failure; unit will be down just long enough to repair the boiler tube (less than 24 hours)
  - Boiler—dry layup (the boiler must be drained for repairs)
  - Deaerator—wet layup
  - Condenser and turbine—wet layup (residual heat should mitigate damage)
- Scheduled outage with return to service within 8 to 24 hours
  - Boiler—wet layup (with nitrogen if pressure decays)
  - Deaerator—wet layup (with nitrogen if pressure decays)
  - Condenser and turbine—maintain steam seals and vacuum on condenser
- Scheduled outage with uncertain return to service; must be able to return to service quickly
  - Boiler—wet layup with nitrogen
  - Deaerator—wet layup with nitrogen
  - Condenser and turbine—dry layup with dehumidified air or wet layup with nitrogen
- Seasonal outage—will be called on to produce power with only one to two days notice
  - Boiler—dry with dehumidified air
  - Deaerator—dry with dehumidified air
  - Condenser and turbine—dry with dehumidified air

3.9 The Potential for Changes in Layup Duration

After the initial planned duration for a unit outage is determined, it is understood that this duration is subject to change. A number of factors can potentially impact unit status and cause the outage duration to change. Although each utility and plant has its particular circumstances, following are some of the key factors that may impact unit status:

- System conditions or dispatch
- System reserve levels
- Unit's cost of generation
- Status of other units
- Equipment inspection results during outage
- Maintenance activities
- Potential for power sales or cost of power purchases

Whatever the reason, a change in outage duration affects the decisions made when the equipment was initially put into layup. Decisions were made to select the most appropriate layup approach based on a number of factors, such as outage duration, maintenance activities (both on the subject equipment and on related equipment), and consumable usage, as known at that time. It is even possible that more than one change in the planned outage duration will occur.

If the outage is shortened, treatment chemicals or nitrogen might have to be dumped and appropriately disposed of, configurations such as blocked valves and blanked piping might have to be returned to an operating configuration, or sufficient makeup water might have to be processed to refill boilers and condensers. If the outage is lengthened, heat might have to be applied to the system (fire the boiler) to facilitate changing from a wet layup approach to a dry layup approach.

As always, the key driver is using an appropriate layup procedure that provides protection for the equipment. Although certain approaches are considered more appropriate for an outage duration, more than one layup approach can provide equipment protection for each timeframe. For instance, wet layup is generally considered for shorter durations of a weekend or one to two weeks. It can be effective for months, if properly implemented and maintained. Dry layup is effective even for the shorter durations, but it might be desirable to avoid draining the equipment if there is a strong potential that the unit could be returned to service on short notice.

Although everyone would like to definitively know each outage's duration, it is not practical; outage durations are subject to change. To optimize plant activities and costs, selection of the appropriate layup approach must take into account the probability of the outage changing and the possible consequences of this change of schedule (cost, response time, and resource availability). In addition to the considerations described in this report as a basis for selection of layup approach, consideration should be given to operating constraints beyond the station and the plant's experience with the possibility and effect of these internal and external factors.

A decision on the likelihood of a change in outage duration (shorter or longer) will be based on the current information available and the plant's experience. Input should be received from the plant personnel familiar with the equipment's current operating and maintenance status and from the system dispatch group or power marketing group. Ongoing communications between the plant and the dispatch group should be maintained to help anticipate changes in outage duration and to keep everyone informed of the effects to costs, equipment reliability, and future outage requirements of any change.

The effects of schedule changes can be measured by their effects on cost and availability. Key factors that can be affected are the following

- Cost and availability of treatment chemicals (and disposal if required)
- Cost and availability of nitrogen
- Cost and availability of makeup water (whether it is available or whether enough can be processed to meet the potential schedule change)
- Cost and time to modify the selected layup configuration (such as changing from wet to dry configuration, changing from dry to wet configuration, or purging the generator)

- Cost and time to return equipment to an operating configuration
  - Remove and install blanks in piping and manways
  - Block and unblock valves
  - Drain and fill condenser and boiler
  - Purge and fill generator with hydrogen
- Effect on return-to-service schedule
  - Ability to meet expected dispatch request
  - Manufacturer's starting and loading requirements
  - Replacement power cost

The best way to account for the effect on these variables of a change in outage duration is to assign a cost to each one when possible. Some factors are based on the time to accomplish them and can be evaluated only on their effect on availability and return-to-service schedule. These must be evaluated subjectively or, if appropriate, as a cost of replacement power. An expected cost can be assigned to most of the following variables and used to assist in deciding the most appropriate layup procedure to use for the expected operating conditions:

- The quantity of water treatment chemicals required to maintain water quality
- The quantity of nitrogen required to fill or blanket the equipment and maintain pressure
- The quantity of labor and materials required to implement the layup configuration
- The quantity of labor and materials required to modify the layup configuration
- The cost of replacement power if the unit is not available
- The cost of auxiliary power to operate equipment (pumps and motors)

The outcome will not always occur as expected, but decisions must be made on the information available at the start of the layup period. Contingency plans should be in place to address an outage duration change. Procedures should describe the steps necessary to change key layup configurations, most notably from wet to dry and from dry to wet processes. The key objective is to preserve the equipment.

4
SHORT-TERM LAYUP

4.1 Short-Term Layup

Short-term layup presumes that the unit will be required to operate within a relatively short timeframe. In consideration of this, no major changes are required from normal operations, except that the unit must be protected from air ingress. Short-term outages are often scheduled outages, as opposed to maintenance outages. The equipment is to be maintained in a standby condition for restart either on a planned schedule or upon request. Typically, unit availability is maintained, and the return to service can be as short as 12–24 hours or up to 72 hours, as in a weekend shutdown.

Short-term outages lend themselves to keeping water in the equipment and excluding oxygen by maintaining pressure on the equipment. When the pressure approaches normal air pressure, nitrogen should be added to prevent oxygen ingress. The chemistry conditions for the feedwater are usually maintained in the normal operating range. There should be no difference in the degree of corrosion protection provided during a short-term or a long-term layup.

As always, selection of the proper layup procedure depends on the appropriate factors surrounding the equipment and operating conditions (equipment design, maintenance, ambient conditions, expected return to service, and so on).

4.2 Equipment Layup Practices

This section describes layup practices that apply to many scenarios for short-term outage conditions [1–3, 7, 8].

4.2.1 Turbine and Condenser—Wet Layup

The following practices should be followed for the turbine and condenser in a wet layup:

- Maintain turbine seals and condenser vacuum if the outage duration is expected to be 24 hours or less. When pressure approaches normal air pressure, add nitrogen to prevent oxygen ingress. This will also protect the drain and extraction lines.
- The hotwell (steam side) remains full of water.

- The hotwell (tube side) is treated by continuously circulating water through the condenser, ensuring that the water contains an adequate concentration of corrosion inhibitors, biocides, and dispersants, if needed. Stagnation should be avoided in any areas of the cooling water system.
- The turning gear remains in service.
- The lubricating oil system remains in service.
- The seal oil system remains in service.
- The main stop and control valve internals are protected by the positive pressure in the turbine casing and from the boiler. If pressure decays, the valve internals are protected by the nitrogen blanket within the turbine. (It is assumed that the boiler will also be inerted with nitrogen.)

4.2.2 Feedwater Heaters—Wet Layup

The following practices should be followed for the feedwater heaters in a wet layup:

- Supply nitrogen through a shell-side line to each heater or by the other piping, such as the reheater (by way of the turbine extraction lines), if pressure approaches normal air pressure.
- Maintain the tube side in wet layup with water treated according to appropriate plant chemistry procedures.

4.2.3 Deaerator and Storage Tank—Wet Layup Using an Auxiliary Steam Blanket

When pressure approaches normal air pressure, add nitrogen, or as an alternative, continue with a steam blanket from a different source (such as an adjacent unit or drum)

4.2.4 Generator

The following practices should be followed for the generator:

- Maintain hydrogen pressure unless the equipment will be opened for inspection and maintenance. The hydrogen pressure can be lowered, following the manufacturer's recommendations, to reduce hydrogen leakage.
- The cooling water systems for the hydrogen and stator water cooling system can be left running or can be shut down. To avoid freezing, keep coolers in service or drain them when the ambient temperature will be below freezing.
- Corrosion-resistant materials in the stator cooling water system, together with the high-purity water, do not require special corrosion protection for layup. Maintain system integrity so that oxides will not produce plugging or clogging of hollow strands or strainers (see Appendix B).
- The seal oil system remains in service.
- The hydrogen supply remains in service.

- The carbon dioxide supply remains in service.
- If the hydrogen is removed to perform maintenance, the generator should be purged and then purged with carbon dioxide after maintenance is completed. Depending on the required turnaround time to return the unit to service, the carbon dioxide atmosphere can be maintained until hydrogen is required.

4.2.5 Exciter

The exciter remains ready for operation.

5
INTERMEDIATE-TERM LAYUP

5.1 Intermediate-Term Layup

This condition typically applies for periods in which the equipment pressure will decay to atmospheric pressure and approach ambient temperature. The length of an intermediate-term shutdown allows some additional flexibility to layup techniques; however, the selected technique should be determined not by the length of the outage alone but together with other factors such as return-to-service needs and maintenance work to be performed.

Wet layup conditions should be used when it might be necessary to return the unit to service on short notice or when makeup water capacity is limited. Under wet conditions, the water chemistry is maintained in the normal or elevated operating range. Positive nitrogen pressure is applied and maintained to prevent air ingress as pressure decays to exclude air from unflooded spaces.

All other conditions being considered, dry storage is the preferred method as the period of the outage increases or is of an indeterminate length.

5.2 Equipment Layup Practices—Wet Layup

This section describes layup practices that apply to many scenarios for intermediate-term outage conditions [1–3, 5, 7, 8].

5.2.1 Turbine and Condenser—Wet Layup with Nitrogen Blanket

The following practices should be followed for the turbine and condenser in a wet layup with nitrogen blanket:

- The hotwell (steam side) remains full of water.
- The hotwell (tube side) can be treated by one of the following two procedures:
  - Continuously circulate water through the condenser, ensuring that the water contains an adequate concentration of corrosion inhibitors, biocides, and dispersants, if needed. Stagnation should be avoided in any areas of the cooling water system.
  - Fill the condenser tube side with cooling tower water containing the appropriate concentrations of treatment chemicals and isolate. Care should be taken to ensure that adequate protection is provided from corrosion and microbiological attack. This procedure is not suitable for systems using once-through cooling systems, unless the source has low total dissolved solids.

- Begin nitrogen addition while the turbine is spinning down. If the feedwater heater drains or vents connect to the condenser, applying nitrogen to the feedwater heaters might be sufficient to blanket the condenser. The condenser will be the largest user of nitrogen.

  Nitrogen will continuously leak out of the seals. The amount of nitrogen used to maintain the nitrogen blanket on the condenser should be quite small compared with the general movement of air around a turbine floor. These areas should be checked to verify acceptable oxygen levels.
- The turning gear remains in service.
- The lubricating oil system remains in service
- The seal oil system remains in service.
- The main stop and control valve internals are protected by the nitrogen blanket within the turbine. (It is assumed that the boiler will also be inerted with nitrogen.)

5.2.2 Feedwater Heaters—Wet Layup with Nitrogen Blanket

The following practices should be followed for the feedwater heaters in a wet layup with nitrogen blanked:

- Nitrogen is supplied through a shell-side line to each heater or through the other piping, such as the reheater, by way of the turbine extraction lines.
- The tube side is maintained in wet layup with water treated according to appropriate plant chemistry procedures.

5.2.3 Deaerator and Storage Tank—Wet Layup with Nitrogen Blanket

The following practices should be followed for the deaerator and storage tank in a wet layup using a nitrogen blanket:

- Add nitrogen to the deaerator as the steam supply is shut off through a deaerator connection in the deaerator or storage tank.
- Nitrogen is often allowed to flow through the deaerator and out the vent for about 20 minutes to remove any air.

5.2.4 Generator

The following practices should be followed for the generator:

- Maintain hydrogen pressure unless the equipment will be opened for inspection and maintenance. The hydrogen pressure can be lowered, following the manufacturer's recommendations, to reduce hydrogen leakage.
- The cooling water systems for the hydrogen and the stator water cooling system can be left running, or they can be shut down, drained, and dried. To avoid freezing, keep coolers in service or drain them when the ambient temperature will be below freezing.
- Corrosion-resistant materials in the stator cooling water system, together with the high-purity water, do not require special corrosion protection for layup. Maintain system integrity so that oxides will not produce plugging or clogging of hollow strands or strainers (see Appendix B).
- The seal oil system remains in service.
- The hydrogen supply remains in service.
- The carbon dioxide supply remains in service.
- If the hydrogen is removed to perform maintenance, the generator should be purged and then purged with carbon dioxide after maintenance is completed. Depending on the required turnaround time to return the unit to service, the carbon dioxide atmosphere can be maintained until hydrogen is required.

5.2.5 Exciter

The exciter remains ready for operation.

5.2.6 Example Procedure

The following procedure is used by a large utility for putting their units into a wet layup condition:

1. After the unit trips and while the turbine is spinning down, examine the nitrogen supply system and ensure that there is pressure on the nitrogen supply line.
2. Hang "Do Not Enter" signs on any equipment that will be blanketed with nitrogen (steam drum, deaerator, and condenser).
3. Slowly open the reheater dump line, and allow the vacuum in the condenser to remove steam from the reheat piping.
4. When the pressure to the turbine steam seals decays, break the vacuum on the condenser by slowly opening the nitrogen supply valve to the condenser.
5. As the vacuum reaches 0, close the main nitrogen line and open the bypass. Set the rotometer to 20 scfh (0.57 m^3/hr).

6. Open the nitrogen supply to the shell side on each of the feedwater heaters.
7. As the pressure decays on the deaerator, open the nitrogen supply to the deaerator through the main valve. Purge the deaerator for 20 minutes, and then close the valve and open the bypass line. Set the rotometer at 20 scfh (0.57 m^3/hr).
8. As the boiler reaches 25 psig (172 kPa), open the nitrogen supply on the superheater vent lines and the steam drum vent line.
9. Check the nitrogen supply every day on the swing shift and ensure that there is pressure on the system and that there are adequate levels of liquid in the tank. Order nitrogen as needed.
10. Check the rotometers on the nitrogen supply on the deaerator and the condenser every day on the swing shift and ensure that the flow is still 20 scfh (0.57 m^3/hr).

5.3 Equipment Layup Practice—Dry Layup

5.3.1 Turbine and Condenser—Dry Layup with Dehumidified Air

The following practices should be followed for the turbine and condenser in a dry layup with dehumidified air:

- Drain equipment hot, at 200°F (93°C) or lower, to help preclude flashing.
- Circulate dry air through the turbine and condenser (steam and water side). Open drains to facilitate draining and air flow. If some low points do not have drains, personnel might need to add drains or open piping flanges.
- The turning gear will be shut down and left so that the turbine and generator can be put on the turning gear periodically.
- The lubricating oil system will be left as is. The system will be operated during the time the turbine and generator are on the turning gear. This should keep the system covered with an oil film.
- The seal oil system will be left in service and operated to provide seals for the dehumidified air supplied to the generator.
- The governor mechanism should remain protected by the amount of oil that surrounds it in the front standard.
- The main stop and control valves will be jacked open so that dry air can circulate.

5.3.2 Feedwater Heaters—Dry Layup with Dehumidified Air

The following practices should be followed for the feedwater heaters in a dry layup with dehumidified air:

- Extractions are left open to supply dry air to the shell side of the feedwater heaters. Low point drains are opened to facilitate air flow.
- Dry air is supplied to the tube side after passing through the turbine sections and boiler (in a reverse direction from normal steam flow).
- Water is drained from the heater drain pumps, check valves are blocked open, and vents and drains are closed.

5.3.3 Deaerator and Storage Tank—Dry Layup with Nitrogen Blanket and Purge

The deaerator and storage tank should be protected by a steady, small nitrogen purge.

5.3.4 Generator

The following practices should be followed for the generator:

- Maintain hydrogen pressure unless the equipment will be opened for inspection and maintenance. The hydrogen pressure can be lowered, following the manufacturer's recommendations, to reduce hydrogen leakage.
- The cooling water systems for the hydrogen and the stator water cooling system can be left running, or they can be shut down, drained, and dried. To avoid freezing, keep coolers in service or drain them when the ambient temperature will be below freezing.
- Corrosion-resistant materials in the stator cooling water system, together with the high-purity water, do not require special corrosion protection for layup. Maintain system integrity so that oxides will not produce plugging or clogging of hollow strands or strainers (see Appendix B).
- The seal oil system remains in service.
- The hydrogen supply remains in service.
- The carbon dioxide supply remains in service.
- If the hydrogen is removed to perform maintenance, the generator should be purged and then purged with carbon dioxide after maintenance is completed.

5.3.5 Exciter

The exciter remains ready for operation.

6
LONG-TERM LAYUP

6.1 Long-Term Layup

For the purpose of this report, a long-term layup covers a shutdown of a few weeks to six months. In selecting the proper layup procedure, more than just the duration of the outage must be considered. Plants should review their particular situations and return-to-service schedules to help provide guidance in selecting the layup procedure. Many of the intermediate-term procedures can effectively protect equipment throughout a six-month period if conditions are properly monitored and maintained. Depending on the conditions and operating requirements, if the expected duration is a few weeks, these long-term procedures might be more applicable.

Dry layup is the procedure chosen to protect critical equipment (turbine, generator, condenser, feedwater heaters, and related piping) for long periods of shutdown. Dry layup can be accomplished by using a nitrogen blanket or dehumidified air. As the outage period is lengthened, by schedule or expectation, dehumidified air is preferred. Both methods limit the presence of air and moisture to prevent serious deterioration of equipment.

Dehumidified air provides the same benefits as nitrogen blanketing and has some additional benefits: it allows for maintenance of components (without the potential safety concerns of a nitrogen environment); it takes less effort to maintain the environment than maintaining nitrogen pressures; it aids in keeping electrical windings, cables, and so on dry; and after the system has been dried to an acceptable level (30% relative humidity or less), equilibrium can be maintained provided moisture is not introduced into the system. A downside to using dehumidified air is the initial capital cost of equipment.

Whichever approach is used, the quality of layup is enhanced when equipment and systems are drained hot. Care should be taken to not cause flashing during the draining process.

The systems and equipment protected by dehumidified air are generally divided into three major sections. Each major section uses a dehumidified air machine (if the flow path configuration supports it). The major sections are the following:

- Water and steam cycle
- Furnace air and gas cycle
- Generator and exciters

This guideline deals with systems and equipment in the water and steam cycle, as well as the generator and exciters. The water and steam cycle includes the following:

- The condenser and hotwell
- The turbine high-, intermediate-, and low-pressure sections
- The main stop valve and control valve internals
- The feedwater heaters (shell and tube sides)
- The deaerator and storage tank
- The steam seals
- Related equipment

This circuit also includes the major boiler sections (superheater, reheater, economizer, waterwalls, and drum), feedwater and condensate system pumps, and piping and other related equipment outside the scope of this guideline.

The generator and exciter cycle includes the main electrical generation equipment and auxiliaries. This closed cycle protects the following equipment:

- Generator
- Generator field
- Exciter
- Hydrogen coolers (gas side)
- Exciter cooling system

6.2 Equipment Layup Practices

This section describes layup practices that apply to many scenarios for long-term outage conditions [1–3, 5, 7, 8].

6.2.1 Turbine and Condenser—Dry Layup with Dehumidified Air

The following practices should be followed for the turbine and condenser in a dry layup with dehumidified air:

- Drain equipment hot, at 200°F (93°C) or lower, to help preclude flashing.
- Circulate dry air through the turbine and condenser (steam and water side). Open drains to facilitate draining and air flow. If some low points do not have drains, personnel might need to add drains or open piping flanges.
- The turning gear will be shut down and left so that the turbine and generator can be put on the turning gear periodically. Operate oil and turning gear once per week for one hour.

- The lubricating oil system will be left as is. The system will be operated during the time the turbine and generator are on the turning gear. This should keep the system covered with an oil film.
- The seal oil system will be left in service and operated to provide seals for the dehumidified air supplied to the generator.
- The governor mechanism should remain protected by the amount of oil that surrounds it in the front standard.
- The main stop and control valves will be jacked open so that dry air can circulate.

6.2.2 Feedwater Heaters—Dry Layup with Dehumidified Air

The following practices should be followed for the feedwater heaters in a dry layup with dehumidified air:

- Extractions are left open to supply dry air to the shell-side of the feedwater heaters. Low point drains are opened to facilitate air flow.
- Dry air is supplied to the tube side after passing through the turbine sections and boiler (in a reverse direction from normal steam flow).
- Water is drained from the heater drain pumps, check valves are blocked open, and vents and drains are closed.

6.2.3 Deaerator and Storage Tank—Dry Layup with Nitrogen Blanket/Purge

The deaerator and storage tank should be protected by a steady, small nitrogen purge.

6.2.4 Generator—Dry Layup with Dehumidified Air

The following practices should be followed for the generator:

- Supply dry, dehumidified air to the generator through an inspection access on one end and return from the other end (or side). Keeping dust and foreign matter out of the generator is of prime concern. A high-efficiency filter should be used to filter the dry air before it enters the generator.
- Drain coolers, dry with dehumidified air, and apply a nitrogen blanket. Leave the seal oil system on to hold gas pressure. (If nitrogen is not being applied, the seal oil system should be shut down to prevent any oil from getting in.) Continuous circulation of dry, dehumidified air is an alternative.
- When the hydrogen is removed, the stator cooling water system should be drained and dried.
- If the generator is not the cause of the outage, the gas and stator water cooling system can remain in service, even for long-term layup. In that case, the stator water chemistry must be properly monitored and maintained. Maintaining them in service should be considered only if

proper monitoring and maintenance can be ensured. Otherwise, ensure that all the water is drained and a nitrogen blanket is maintained.

- The hydrogen supply system should be isolated from the supply, and lines should be purged and blanketed with nitrogen.
- The carbon dioxide supply system should be isolated from the supply, and lines should be purged and blanketed with nitrogen.

6.2.5 Exciter—Dry Layup with Dehumidified Air

The following practices should be followed for the exciter in a dry layup with dehumidified air:

- Supply dry, dehumidified air with a supply line from the dehumidifier machine and back. For best results, the connection should be made into the ductwork of the exciter cooling system and returned from an inspection port on the exciter housing.
- Remove brushes to prevent pitting. The collector ring might begin to rust if the unit is off the turning gear. If the brush assembly is removed, it can take 1 to 2 days to reinstall it.

7 MONITORING

7.1 Surveillance Techniques

All layup conditions, dry or wet, should be either continuously or periodically monitored to ensure that the layup water or air quality is maintained. Maintaining layup integrity is essential to a successful program that maintains the asset and provides for return to service of a reliable unit when needed, without unbudgeted expense. The result of inadequate maintenance can be serious corrosion damage to equipment. The layup program should be carefully monitored to ensure that corrosion control is maintained. For example, the loss of pressure within a closed vessel indicates a leak. If pressure is lost, moist air can enter the equipment and form condensate on surfaces. Condensate can absorb oxygen and carbon dioxide at the air–water interface and corrode the metal surfaces. If atmospheric chloride also enters the equipment, the combination of moisture, carbon dioxide, and chloride can result in severe corrosion attack to the metal [1].

To monitor the effectiveness of the layup practices and to differentiate between the effects of power operation and layup, it would be necessary to inspect several individual components immediately after plant shutdown and again just before startup. It would not be practical to perform such detailed inspections for the outages contemplated in this report. This practice would impact the critical path for startup, and no utility would increase the length of the outage for this purpose. It would be counterproductive for plants to delay startup to facilitate layup surveillance. It would also be counterproductive to take a component out of layup to perform prolonged layup surveillance. For short-duration layups, monitoring of the status of layup procedures and conditions is needed to ensure proper protection of equipment.

A layup surveillance program will ensure that layup procedures and techniques are dynamic—that is, updated and enhanced based on the observed degradation. The surveillance program will ultimately help to ensure that component integrity and performance and functional requirements are met during plant operations.

A number of surveillance techniques can be applied to monitor the condition of equipment. These techniques are grouped into three categories—process control, flaw detection, and others—as shown in Table 7-1 [4]. For the layup periods described in this report, where layup periods are short and often of indeterminate duration, plants should typically use the process control techniques to monitor the status of layup activities. Appendix D presents a lookup table of monitoring techniques for various layup durations.

Table 7-1
Grouping of Surveillance Techniques

Surveillance Type	Surveillance Technique
Process control	Chemical analysis Relative humidity
Flaw detection	Eddy current inspection Magnetic particle testing Liquid penetrant testing Ultrasonic inspection Pulled tube examination Radiographic testing
Other	Video or visual inspection Failure analysis Volume or mass of sludge Analysis of deposit Heat balances

7.1.1 Process Control Techniques

Chemical analysis is used to verify wet layup conditions according to specified limits. When parts, components, and systems are maintained in wet layup, chemical parameters are carefully monitored and controlled for the duration of the outage (for example, cation conductivity, chlorides, pH, and oxygen). Sampling and sample point selection are important—and, in some cases, critical—to layup effectiveness. For wet layup, utilities routinely perform chemical analysis of layup water to verify that system fluids are maintained within specifications. System chemistry is adjusted as appropriate. It can be effectively used as part of the process control program to maintain specified layup conditions.

Relative humidity is typically used to verify dry or drained layup techniques according to specified limits. Relative humidity is the ratio of water vapor in a given volume of air at a given temperature to the maximum amount of water vapor that would be present if the air were saturated with water at that temperature. Relative humidity can be used quite effectively as part of the process control program to maintain specified layup conditions. Based on experience, relative humidity data must be routinely trended and monitored to be effective. Instrumentation can be used to alarm when relative humidity is outside the parameters. Relative humidity must be coupled with other inspections, such as inspection for moisture accumulation at low-point drains (drain and flush as appropriate), to ensure that the desired dry layup condition is maintained.

7.1.2 Flaw Detection Techniques

Flaw detection techniques will generally not be practical for the layup durations contemplated in this guideline unless a specific concern with equipment condition must be studied. These techniques are generally too time consuming and would remove the affected equipment from its protective environment, allowing corrosion and degradation to occur. These techniques can effectively be used to monitor layup effectiveness for long-term layup or mothballing.

7.1.3 Other Techniques

Other techniques to be used in monitoring the status of layup conditions include video or visual inspection and analysis of sludge or corrosion products.

Various sizes and types of cameras and fiberscopes or borescopes are used in the industry for *in situ* examination of internal and external surfaces of power plant systems, components, and parts. Video cameras with associated light sources or fiberscopes or borescopes with delivery and manipulation tooling (using video, 35-mm, or Polaroid cameras for documentation) can be used to provide real-time inspection of surfaces of components or parts. Typically, video or visual inspection is used to locate degradation (corrosion, erosion, and so on) of system or component materials as well as deposits and sludge. This technique can encompass a variety of methods, including examination with the naked eye, the use of microscopes for measuring the depth of scratches, the use of computerized equipment to measure deposit thickness and so on, and *in situ* chemical analysis. Video or visual techniques for inspection of components maintained in wet or dry layup are typically used to evaluate first-time layup implementation to verify the effectiveness of the layup technique being used. Subsequently, process monitoring is performed to verify that the component or system is being maintained in the specified condition.

Analysis of corrosion products is also used to monitor layup conditions. Sludge is typically composed of corrosion products that have been transported from other parts of the system; it is typically found on tube sheets and support plates of heads of feedwater heaters and condenser hotwells. (Removal depends on several variables—the characteristics of the material, the materials of construction, where the sludge has been deposited, and the geometry.) The quantity and composition of the sludge is indicative of the source of corrosion or contaminants as well as the extent or degree of system corrosion problems.

7.2 Trending Layup Performance

The outage durations contemplated for this report are unlike traditional mothballing scenarios. Under these operating constraints, the equipment will be removed from and returned to service several times each year. This allows for many opportunities to have corrosion mechanisms attack the components and gradually affect equipment condition. Each change of state exposes the metal surfaces to air and moisture and presents an opportunity for deviations from proper layup procedures.

The layup program should be carefully monitored to ensure that corrosion control is maintained and equipment reliability is enhanced. It is important that the appropriate process variables be selected when the layup procedure is developed. Deviations from the set and normal levels must be addressed and corrected. Historical information is beneficial for this purpose. It can be referred to in the future to confirm the proper layup of equipment.

A routine monitoring program must be established to check the effectiveness of the layup program. Routine collection of process variables such as relative humidity, pH, and hydrazine concentrations allows plant personnel to better troubleshoot problem areas and be proactive in preventing equipment degradation. Trending equipment condition and critical process variables (in a tabular or graphical format) over time can provide a valuable tool to maintain proper layup procedures and equipment condition. Some key variables to monitor and trend are the following:

- **Heat balances.** Know the proper steady-state conditions before starting the layup program, and periodically compare results after equipment layup outages to determine any detrimental trend.
- **Video or visual inspections.** Record conditions found over time to note trends such as changes in material condition or areas in which deposits continue to form.
- **Relative humidity.** When using a dry layup approach, it is important to maintain relative humidity levels below 40% in all affected areas. Maintaining records and trending the results will show if problems exist in any areas (such as poor flow distribution, moisture in-leakage through valves or environmental breaches, or failure to maintain a positive pressure in key areas).
- **Chemical analysis.** When using a wet layup approach, proper chemistry levels and concentrations must be maintained according to the plant's appropriate chemistry regime. Trending these results will help monitor chemical addition programs and system isolation.
- **Nitrogen pressure.** Nitrogen pressure must be maintained to ensure exclusion of ambient air, whether used as a dry layup approach or as part of a wet layup approach.

Monitoring and trending layup performance against set criteria will enhance the performance of a layup program and help ensure that the cost and effort put into protecting plant equipment is not undermined.

8 REFERENCES

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A
DEHUMIDIFICATION CONFIGURATIONS

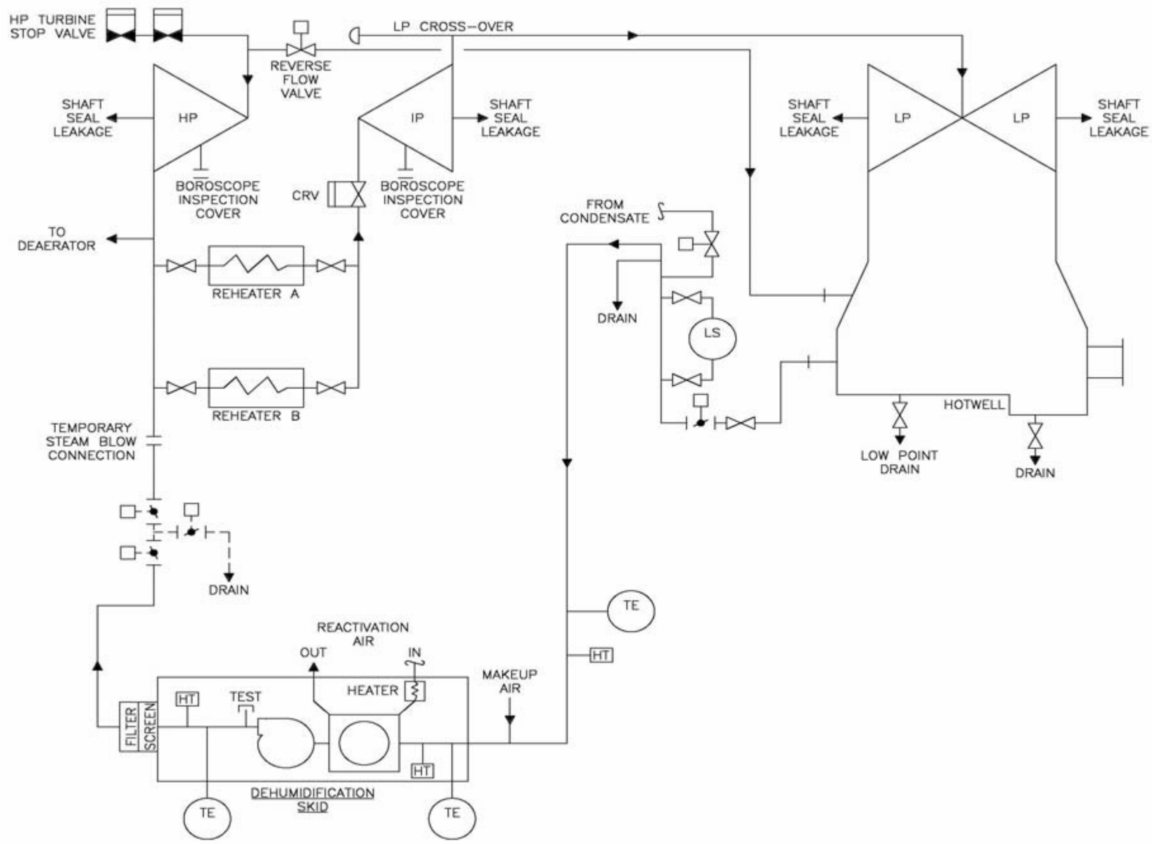

Figure A-1
Arrangement of a Single Dehumidification Skid for Servicing High-, Intermediate-, and Low-Pressure Turbine Sections and Reheater [5]

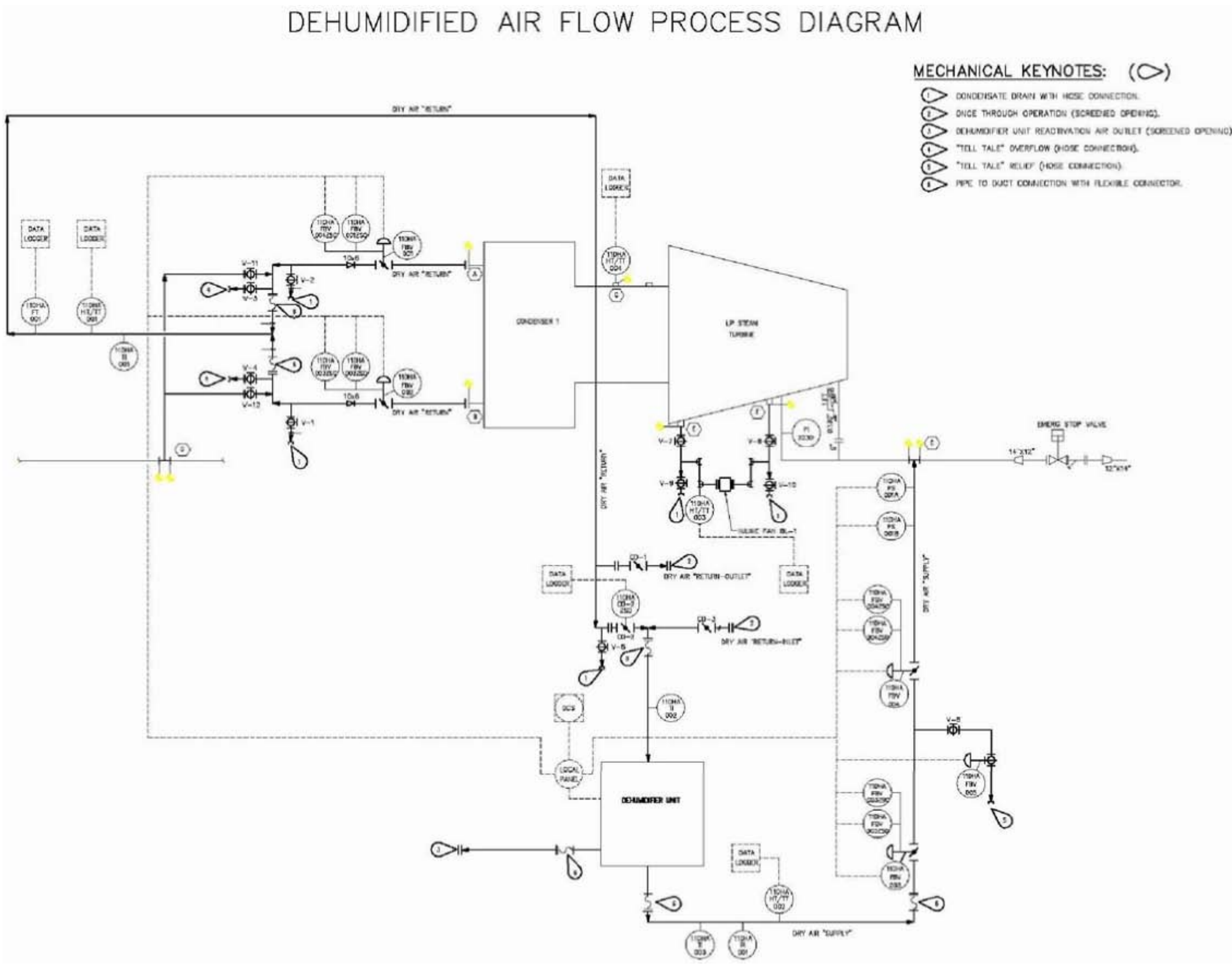

Figure A-2
Dehumidified Air Flow Process Diagram

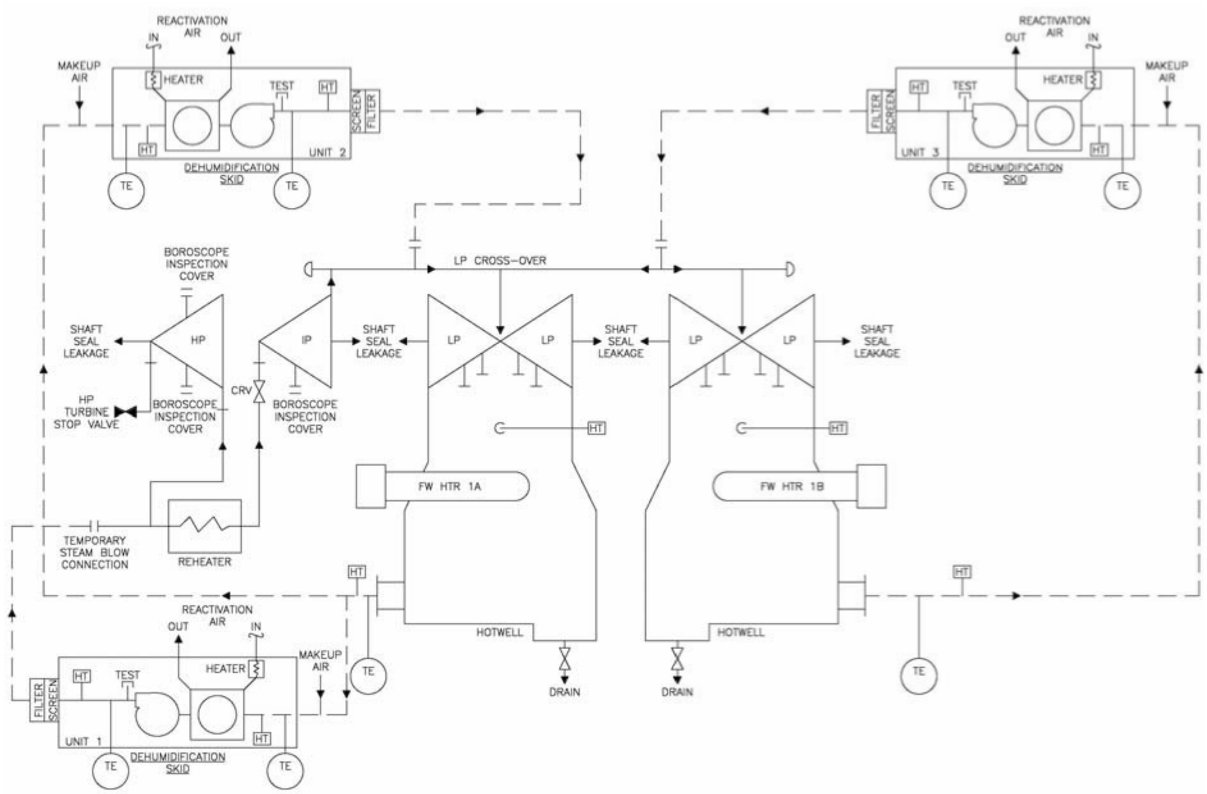

Figure A-3
Arrangement of Triple Dehumidification Skids for Servicing High-, Intermediate-, and Low-Pressure Turbine Sections and Reheater [5]

B

GENERATOR STATOR WATER COOLING SYSTEM LAYUP

Table B-1 describes layup options for generator stator water cooling systems, and Figure B-1 shows a decision flowchart.

Table B-1
Layup Options for Copper Conductors

Duration*	Leave System Running	Close Pumps and Leave System Filled with Water	Drain and Dry
Layup for ≤3 days	X	X	
Layup for >3 days			X

* The 3-day limit is arbitrary, but experience has shown that water chemistry can usually be upheld for this period.

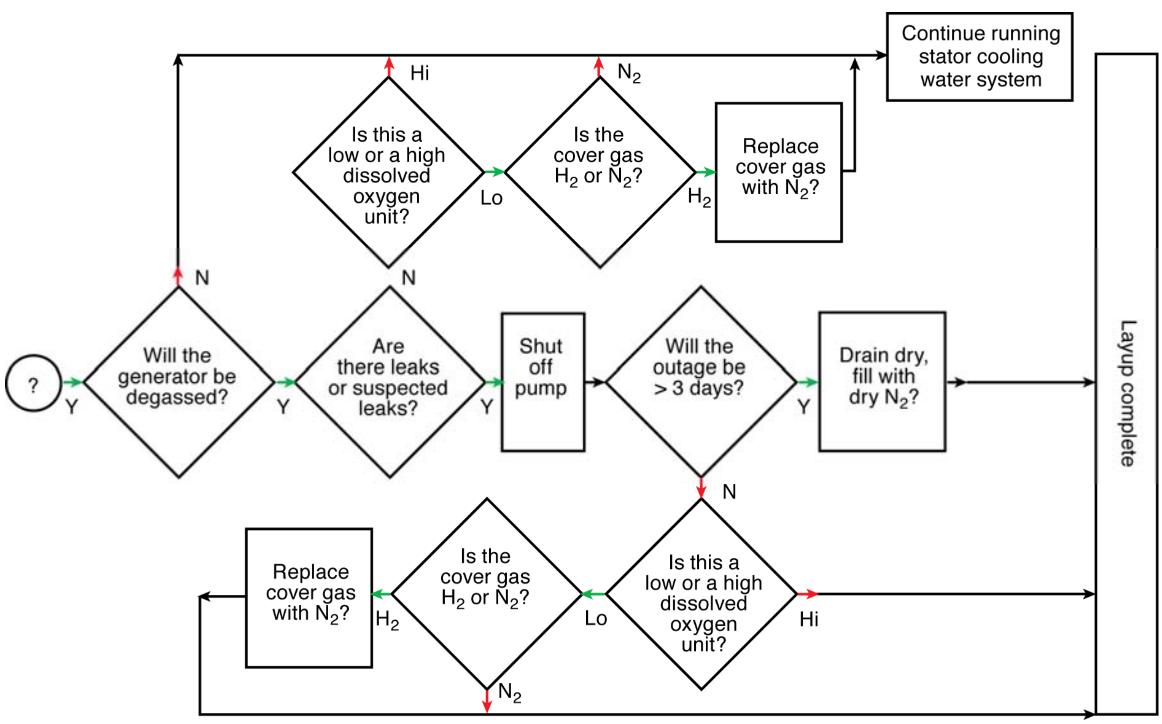

Figure B-1
Decision Flowchart for Stator Cooling Water System Layup

C

BOILER AND TURBINE LAYUP PRACTICES

Figure C-1 shows typical steps involved in layup practices.

Hot Standby

- Main condenser vacuum and steam seals.
- Before or during shutdown, ensure that boiler pH is > 9.5.
- Fire boiler as needed to maintain positive pressure on the boiler and deaerator.
- Blanket any equipment with nitrogen that would be exposed to air.

Dry Layup (Air)

- Allow boiler to cool to 25 psig (172 kPa).
- **While boiler is cooling, do the following:**
- Drain deaerator storage tank as soon as steam to the deaerator is isolated.
- Open feedwater heater shell-side drains while feedwater heaters are hot.
- Put the reheater under vacuum by opening the reheater drain lines while maintaining condenser vacuum.
- Drain the hotwell completely while it is still hot.
- Flow dehumidified air through the low-pressure turbine and out the hotwell.
- Drain all related feedwater piping, drip tanks, boiler feed pump turbine, condensers, and so on.
- Drain boiler when 25 psig (172 kPa) is reached. Dry compressed air can be used to facilitate draining and drying.
- Establish dehumidified air flow through the boiler, superheater, deaerator, and related equipment and piping. Achieve < 35% relative humidity throughout.

Dry Layup (Nitrogen)

- Allow boiler to cool to 25 psig (172 kPa).
- Drain deaerator storage tank under nitrogen as soon as steam to the deaerator is isolated.
- Open feedwater heater shell-side drains while feedwater heaters are hot.
- Put the reheater under vacuum by opening the reheater drain lines while maintaining condenser vacuum.
- Drain the hotwell completely while it is still hot.
- Flow dehumidified air through the low-pressure turbine and out the hotwell.
- Drain all related feedwater piping, drip tanks, boiler feed pump turbine condensers, and so on.
- Apply nitrogen to the superheater vent and drain the superheater and boiler under nitrogen when the boiler reaches 25 psig (172 kPa).
- Post warning signs on all confined spaces in the steam cycle that equipment is nitrogen filled.
- Maintain a slight positive pressure of nitrogen on the boiler during the entire layup and through the subsequent boiler fill.

Wet Layup

- Allow boiler to cool to 5 psig (34 kPa).
- **While boiler is cooling, do the following:**
- Before or during shutdown, ensure that boiler pH is > 9.5. If the unit normally uses a reducing agent, the residual can be increased.
- Establish nitrogen blanket on the deaerator as steam to the deaerator is isolated.
- Establish nitrogen blanket on the shell side of the feedwater heaters as pressure to the heaters is isolated.
- Put the reheater under vacuum by opening the reheater drain lines while maintaining condenser vacuum.
- Add nitrogen to the reheater to break vacuum on the condenser (or add nitrogen separately to break vacuum).
- Open nitrogen supply to the superheater when boiler pressure is at 5 psig (34 kPa). Nitrogen will fill the boiler and superheater as the steam collapses.
- Establish a nitrogen blanket (or drain dry) any drip tanks, auxiliary condensers, or other wet equipment.
- Post warning signs on all nitrogen-containing equipment.

Figure C-1
Flowchart for Layup Practices [3]

D

MONITORING METHODS FOR VARIOUS LAYUP DURATIONS

Table D-1 presents monitoring methods for various layup durations.

Table D-1
Monitoring Methods for Various Layup Durations

Layup Option	Monitoring Method	Frequency	Comments
Short Term (Overnight to a Weekend)	Chemical analysis	Daily operator rounds	For wet layup
	Relative humidity	Daily operator rounds	For dry layup
	Visual or video inspection	On initial layup	Verify procedure effectiveness
Intermediate Term (Up to One Week)	Chemical analysis	Daily operator rounds	For wet layup
	Relative humidity	Daily operator rounds	For dry layup
	Visual or video inspection	On initial layup	Verify procedure effectiveness
Long Term (More Than One Week to Six Months)	Chemical analysis	Daily operator rounds	For wet layup
	Relative humidity	Daily operator rounds	For dry layup
	Visual or video inspection	On initial layup	Verify procedure effectiveness
Mothballed Condition	Relative humidity	Daily	For dry layup
	Visual or video inspection		Verify procedure effectiveness

Table D-1 (continued)
Monitoring Methods for Various Layup Durations

Layup Option	Monitoring Method	Frequency	Comments
Mothballed Condition (continued)	Eddy current inspection Magnetic particle testing Liquid penetrant testing Ultrasonic inspection Pulled tube examination Radiographic testing	At the beginning and end of the layup period for suspect equipment	Not used for shorter durations unless problems are suspected

Notes:

Volume or mass of sludge and analysis of deposit tests should be performed on material found during inspections and maintenance in areas such as tubesheets, feedwater heads, and the condenser hotwell.

Failure analysis should be performed on equipment after damage has occurred to determine the cause of failure.

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