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IEEE Recommended Practice for the Design and Installation of Electric Heat Tracing Systems for Nuclear Power Generating Stations

Sponsor

**Power Generation Committee
of the
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Foreword

(This Foreword is not a part of IEEE Std 622-1987, IEEE Recommended Practice for the Design and Installation of Electric Heat Tracing Systems for Nuclear Power Generation Stations.)

The realization that electric heat tracing systems play an important role in the normal operation of both nuclear and non-nuclear processes in nuclear power generating stations has now come of age. This is apparent by the increased amount of space being devoted to electric heat tracing in station technical specifications, system descriptions, and operating criteria. Such electric heat tracing systems are applied on borated water systems and on water treatment systems such as caustic. Since boric acid and caustics in water will crystalize or precipitate out of the solution depending on their concentrations at temperatures above ambient, and since such crystallization can make the piping system inoperable for normal operation, electric heat tracing systems are required to keep the solutions and piping systems in a state to perform their intended functions. Electric heat tracing systems may also be applied on piping located outdoors at nuclear generating stations for the purpose of preventing the piping systems from freezing. It should be noted that each and all of these piping systems can include valves, pumps, strainers, tanks, and instrumentation components that can be rendered inoperable due to solutions crystallizing or freezing. Therefore, a definite need exists within the power industry for recommendations that provide a uniform method for the design and installation of electric heat tracing systems that meet the requirements for rendering reliable operation of the piping system. Without such recommendations, station reliability may be jeopardized.

This recommended practice is intended to meet the design and installation needs for pressurized water reactor (PWR) and boiling water reactor (BWR) nuclear generating stations. Breeder reactors and other types of applications are outside the scope of this document. Also, the principles in this document are applicable to all types of generating stations, for example, fossil, hydroelectric, etc. Presented herein are such recommendations and topics as identification of piping systems to be heated, temperature requirements, heater design considerations, heat tracing systems design (including control and monitoring), power systems design, installation of electric heat tracing systems, testing of the systems, and maintenance considerations.

Since electric heat tracing systems are interrelated with electric power and alarm systems, other IEEE standards should be referred to when using this recommended practice. The recommendations presented herein are not intended to supersede any current IEEE standards or practices, and sound engineering judgment should always be used when applying this or any other IEEE standard.

Electric heat tracing systems play an important role in the normal operation of nuclear generating stations. Therefore, redundant circuit and heater considerations with respect to station reliability are covered in this recommended practice along with alarm considerations. This document recommends that electric heat tracing systems not be classified as Class IE systems and that critical process control systems be powered from reliable station power sources. If these reliable power sources are the engineered safety features (ESF) buses, then the electric heat tracing systems should be powered through suitable isolation devices in accordance with ANSI/IEEE Std 308-1980, IEEE Standard Criteria for Class IE Power Systems for Nuclear Power Generating Stations, and ANSI/IEEE Std 384-1981, IEEE Standard Criteria for Independence of Class IE Equipment and Circuits.

The recommendation for not classifying electric heat tracing systems as Class IE is based on station operating criteria. In its investigation of electric heat tracing systems for critical process piping, the working group could find no evidence that a properly designed system would come under a Class IE classification for proper performance. Electric heat tracing systems that are applied on reactor injection piping systems do not perform any safety functions either during or after a postulated loss-of-coolant accident (LOCA). Instead, electric heat tracing systems render such piping systems operable during normal station operation and thus are not needed during or after a postulated LOCA. For further discussion and technical explanations on normal and accident station operations with respect to nonClass IE electric heat tracing systems, reference should be made to Appendix B of this document.

An exception to this recommendation is the classification of electric heat tracing systems applied on post-accident sampling systems. Such post-accident sampling systems were mandated by the Nuclear Regulatory Commission as

part of the Three Mile Island Unit 2 retrofit program initiated after this standard was first published in 1979. Explanation of these requirements may be found in Appendix C of this document.

This recommended practice correlates industry practices; it is not intended to be an exhaustive compilation or a rigid procedure manual. The document was prepared by the working group on Electric Heat Tracing Systems, which was formed by the Station Design Subcommittee of the Power Generation Committee.

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IEEE Recommended Practice for the Design and Installation of Electric Heat Tracing Systems for Nuclear Power Generating Stations

1. Scope and Purpose

This document provides recommended practices for designing and installing electric heat tracing systems in nuclear power generating stations. These electric heat tracing systems are applied, both for critical process temperature control and for process temperature control, on mechanical piping systems that carry borated water, caustic soda, and other solutions. Electric heat tracing systems are also applied on water piping systems to prevent them from freezing in cold weather. The recommendations include identification of requirements, heater design considerations, power systems design considerations, temperature control considerations, alarm considerations, finished drawings and documents, installation of materials, startup testing, temperature tests, and maintenance of electric pipe heating systems.

The purpose of this document is to provide recommendations that may be used in the design, installation, and maintenance of electric heat tracing systems as applied to mechanical piping systems. These recommendations are intended to ensure that the piping systems will be maintained at specified operating temperatures, which in turn will ensure that the piping systems' fluids will be available not only during station operation but also during normal and emergency shutdown.

2. Definitions

The following definitions apply specifically to the subject matter in this recommended practice. In some cases, more than one term or phrase is defined because in industry practice the terms or phrases are used interchangeably. Additional definitions of terms or phrases used in this document may be found by referring to ANSI/IEEE Std 100-1984 [2].¹

base line data: Information retained for the purpose of evaluation against repeated information in order to establish trends in parameters.

¹The numbers in brackets correspond to those of the references listed in Section 3.

controller: A device that regulates the state of a system by comparing a signal from a sensor located in the system with a predetermined value and adjusting its output to the predetermined value. Controllers, as used in electric heat tracing systems, regulate temperatures on the system and can be referred to as *temperature controllers* or *thermostats*. Controllers can be mechanical (bulb, bimetallic) or electrical (thermocouple, RTD, thermistor).

critical freeze protection: The use of electric heat tracing systems to prevent the temperature of fluids from dropping to or below the freezing point of the fluid in important or critical outdoor (usually) piping systems at nuclear generating stations. An example of a critical freeze protection system is the heating for the nuclear service water system.

critical process control: The use of electric heat tracing systems to increase or maintain (or both) the temperature of fluids (or processes) in important or *critical* mechanical piping systems including pipes, pumps, valves, tanks, instrumentation, etc. An example of an important or critical mechanical piping system would be the safety injection system.

electric heat tracing system: A system of components and devices consisting of electric heaters, controllers, sensors, dedicated power systems components, such as transformers, panelboards, cables, and system alarm devices (as required) that, when taken together as a system, are used to increase or maintain the temperature of fluids in mechanical pipes, valves, pumps, tanks, instrumentation, etc.

electrical insulation, insulation (cable): A part that is relied upon to insulate the conductor from other conductors or conducting parts or from ground. Electrical insulation as related to electric heat tracing systems includes that part of a heater that electrically insulates the current-carrying conductor(s) from the sheath material.

freeze protection: The use of electric heat tracing systems to prevent the temperature of fluids from dropping to or below the freezing point of the fluid. Freeze protection is usually associated with piping, pumps, valves, tanks, instrumentation, etc, such as water lines, that are located outdoors or in unheated building.

heater, electric heater, heating element: A length of resistance material connected between terminals and used to generate heat electrically. Heaters, as used in this application, can take the form of cables with various sheath materials, blankets, and pads.

heat sink: A part that absorbs heat. Heat sinks, as related to electric heat tracing systems, are those masses of materials that are directly connected to mechanical piping, valves, tanks, etc, that can absorb the heat generated by heaters, thus reducing the effect of the heater. Typical heat sinks can be pipe hangers, valve operators, etc.

process control: The use of electric heat tracing systems to increase or maintain, or both, the temperature of fluids (or processes) in mechanical piping systems including pipes, pumps, valves, tanks, instrumentation, etc, in power generating stations.

redundant, redundancy: The introduction of auxiliary elements and components to a system to perform the same function as other elements in the system for the purpose of improving reliability. Redundant electric heat tracing systems consist of two heaters and two controllers, each with its own sensor, supplied from two power systems and two alarms, each system independent of the other but all applied to the same mechanical piping, valves, tanks, etc. Redundant electric heat tracing systems are referred to as *primary* and *backup* in this recommended practice.

sensor, sensing element: The first system element that responds quantitatively to the measurand and performs the initial measurement operation. Sensors, as used in electric heat tracing systems, respond to the temperature of the system and may be directly connected to controllers, alarms, or both. Sensors can be mechanical (bulb, bimetallic) or electrical (thermocouple, RTD, thermistor).

thermal insulation: A material having a relatively high resistance to heat flow and used primarily to retard the flow of heat.

3. References

The following publications shall be used in conjunction with this standard:

- [1] ANSI/ASME NQA-2-1986, Quality Assurance Requirements for Nuclear Power Plants.²
- [2] ANSI/IEEE Std 100-1984, IEEE Standard Dictionary of Electrical and Electronics Terms.³
- [3] ANSI/IEEE Std 306-1980, IEEE Standard Criteria for Class IE Power Systems for Nuclear Power Generating Stations.
- [4] ANSI/IEEE Std 384-1981, IEEE Standard Criteria for Independence of Class IE Equipment and Circuits.
- [5] ANSI/IEEE Std 515-1983, IEEE Recommended Practice for the Testing, Design, Installation, and Maintenance of Electrical Resistance Heat Tracing for Industrial Applications.
- [6] ANSI/IEEE Std 622A-1984, IEEE Recommended Practice for the Design and Installation of Electric Pipe Heating Control and Alarm Systems for Power Generating Stations.
- [7] ANSI/NFPA 70-1987, National Electrical Code.⁴

4. Design of Electric Heat Tracing Systems

The function of an electric heat tracing system is to provide, to an insulated mechanical piping system, heat that will maintain the fluid in the system within its specified operating temperature range. On some occasions, heatup of the fluid to its operating temperature range may be required. Various thermal, physical, mechanical, electrical, and operational design parameters should be considered to ensure proper design of the electric heat tracing system. The mechanical and electrical properties of the heating system should not be impaired by continuous or intermittent operation under the environmental and operating conditions specified.

4.1 Identification of Requirements

An electric heat tracing system design should clearly identify the thermal, physical, mechanical, electrical, and system associated requirements, such as hazardous and corrosive environments.

4.1.1 Piping and Related Equipment to be Heated

To determine the heating requirements of a mechanical piping system, it is necessary to know the following:

- 1) Lowest and highest expected ambient temperatures
- 2) Desired maintain temperature
- 3) Maximum and minimum operating temperature
- 4) Pipe size, length, and material
- 5) Type and number of valves
- 6) Type and number of pipe joints
- 7) Type and number of hangers and supports
- 8) Flow patterns
- 9) Insulation type, thickness, dimensions, and jacket used, if any
- 10) Insulation K factor
- 11) Heatup requirements

²All ANSI publications are available from the Sales Department, American National Standards Institute, 1430 Broadway, New York, NY 10018; ASME publications are available from the Order Department, American Society of Mechanical Engineers, 22 Law Drive, Fairfield, NJ 07007.

³IEEE publications are available from the Service Center, The Institute of Electrical and Electronics Engineers, 445 Hoes Lane, PO Box 1331, Piscataway, NJ 08855-1331.

⁴NFPA publications can be obtained from Publications Sales, National Fire Protection Association, Batterymarch Park, Quincy, MA 02269.

- 12) Type of control
- 13) Wind factor (if outdoors)
- 14) High and low alarm points (when required)
- 15) Number, size, and length of vertical pipe runs
- 16) Type of fluid and minimum and maximum flow
- 17) Process fluid freezing, boiling or crystalization point.

It is important to determine specifically any additional heat required for pipe hangers, supports, and restraints that cannot be completely or properly insulated to avoid their being heat sinks. Small tanks, pumps, and other irregular surfaces may require separate enclosures, heaters, and controls for system integrity and maintenance considerations. Large insulated tanks may use surface, immersion, or circulation-type heaters. Equipment such as *canned* pumps that utilize heated enclosures should have provisions for heat release when the pumps are running. Other lines that may require heating are instrument, drain, and sample lines. Unheated piping that interfaces with piping to be heated can create a large heat sink. Thus heating circuits may be necessary to heat portions of the interface piping.

Special consideration should be given when heating temperature-sensitive pipe (plastic, plastic lined, fiberglass, etc) to ensure that the maximum sheath temperature of the heater is below the maximum allowable temperature of the pipe material. Since the thermal conductivity of nonmetallic material is much lower than that of steel, the electric heat tracing design should take into consideration this resistance to heat flow through the pipe wall.

4.1.2 Heater Requirements

Heater requirements should take the following into consideration:

4.1.2.1 Maintained Process Temperature

Some process systems require that the fluids being carried by the pipe be *maintained* at a temperature consistent with the temperature at which the fluid enters the system, the solubility level of the fluid or its viscosity, or both, and the end-use requirements.

Examples of such process systems are:

- 1) Boron recovery
- 2) Safety injection
- 3) Chemical and volume control
- 4) Liquid waste disposal
- 5) Sodium pentaborate
- 6) Boric acid transfer
- 7) Solid waste disposal
- 8) Waste management
- 9) Caustic soda
- 10) Standby liquid control
- 11) Fuel oil
- 12) Normal operation gas analysis

The amount of heat applied to maintain a fluid at a given temperature should be sufficient to replace the losses through the thermal insulation and heat sinks at a temperature above the controller turnoff point.

Any static piping system with a requirement for maintained process heating should be initially filled at operating temperature, or considerable time (days) allowed for heatup.

4.1.2.2 Heatup Requirements

Some process systems require that the fluids be increased in temperature. When electric heat tracing systems are used in such capacities, it is necessary to supply additional heat above that required to maintain the operating temperature. The extent of the additional heating will depend on the maximum temperature required, the lowest starting temperature, the process flow rate, the length of time specified to reach the heatup temperature, and the specific heat of the process, pipe, and insulation.

4.1.2.3 Freeze Protection Requirements

Where process or storage systems are subject to temperatures that can fall to or below the freezing temperatures of the fluid, it becomes necessary to protect the fluid from freezing with electric heat tracing and thermal insulation.

4.1.3 Temperature Requirements

The specified operating temperature range of an electric heat tracing system is determined by the fluid's physical and chemical characteristics and the heating system's compatibility with the piping system, including pump, seal and gasket material, pipe lining, heat exchangers, etc. The temperature requirements for the various electric heat tracing systems are outlined as follows:

- 1) Critical process control (such as boric acid and sodium pentaborate systems) should have operating temperature ranges set above the crystallization temperature of the fluid to prevent plugging of the piping during normal and abnormal operating conditions. In addition, the maximum temperature should be that temperature that will not physically damage the mechanical equipment to which the heating is applied nor be detrimental to the process fluid.
- 2) Process control (such as caustic and fuel oil systems) should have operating temperature ranges set above the minimum temperature at which the pumping system, etc, will continue to function at design flow rate and pressure. The maximum temperature should be that temperature that will not result in detrimental fluid vaporization or pumping system operation.
- 3) Freeze protection control (such as outdoor water systems) should have a minimum temperature set approximately 5 °C (9 °F) above the process freeze point to prevent any freezing caused by variations in the ambient temperature along the piping system. The maximum temperature should be that temperature that will not result in detrimental fluid vaporization or pumping system operation.
- 4) Critical freeze protection control (such as makeup water storage systems) should have the temperature set the same as described under freeze protection. However, separate pipe sensing controllers are recommended for critical freeze protection.

The minimum ambient temperature of any area containing mechanical piping systems to be heated should be determined. Typically, indoor systems use 10 °C (50 °F) as the minimum ambient and outdoor systems use the minimum temperature established for that geographical location.

Tables A.1 and A.2 and Figs A.1 and A.2 in Appendix A show the typical ranges of operating temperatures, solubility curves, and other pertinent data for the various solutions found in nuclear power generating stations.

4.1.4 Thermal Insulation

The type and thickness of thermal insulation are important in determining the heat loss of the piping system. To determine actual losses for a given set of conditions, a complete thermal insulation specification, including the thermal conductivity K at several mean temperatures, should be consulted. All physical and thermal properties of the specified thermal insulation should be available together with information regarding weather barrier materials.

4.1.4.1 Heat Loss Characteristics

The thickness of thermal insulation required to reduce heat transfer and maintain a desired temperature differential between ambient air and the pipe wall should be determined. The K factor of thermal insulating materials increases with temperature. When referring to a K factor of a thermal insulating material, it is important to note the corresponding mean temperature.

4.1.4.2 Weatherproofing Considerations

Provisions should be made to prevent moisture from entering the thermal insulation. Most thermal insulation materials are susceptible to moisture absorption (which reduces their insulating properties) and should be protected from this by waterproofing or other appropriate methods. Electric heat tracing normally does not have sufficient heat output to dry out wet thermal insulation. Proper operation of an electric heat tracing system depends on the thermal insulation being dry so as to maintain its design insulating characteristics.

4.1.4.3 Thermal Insulation Materials and Application

The most generally used thermal insulation for electric heat tracing systems and their typical maximum service temperatures are:

Type of Material	Typical Maximum Service Temperature
Calcium Silicate	677 °C (1250 °F)
Mineral Wool	677 °C (1250 °F)
Fiberglass	232 °C (450 °F)
Cellular Glass	232 °C (450 °F)

Care should be taken during insulation selection to ensure that the insulation is chemically compatible with the heater cable sheath and pipe. This is particularly true of some insulation materials that may have free chlorides that can cause stress corrosion in stainless steel.

Thermal insulation used on systems located in difficult access or high radiation areas should be designed for quick and easy removal and reinstallation for maintenance.

Some heating cables require oversized thermal insulation to allow for the overall diameter of the pipe and cable(s). Oversized insulation creates an air space, or annulus, between the insulation and the pipe. On vertical piping runs, the air space can allow heat to be convected upwards via the “chimney effect.” This can cause reduced pipe temperatures at lower elevations due to heat loss by convection to the piping at higher elevations. Convection stops may be added on all vertical piping runs to ensure that the “chimney effect” is eliminated or minimized.

Most thermal insulation systems consist of one or two-piece preformed or molded rigid sections composed of insulant materials covered with a vapor barrier laminate. Jacketing used over thermal insulation for mechanical and weather protection may be sheet aluminum, sheet steel, sheet stainless steel, glass cloth, or polymeric materials.

Heat transfer by convection within the fluid-filled pipe cannot be controlled by the insulation system, but is not usually of any significance on smaller pipe sizes. The electric heat tracing designer should be consulted on maximum vertical rise in a common heating circuit and especially on the location of the temperature sensor used for control. Insulation and heating on outdoor piping should be continued a minimum of 1 m (3.3 ft) inside the buildings where they enter.