Methodology and Installation of Radiation and Temperature Monitors

Research for Installed Cables at U.S. Nuclear Power Plants in Support of Long-Term Operations

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All or a portion of the requirements of the EPRI Nuclear Quality Assurance Program apply to this product.

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ABSTRACT

This report is a follow-up to the 2013 Electric Power Research Institute (EPRI) report *Long-Term Operations: Normal Temperature and Radiation Dose to Installed Cable for U.S. Nuclear Power Plants in Containment* (3002000816).

In support of the current plans for a second relicensing of nuclear power plants beyond a 60-year operating license, EPRI is conducting research to assess the condition of the existing electrical cabling infrastructure. In order to operate through a subsequent licensing period of more than 60 years, plants must demonstrate that the existing cabling can continue to provide safe and reliable plant operation in all expected design conditions (normal and post-accident).

Understanding the actual operating environments that cables are subject to is an important variable in determining how the cables will degrade and the service life that cables will be able to reliably perform. Little information could be gathered from the industry to support the actual temperature and radiation levels in locations of cables in any given plant for Phase I of this project (EPRI report 3002000816). Therefore, this second phase was initiated to install monitors in two host plants (one boiling water reactor and one pressurized water reactor) in a reasonably robust number of locations and collect one fuel cycle's worth of data. This report describes the efforts to identify which monitoring equipment to use, to determine how many monitors should be used, and to determine locations for placing the monitors. It also provides the engineering documentation needed to support the installation and removal of the monitors and analysis of the data that were obtained. The actual results of the data collection and data analysis will be in provided in the final project report, which will be issued in 2017, after the recorders are removed, the data are retrieved, and analysis of the data is performed.

Keywords
Aging (materials)
Cable
Environmental qualification
Long-term operation
Radiation monitoring
Temperature monitoring

EXECUTIVE SUMMARY

The project that is the subject of this report is part of a research strategy to determine whether electrical cables installed in nuclear power plants will be able to perform reliably if they are operated beyond the currently allowed 60-yr licensing period. A major gap informing cable aging research to understanding the expected degree and rate of degradation of cables involves the thermal conditions and radiation exposure that cables are subjected to in their operating environments. An initial attempt was made to close this gap with the 2013 ERPI report *Long-Term Operations: Normal Temperature and Radiation Dose to Installed Cable for U.S. Nuclear Power Plants in Containment* (3002000816).That effort attempted to quantify these environments by obtaining existing data from nuclear power plants in the United States. However, the data that were obtained were insufficient to draw any supportable conclusions on the level of dose that cables are exposed to in actual installed locations. These data are important because the amount of radiation that cables are exposed to will determine whether radiation is a significant contributor to insulation aging. Thermal aging is well understood, but many questions remain on the effects of radiation. Whether radiation plays a role in cable insulation aging cannot be fully understood without real data that can be used to accurately estimate lifetime exposure that the cables will receive.

Qualification of cable aging is of particular concern because replacing existing cable runs would be cost-prohibitive and existing cable qualification testing might be insufficient to envelop the long-term normal radiation dose along with accident qualification. Additional cable qualification testing would be expensive and might be unable to envelop the higher plant radiation dose (including accident).

This report provides inputs to be used for when radiation and temperature monitoring equipment is installed in nuclear plants, in order to quantify normal service conditions in the general vicinity of nuclear power plant cables, for potential extrapolation of lifetime radiation on thermal conditions through long-term operation. In addition, it provides updates on host plant selections and current progress.

Based on reviews of available industry information, the following topics are covered in this report, with decisions identified regarding the installation of temperature and radiation monitors within EPRI host plants:

- **Selection of temperature and radiation monitoring equipment**. The section dealing with this topic identifies a series of currently available common temperature monitors, radiation monitors, and combined temperature and radiation monitors and selects a monitor for this particular project purpose. The Westinghouse LIFETIME[1] equipment monitor was chosen as the suggested monitoring device.

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[1] *LIFETIME* is a registered trademark of Westinghouse Electric Company.

- **Administrating planning for implementing a temperature and radiation monitoring program**. Planning includes the following topics:
  - **Plant cable aging temperature and radiation research**. Current and historical normal temperature and radiation data should be identified as a baseline. All possible current and historical plant data should be reviewed prior to making plans for future temperature and radiation monitoring.
  - **Installation procedure considerations**. Each plant must determine the appropriate procedure for monitor installation.
  - **Code of Federal Regulations (CFR) considerations**. The Nuclear Regulatory Commission's 10CFR50.59 screening process or complete evaluation process might be required in order to install monitors for this specific purpose of long-term operation cable thermal and radiation monitoring.
  - **Work package considerations**. Any work package for the installation of the temperature and radiation monitors to evaluate for cable aging for long-term operation needs to consider any affected other plant programs and any plant programs that might wish to obtain the resulting data.
  - **Calibration requirements**. Calibration requirements must be followed and vary depending upon the type of monitor used.
- **Technical planning for implementing a temperature and radiation monitoring program**. Planning includes the following topics:
  - **Total number of monitors**. A minimum of 20 monitors might be needed inside containment (pressurized water reactor [PWR])/drywell (boiling water reactor [BWR]), and a minimum of 20 monitors might be needed outside containment (PWR)/reactor building (BWR) for this particular purpose.
  - **Monitor placement**. Placement of monitors depends upon plant-specific equipment considerations (for example, PWR pressurizers).
  - **Installation accessibility and mounting adjustments**. These must be considered when choosing locations.
  - **Monitoring frequency**. A recommended monitoring frequency of at least once a day is considered acceptable if active monitoring equipment is used.
  - **Monitoring duration**. A recommended monitoring duration of between one year and one refuel cycle is considered acceptable.
- **Monitor data analysis**. The section dealing with this topic covers the following data-related topics for long-term cable aging monitoring:
  - Data retrieval frequency
  - Data type to be retrieved
  - Data format
  - Plant monitoring data record sorting
  - Determination of margins between the design and monitored temperature and radiation values (This is the primary evaluation section of this project: to identify whether there are margins between the recorded data and the existing plant design or other currently used data.)

- **Monitor data recording and record keeping**. The section dealing with this topic covers topics related to post monitoring data storage as follows:
  - **Record keeping/data storage**. Data from this project should be maintained for the life of the plant.
  - **Data maintenance**. The technical data recorded as part of this project are acceptable for the lifetime of the plant, dependent on consideration of any design changes, modifications, 10CFR50.59 screenings, condition reports, and so forth that could affect normal temperature or radiation conditions.
  - **Maintainability of electronic records**. Electronic data must be maintained in the most current storage formats to ensure retrievability.
- **Host plant installation**. The section on this topic provides details, as follows, on how the host plants were selected and the status of the host plants to the current time with regard to implementation of the monitoring programs:
  - Host plant selections
  - Pre-installation research
  - Work package development
  - Monitor installation
  - Data analysis

A PWR host plant has been selected, and more than 50 monitors were installed in fall 2015 in the PWR for an 18-month fuel cycle. Selection of a BWR host plant was ongoing at the time this report was written.

The primary target audience of this report is engineers who are responsible for determining the lives of cables in relation to long-term operation. Cable engineers and related personnel can use this report as a guide to identify plant specifics regarding the placement of temperature and radiation monitors relative to long-term operation cable aging.

A secondary audience is any site personnel interested in monitoring temperature and/or radiation environments, because this specification in some ways compiles monitoring strategies, albeit specific to cable long-term operation, that have been identified since the release in 1991of EPRI report NP-7399, *Guide for Monitoring Equipment Environments During Nuclear Plant Operation*.

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1
INTRODUCTION

1.1 Background

The Electric Power Research Institute (EPRI) published report 3002000816, *Long-Term Operations: Normal Temperature and Radiation Dose to Installed Cable for U.S. Nuclear Power Plants in Containment*, in 2013 to conduct research to assess the condition of the existing electrical cabling infrastructure [1].

In order to operate through a subsequent licensing period (60–80 yr of operation), plants must demonstrate that the existing cabling has adequate margins remaining to ensure safe operation. The 2013 report provided the preliminary results of an effort to collect environmental service condition data during normal plant operations in plant locations where cables were installed. Specifically, temperature and radiation data were collected so that the effects on cable insulation thermal and radiation aging could be evaluated for long-term operation.

The collection of data at that time was inadequate to reach any conclusions on the likelihood of cables being able to perform reliably during periods of extended operation. However, the radiation and temperature monitoring data that were provided did indicate that original plant design bases for radiation and temperature values could have excessive conservatism or margin as compared with typical plant conditions, with exceptions typically based on stratification, reactor and containment type, and elevation. Therefore, it was recommended that a more specific research and monitoring project be undertaken to gather conclusive evidence regarding this preliminary conclusion.

Accordingly, this report covers using a boiling water reactor (BWR) plant and a pressurized water reactor (PWR) plant as host plants for radiation and temperature monitors in support of this research effort. Generically, this report considers the types of radiation and temperature monitoring equipment that are available, suggested generic locations for installation, and generic monitoring frequency and duration. In addition, generic evaluation criteria are provided to be used for the monitoring that is to be performed at the host plants. For the PWR host plant, installation of radiation and temperature monitors occurred in the fourth quarter of 2015. For the BWR host plant, preliminary steps are ongoing prior to monitor installation in 2016.

1.2 Methodology

The report format provides the following methodology, in sequence, first in a series of generic considerations, and second in identification as to how the generic considerations are applied to the host plants:

- **Select temperature and radiation monitoring equipment**. This section identifies a series of currently available common temperature monitors, radiation monitors, and combined temperature and radiation monitors and describes the selection of a monitor for this particular project.

- **Monitor administrative planning**. This section provides details that need to be performed administratively prior to any activity associated with installation. These actions include plant cable aging research, installation procedure considerations, 10CFR50.59 considerations, work package considerations, and any monitoring calibration requirements.
- **Monitor installation planning**. This section provides administrative details that need to be performed regarding the actual installation. Such activities include identifying the total number of monitors to use, the possible monitor locations, the monitor recording frequency and duration of the monitoring, and any installation access and mounting adjustments.
- **Monitor data processing and analysis**. This section provides details on the data retrieval frequency, the type of data to be retrieved, the data format, sorting the data, and determining the margin between the design and monitored conditions.
- **Monitor data recording and record keeping**. This section provides details on how to store and maintain the data and when it might be necessary to reconfirm the validity of the data.
- **Host plant updates**. Throughout the report, information is provided related to the specific monitoring approaches at the anonymous host nuclear power plants.

2

SELECTION OF TEMPERATURE AND RADIATION MONITORING EQUIPMENT

There are three types of temperature and radiation monitoring equipment that must be evaluated and then selected as applicable. They are as follows:

- Temperature (only) monitoring equipment
- Radiation (only) monitoring equipment
- Temperature and radiation monitoring equipment

This project is focused on both temperature and radiation monitoring. Therefore, for simplicity, a combined temperature and radiation monitor might have been the best selection. However, the associated cost of such a device also needed to be compared with the use of singular temperature and radiation monitors installed in close proximity. Accordingly, all three types of monitors were evaluated in case there were any special applications or uses of a particular monitor that promoted its use.

Monitoring equipment can generally be categorized as *active* or *passive*. For the purposes of this report, active equipment includes equipment that takes measurements periodically and records it (data loggers). Active equipment requires a power source. Passive equipment does not take periodic measurements but instead accumulates information over time and does not require a power source.

Various monitoring equipment was considered; however, monitoring equipment typically is not covered in the following sections if the monitoring equipment was developmental, had not been used in a U.S. commercial nuclear plant, or had only been available for nongeneral applications.

Accordingly, this section is separated into the following parts related to temperature and radiation monitors:

- Temperature monitoring equipment
- Radiation monitoring equipment
- Combined temperature and radiation monitoring equipment
- Monitor mounting and connection equipment
- Selection of temperature and radiation monitors and associated mounting equipment for host plants

2.1 Temperature Monitoring Equipment

Table 2-1 identifies various temperature monitors that have been used to monitor temperature environments, typically in support of commercial nuclear plant environmental qualification (EQ) considerations. Other temperature monitors might have been used in non-EQ applications; however, use of research from EQ applications provided a solid litmus test to be considered and in some ways closely related to the use of the monitors in this particular project.

Table 2-1
Temperature monitors used in support of qualification activities

Monitoring Equipment: Manufacturer and Model	References in Which Cited*				
	[1]	[2]	[3]	[4]	[5]
ACR SmartReader		✓			✓
HOBO[2] temperature		✓			✓
Sensa distributed sensor system		✓			✓
Rustrak Ranger		✓			✓
Westinghouse contact integrating thermal monitor (CITM)	✓	✓			✓
Omega Engineering Model RD-TEMP-XT			✓		
Omega Engineering Model OM-480				✓	
Tel-Tru Model 2103				✓	
Logic Beach Bitlogger Model BL-1				✓	

*__References__:

1. *Long-Term Operations: Normal Temperature and Radiation Dose to Installed Cable for U.S. Nuclear Power Plants in Containment*. EPRI, Palo Alto, CA: 2013. 3002000816.
2. *Plant Support Engineering: Nuclear Power Plant Equipment Qualification Reference Manual, Revision 1*. EPRI, Palo Alto, CA: 2010. 1021067.
3. *Guideline for the Management of Adverse Localized Equipment*. EPRI, Palo Alto, CA: 1999. 109619.
4. *Guide for Monitoring Equipment Environments During Nuclear Plant Operation*. EPRI, Palo Alto, CA: 1991. NP-7399.
5. Scientech Equipment Qualification Data Bank (EQDB) 2005 topical report, Temperature/Radiation Monitoring Program Considerations.[3]

Table 2-2 provides additional information on the equipment in Table 2-1.

[2] *HOBO* is a registered trademark of Onset Computer Corporation.
[3] *EQDB* is the EQ Data Bank, a member-supported service originated in 1981 by Scientech, LLC, under license from EPRI. Therefore, use of this reference is acceptable.

Table 2-2
Temperature monitor research

Monitoring Equipment: Manufacturer and Model	Website	Catalog Available?	Available for Purchase?	Comment
ACR SmartReader	http://www.acrsystems.com/products/	http://www.acrsystems.com/support/resources/product-catalog/	Yes	SmartReader 1 is a two-channel temperature data logger, with one internal channel for ambient temperature and one channel for temperature (with thermistor probe), resistance, or switch status. Another ACR temperature logger that has been anecdotally reported as being used in a nuclear plant is the ACR Nautilus; therefore, this second ACR temperature logger will also be covered in this report.
HOBO temperature	http://www.onsetcomp.com/	http://www.onsetcomp.com/learning/catalogs	Yes	The HOBO U12 Stainless Temp Logger is a miniature, reusable data logger that continuously measures temperature in remote locations.
Sensa distributed sensor system	http://www.sensa.org/	N/A	N/A	This is a fiber-optic transducer with sensitivity over the entire length of the fiber. Therefore, this specific cable measurement is overly focused as compared with the more general area recordings that are to occur as part of this project.
Rustrak Ranger	http://technical-sys.com/Ranger.htm	Unable to locate information specific to temperature monitoring	N/A	Unable to locate information specific to temperature monitoring. Temperature data logger appears to be discontinued.

Table 2-2 (continued)
Temperature monitor research

Monitoring Equipment: Manufacturer and Model	Website	Catalog Available?	Available for Purchase?	Comment
Westinghouse CITM	http://westinghousenuclear.com/	http://www.westinghousenuclear.com/Portals/0/operating%20plant%20services/engineering/nsss%20system%20&%20component%20design/NS-ES-0061%20Equip%20Lifetime%20Monitors.pdf	Yes	Westinghouse provides a combined LIFETIME and CITM data sheet [6] rather than a catalog with specifications.
Omega Engineering Model RD-TEMP-XT	http://www.omega.com/	http://www.omega.com/manuals/index.html?s=all (A specific catalog exists: http://www.omega.com/manuals/manualpdf/M1667.pdf.)	No	Model is no longer available for purchase. There are other products available on the vendor website. However, because no more recent nuclear power plant uses have been identified, this company will not be evaluated any further.
Omega Engineering Model OM-480	http://www.omega.com/	http://www.omega.com/manuals/index.html?s=all (A specific catalog exists: http://www.omega.com/manuals/manualpdf/M0668.pdf.)	Yes	Model is no longer available for purchase. There are other products available on the vendor website. However, because no more recent nuclear power plant uses have been identified, this company will not be evaluated any further.
Tel-Tru Model 2103	http://www.teltru.com/	http://www.teltru.com/t-TT_Catalogs.aspx	N/A	A 2103 search on the product website did not identify any entries. A query of the product catalog headings indicates its products include resistance temperature detectors, thermowells, and thermometers rather than data loggers, which are needed for this project.

Table 2-2 (continued)
Temperature monitor research

Monitoring Equipment: Manufacturer and Model	Website	Catalog Available?	Available for Purchase?	Comment
Logic Beach Bitlogger Model BL-1	http://www.logicbeach.com/	http://www.logicbeach.com/downloads.html http://www.logicbeach.com/manuals/	No	Unable to retrieve any information on Model BL-1. There are other products available on the vendor website. However, because no more recent nuclear power plant uses have been identified, this company will not be evaluated any further.
LogTag TRIX-8	http://www.logtagrecorders.com/	http://www.logtagrecorders.com/products/trix-8.html	Yes	The LogTag TRIX-8 is a versatile, wide-range, multitrip temperature recorder, featuring high-resolution temperature readings over a measurement range of -40°C–+85°C (-40°F–+185°F).
Lascar Electronics EL-USB-1-PRO	http://www.lascarelectronics.com/	http://www.lascarelectronics.com/temperaturedatalogger.php?datalogger=382	Yes	The EL-USB-1-PRO data logger measures and stores up to 32,510 temperature readings over the -40°C–+125°C (-40°F–+257°F) measurement ranges. The logger is housed in a stainless steel case to protect the logger from corrosion, impact and moisture. A long-life lithium battery is included, which allows logging for up to 3 yr.

In addition to researching actual monitors documented publicly as being used in commercial nuclear power plants, various experienced plant personnel have informally determined through the project that is the subject of this report that other temperature monitors, such as the LogTag[4] and Lascar EL recorders, are being used or considered for nuclear power plant monitoring. For example, the LogTag TRIX-8 is used for monitoring temperatures in outside containment locations at a U.S. plant. The Lascar Electronics EL-USB-1-PRO is being considered for use at a European plant. These items are included in Table 2-2.

Other monitoring equipment manufacturers and models and even other monitoring methods (for example, temperature dots) exist; however, the items considered were deemed the most compatible with the purpose of a long-term operation cable aging management program.

Based on this preliminary research, the following temperature data loggers were considered for this project:

- ACR SmartReader
- ACR Nautilus
- HOBO temperature
- LogTag TRIX-8
- Lascar Electronics EL-USB-1-PRO

These data loggers were evaluated for the various characteristics and parameters shown in Table 2-3.

[4] *LogTag* is a registered trademark of LogTag Recorders, Ltd.

Table 2-3
Temperature monitor specifications

Parameter	Monitoring Device				
	ACR SmartReader 1 [7, pp. 15–16]	**ACR Nautilus [7, p. 22]**	**HOBO U12 Stainless Temp Logger [8, pp. 10 and 31, 9]**	**LogTag TRIX-8 [10, 11]**	**Lascar Electronics EL-USB-1-PRO [12]**
Size	4.2 in. x 2.9 in. x 0.9 in. (107 mm x 74 mm x 22 mm)	0.7 in. x 5.0 in. (18 mm x 127 mm)	0.69 in. x 4.0 in. (17.5 mm x 101.6 mm)	3.4 in. x 2.15 in. x 0.34 in. (86 mm x 54.5 mm x 8.6 mm)	0.69 in. x 4.33 in. (17.5 mm x 110 mm)
Weight	3.75 oz (110 g)	Aluminum case: 1.8 oz (51 g) Stainless steel case: 4.0 oz (112 g)	2.5 oz (72 g)	1.23 oz (35 g)	2.5 oz (72 g)
Operating temperature	-40°F–158°F (-40°C–70°C) and 0%–95% relative humidity (noncondensing)	Nautilus85: -40°F–185°F (-40°C–85ºC) Nautilus135: 50°F–275°F (10°C–135°C)	Logging: -40°F–257°F (-40°C-125°C) Launch/readout: 32°F–122°F (0°C–50°C), according to USB specification	-40°F ~ +185°F (-40°C ~ +85°C)	-40°F–257°F (-40°C–125°C)
Mounting support	Magnetic backing or locking eyelet		A 3/16-in. (4.8-mm) diameter hole provided in the end cap to secure the logger to an object	Hole provided; optional wall mount bracket available	Hole provided
Number of channels	Two	One	One	One	One
Memory size	32 kB	32 kB (up to 244,800 readings with data compression)	64 kB (43,000 measurements)	8000 temperature readings (16K bytes memory)	32,510 readings
Sampling interval	User selectable rates from 8 s to once every five days	User selectable from 8 s to 34 min	Not stated	Configurable from 30 s to several hours	1 s, 10 s, 1 min, 5 min, 30 min, 1h, 6h, 12h

Table 2-3 (continued)
Temperature monitor specifications

Parameter	Monitoring Device				
	ACR SmartReader 1 [7, pp. 15–16]	**ACR Nautilus [7, p. 22]**	**HOBO U12 Stainless Temp Logger [8, pp. 10 and 31, 9]**	**LogTag TRIX-8 [10, 11]**	**Lascar Electronics EL-USB-1-PRO [12]**
Battery	3.6-V lithium, 1 amp-hour	3.6-V lithium, 0.95 amp-hour	Not stated	3-V Lithium battery	2/3AA 3.6-V high-temperature lithium battery
Battery life	10 yr under normal use (factory replaceable)	Nautilus85: 10 yr under normal use Nautilus135: 3 yr under normal use	3 yr typical, factory replaceable	2~3 yr typical use—longer (up to 5–10 yr) if recorder is hibernated between uses	3 yr
Accuracy	+/- 0.3°F over the range of 32°F–158°F (+/- 0.2°C over the range of 0°C–70°C)	Nautilus85: +/- 0.3°F over the range of 32°F –158°F (+/- 0.2°C over the range of 0°C–70°C) Nautilus135: +/- 0.9°F (+/- 0.5°C)	± 0.45°F from 32°F to 122°F (± 0.25°C from 0°C to 50°C)		Typ: ±0.2°C (±0.4°F) Max: ±0.5°C (±1°F)
Calibration adjustment	No (Factory calibration verification and National Institute of Standards and Technology [NIST] certificates are available upon special request.)	No (Factory calibration verification and NIST certificates are available upon special request.)	NIST certificate available for additional charge	Yes, with an application called *LogTag Calibrate*	Calibration certificate provided with a data logger at the time of original purchase
Clock accuracy	+/- 2 s per day	+/- 2 s per day	±2 min per month at 77°F (25°C)	Uses real-time clock	Not stated
Resolution	8-bit (1 part in 256)	8-bit (1 part in 256)	0.05°F at 77°F (0.03°C at 25°C)	0.1°C	0.1°C

Table 2-3 (continued)
Temperature monitor specifications

Parameter	Monitoring Device				
	ACR SmartReader 1 [7, pp. 15–16]	**ACR Nautilus [7, p. 22]**	**HOBO U12 Stainless Temp Logger [8, pp. 10 and 31, 9]**	**LogTag TRIX-8 [10, 11]**	**Lascar Electronics EL-USB-1-PRO [12]**
PC requirements	PC running Windows 2000 SP4, Windows XP SP1, or Windows Vista 32 bit (PC must have one free serial or USB port, depending on connection.)	PC running Windows 2000 SP4, Windows XP SP1, or Windows Vista 32 bit (PC must have one free serial or USB port depending on connection.)	Windows: 8, 7 (Pro, Ultimate, and Home Premium), and XP (Pro and Home)	Windows: 8, 7 (64 and 32 bit versions); Apple Mac	Windows 2000, XP, Vista, 7, and 8
Software base	TrendReader[5] 2	TrendReader 2	HOBOware[6]	LogTag Analyzer	EL-WIN-USB
Interface	Serial or USB	Serial or USB	USB interface	Interface cradle	USB interface
Exportable to spreadsheet	Yes	Yes	Yes	Yes	Yes
Zoom capability	Yes	Yes	Yes	Yes	Yes
Real-time readings	Yes	Yes	Yes	Yes	Yes
Display multiple graphs	Yes	Yes	Yes	Yes	Yes

[5] *TrendReader* is a registered trademark of ACR Systems, Inc.
[6] *HOBOware* is a registered trademark of Onset Computer Corporation.

Table 2-3 (continued)
Temperature monitor specifications

Parameter	Monitoring Device				
	ACR SmartReader 1 [7, pp. 15–16]	**ACR Nautilus [7, p. 22]**	**HOBO U12 Stainless Temp Logger [8, pp. 10 and 31, 9]**	**LogTag TRIX-8 [10, 11]**	**Lascar Electronics EL-USB-1-PRO [12]**
Price	$299 (SmartReader 1) $109 (TrendReader 2) (prices listed on website http://store.acrsystems.com)	$279 (Nautilus85 Al) $359 (Nautilus85 SS) $399 (Nautilus135 Al) $459 (Nautilus135 SS) $109 (TrendReader 2) (prices listed on website http://store.acrsystems.com)	$272 (U12) (prices listed on website http://www.onsetcomp.com/products/data-loggers/u12-015)	$33 (TRIX-8) $44 (USB reader) (prices from Amazon.com)	$150 (EL-USB-1-PRO) Free software

typ = typical
max = maximum

2.2 Radiation Monitoring Equipment

Table 2-4 identifies various radiation monitors that have been used to monitor radiation environments in support of commercial nuclear plant EQ considerations. Other radiation monitors may have been used in non-EQ applications; however, use of research from EQ applications provides a solid litmus test in order to be considered herein and in some ways closely relates to the use of the monitors in this particular project.

Table 2-4
Radiation monitors used in support of qualification activities

Monitoring Equipment: Manufacturer and Model	References in Which Cited*				
	[4]	[5]	[13, p. 2-10]	[14, p. 3-3]	[15, p. B-1]
Bicron (Thermo) RSO-50				✓	
Bicron (Thermo) RSO-500				✓	
Eberline E-530			✓	✓	
Eberline E-530N with shielding probe (HP-220A)				✓	
Eberline HP-220				✓	✓
Eberline Model SRM-2001	✓			✓	
Eberline PIC-6			✓	✓	
Eberline PRS-2					✓
Eberline RO-20A				✓	
Eberline RO-2A			✓	✓	
Eberline Telector-6112			✓	✓	
General atomic radiation detectors		✓			✓
MGP MG-90 (electronic dosimeters)				✓	
Victoreen[7] Cutie Pie			✓		
Victoreen Radector III (AB-100-SR)			✓		
Xetec-330				✓	
Xetex-302			✓		

* **References**:

4. *Guide for Monitoring Equipment Environments During Nuclear Plant Operation*. EPRI, Palo Alto, CA: 1991. NP-7399.
5. Scientech Equipment Qualification Data Bank (EQDB) 2005 topical report, *Temperature/Radiation Monitoring Program Considerations*.
13. *PWR Radiation Fields Through 1982*. EPRI, Palo Alto, CA: 1983. NP-3432.
14. *Application of the EPRI Standard Radiation Monitoring Program for PWR Radiation Field Reduction*. EPRI, Palo Alto, CA: 2007. 1015119.
15. *BWR Radiation Field Assessment: 1986–1988*. EPRI, Palo Alto, CA: 1990. NP-6787.

[7] *Victoreen* is a trademark of Fluke Corporation.

In addition to researching actual monitors documented publicly being used in commercial nuclear power plants, various experienced plant personnel have informally determined through this project that other radiation monitors are being considered, such as Bruker Alanine dosimeter readers and Landauer Luxel[8]+ dosimeters. These items are included in Table 2-5.

[8] *Landauer* and *Luxel* are registered trademarks of Landauer, Inc.

Table 2-5
Radiation monitor research

Monitoring Equipment: Manufacturer and Model	Website	Catalog Available?	Available for Purchase?	Comment
Bicron[9] (Thermo) RSO-50	http://www.thermo.com	No	No [14]	
Bicron (Thermo) RSO-500	http://www.thermo.com	No	No [14]	
Bruker	https://www.bruker.com/	https://www.bruker.com/products/mr/epr/e-scan/alanine-dosimeter-reader/overview.html	Yes	Bruker introduced a new dosimetry system that combines the e-scan alanine dosimeter with the BioMax[10] alanine dosimeter film.
Eberline[11] E-530	http://www.thermo.com	No	No	No information on this model was available on the company website. Internet searches returned only results that indicated this model is no longer manufactured.
Eberline E-530N with Shielding Probe (HP-220A)	http://www.thermo.com	No	No	No information on this model was available on the company website. Internet searches returned only results that indicated this model is no longer manufactured.
Eberline HP-220	http://www.thermo.com	No	No	Newer Thermo Model HP-270 and HP-290 available.
Eberline Model SRM-2001	http://www.thermo.com	No	No	No information on this model was available on the company website. Internet searches returned only results that indicated this model is no longer manufactured.
Eberline PIC-6	http://www.thermo.com	No	No [14]	

[9] Bicron was purchased by Thermo Fisher Scientific.
[10] *BioMax* is a registered trademarks of the Eastman Kodak Company.
[11] *Eberline* is a brand name of Thermo Fisher Scientific that is no longer used. The new brand name is *Thermo*.

Table 2-5 (continued)
Radiation monitor research

Monitoring Equipment: Manufacturer and Model	Website	Catalog Available?	Available for Purchase?	Comment
Eberline PRS-2	http://www.thermo.com	No	No	No information on this model was available on the company website. Internet searches only returned results that indicated this model is no longer manufactured.
Eberline RO-20A	http://www.thermo.com	http://www.thermoscientific.com/en/product/ro-20-ion-chamber-survey-meters.html	Yes	*Eberlin*e name is no longer used. Now called *Thermo Scientific Model RO-20*.
Eberline RO-2A	http://www.thermo.com	No	No [14]	
Eberline Telector-6112	http://www.thermo.com	No	No [14]	
General atomic radiation detectors	http://www.ga.com/	http://www.ga.com/nuclear-power-plant-radiation-monitoring-systems	Yes	
Landauer Luxel+	http://www.landauer.com/	http://www.landauer.com/Industry/Products/Dosimeters/Dosimeters.aspx	Yes	The Luxel+ can be used for up to 1 yr.
MGP[12] MG-90 (electronic dosimeters)	https://www.mirion.com/industries/nuclear-power/	No	No	No information on this model was available on the company website. Internet searches returned only results that indicated this model is no longer manufactured.

12 MGP Instruments is now part of Mirion Technologies (https://www.mirion.com/products/in-plant-and-safety-monitoring-systems/).

Table 2-5 (continued)
Radiation monitor research

Monitoring Equipment: Manufacturer and Model	Website	Catalog Available?	Available for Purchase?	Comment
Victoreen[13] Cutie Pie	http://www.flukebiomedical.com/biomedical/usen/Home/default.htm	No	No	Cutie Pie was the name for Victoreen portable radiation detectors. No information on this model was available on the company website. Internet searches returned only results that indicated this model is no longer manufactured.
Victoreen Radector III (AB-100-SR)	http://www.flukebiomedical.com/biomedical/usen/Home/default.htm	No	No	No information on this model was available on the company website. Internet searches returned only results that indicated this model is no longer manufactured.
Xetec-330	None	No	No	No information on this company or model was found using Internet searches.
Xetex-302	None	No	No	No information on this company or model was found using Internet searches.

[13] *Victoreen* is a legacy brand of Fluke Biomedical, according to the company website (http://www.flukebiomedical.com/biomedical/usen/About/Profile/default.htm).

Based on this preliminary research, the following radiation data loggers were considered for this project:

- Thermo Model HP-270 (general purpose Geiger-Mueller [GM] probe) and HP-290 (higher range GM probe), which measure exposure rate
- Thermo Model RO-20 (portable air-ionizing chamber instrument that measures exposure rate)
- General atomic radiation detectors
- Bruker alanine dosimeter
- Landauer Luxel+

Most of the radiation detectors listed in Table 2-5 are no longer manufactured or are not in wide commercial nuclear power plant use. In addition, some of the monitors measure dose rate and do not appear to be able to accumulate data over a long period of time.

EPRI report NP-7399, Part II [4, p. II-2-1-7], describes the radiation data acquisition for the Surry Power Station nuclear plant as using one Eberline model SRM-2001 (no longer manufactured) radiation monitor located in containment that was feeding data to a Compaq PC with a 40-MB hard disk located outside containment. Data at each location were recorded once a minute and stored on the PC hard disk. Every three to four weeks, data were transferred from the hard disk to a floppy disk.

Thermo Scientific (Eberline Division) was contacted to obtain information on radiation monitors that could be used for the project and recommended Thermo Model RMS-3 with an external probe (DA-1-8). The customer service representative stated that dosimeter-type monitors could not be left in place for long periods of time (such as an entire fuel cycle) and recommended an ion chamber-type of monitor because they are reliable and can withstand high doses expected inside a containment or drywell. However, ion chamber monitors need to be externally powered. GM-type monitors were not recommended because they need to be recalibrated every year and are not as reliable. The Thermo representative also mentioned another manufacturer, Ludlum Measurements, Inc., as making detectors that fit the needs of this project. Ludlum Measurements has been researched and does have a product catalog publicly available on its website; however, because the company was not included in any of the aforementioned research products or surveys, it was not considered any further as part of this effort.

General Atomics (http://www.ga.com/data-acquisition-systems) manufactures the LPU-2 data processing unit, which is used for monitoring, process management, and data handling purposes. It can be used with GM tubes, ionization chambers, scintillation detectors, solid-state detectors, proportional counters, and so forth.

These radiation monitors were evaluated for the various characteristics and parameters shown in Table 2-6.

Table 2-6
Radiation monitor specifications

Parameter	Monitoring Device						
	Thermo Model HP-270 [16]	**Thermo Model HP-290 [16]**	**Thermo Model RO-20 AA [17]**	**Thermo Model RMS-3 [18]**	**General Atomic Radiation Detector Model LCU-04 [19]**	**Bruker Alanine Dosimeter [20]**	**Landauer Luxel+ [21]**
Size	6 in. long, 1.5 in. diam (152.4 mm long, 38.1 mm diam)	3.5 in. long, 1.0 in. diam (88.9 mm long, 25.4 mm diam)	7.9 in. x 4.2 in. x 7.7 in. (201 mm x 1047 mm x 196 mm)	9.5 in. x 6.25 in. x 5 in. (241 mm x 158.7 mm x 127 mm)	Various (12–23 in. x 17–31 in. x 6–12 in. [304.8–584.2 mm x 431.8–787.4 mm x 152.4–304.8 mm])	Not identified BioMax film holder or optional pellet holder	Not identified
Weight	5 oz (142 g)	2 oz (57 g)	3.3 lb (1.47 kg)	5 lb (2.3 kg)	33–110 lb (15–50 kg)	Not identified	Not identified
Operating temperature	-40°F–167°F (-40°C–75°C)	-40°F–122°F (-40°C–50°C)	-104°F–140°F (-40°C–60°C)	-104°F–140°F (-40°C–60°C)	-104°F–158°F (-40°C–70°C)	Not identified	Not identified
Power supply	900 ± 50 V	550 ± 50 V	Main: five AA cells Chamber bias: 36 V	100–240 Vac	110 V or 220 V	N/A—dosimeter 100–250 Vac—e-scan reader	N/A
Battery life	N/A	N/A	125–2500 h	N/A	N/A	N/A	N/A
Accuracy	~1200 cpm/mR/h (137 Cs)	~1200 cpm/mR/h (137 Cs)	2%	Not identified	Not identified	1% or better	Not identified
Applications	Beta/gamma exposure surveys	Beta/gamma exposure surveys	Beta, gamma, X-ray	Gamma at minimum	Not identified	Gamma, E-beam, or X-ray	Gamma, beta, neutron, X-ray

Table 2-6 (continued)
Radiation monitor specifications

Parameter	Monitoring Device						
	Thermo Model HP-270 [16]	**Thermo Model HP-290 [16]**	**Thermo Model RO-20 AA [17]**	**Thermo Model RMS-3 [18]**	**General Atomic Radiation Detector Model LCU-04 [19]**	**Bruker Alanine Dosimeter [20]**	**Landauer Luxel+ [21]**
Description	Energy-compensated beta/gamma detector	Energy-compensated beta/gamma detector	Energy-compensated beta/gamma/ X-ray detector	Energy-compensated gamma detector at minimum	Local control unit	Alanine dosimetry, electron paramagnetic resonance	Proprietary optically stimulated luminescence dosimetry
Detectors	Energy-compensated GM material	Energy-compensated GM material	Air-filled ionization chamber	Energy-compensated GM material	GM detectors	Alanine dosimeter	Optically stimulated luminescence dosimeter
Wall	Stainless steel	Stainless steel	Phenolic wall	Not identified	Plastic or metal	Not identified	Not identified
Housing	Acrylonitrile butadiene styrene plastic	Acrylonitrile butadiene styrene plastic	Aluminum case	Not identified	Plastic or metal	N/A	Not identified
Performance	Dead time: 100 µs (typical)	Dead time: 100 µs (typical)	90% of final reading within 5 s	±10% (using dead-time compensation)	Not identified	Not identified	N/A
Connections	BNC Series coaxial	BNC Series coaxial	Not identified	RS-232C communication port/small serial to Ethernet converter	Not identified	N/A	N/A

Table 2-6 (continued)
Radiation monitor specifications

Parameter	Monitoring Device						
	Thermo Model HP-270 [16]	Thermo Model HP-290 [16]	Thermo Model RO-20 AA [17]	Thermo Model RMS-3 [18]	General Atomic Radiation Detector Model LCU-04 [19]	Bruker Alanine Dosimeter [20]	Landauer Luxel+ [21]
Detection range	600 R/h (6 Gy/h)	600 R/h (6 Gy/h)	50 R/h (0.5 Gy/h)	Background levels to 10,000 R/hr. (100 Gy/h)	Not identified	1,000 R to 2.0E+07 R (10 Gy to 200 kGy)	1 mrem to 1,000 rem (10 µSv to 10 Sv
Energy range	30 keV to 1.3 MeV	30 keV to 1.3 MeV	8 keV to 1.3 MeV	0.3–60 mV	Not identified	Not identified	5 keV to > 40 MeV

diam = diameter
cpm = counts per minute

The difficulty with the pieces of equipment in Table 2-6 is that either they are not battery powered or the battery will not last an entire fuel cycle of 1.5–2 yr. Some of the pieces of equipment listed are only detectors and do not log the doses over a period of time.

International Atomic Energy Agency (IAEA) report IAEA-TECDOC-1188 [22] identifies that the dose rate distribution in the plant can be measured with the aid of dosimeters installed at the most severe and other representative cable positions. In order to improve the validity of such measurements, it is recommended that the measurement period be extended to cover two operating cycles. The type of radiation dosimetry used for personnel purposes might not be appropriate for monitoring long-term dose exposures to cables. Alanine dosimeters have proven to be particularly suitable for such long-term measurements for the following reasons:

- They are not significantly affected by temperature (0.2%/K).
- Their fading at moderate temperatures is limited to 1% per year.
- The influence of humidity can be overcome by hermetic sealing of the dosimeter.
- The neutron dose to cable materials can generally be neglected during normal plant operation.

Dosimetry using alanine is well-established and widely used. The method is based on radiation-induced formation of stable radicals in alanine, using electron spin resonance (ESR) to measure the number of radicals present in the dosimeter. Because radiation fields can be quite variable within a plant, dosimetry at the location of the cables is desirable.

A Korean Nuclear Society paper [23] describes using an ESR system with BioMax alanine dosimeters for determining doses at cable locations at the Wolsung nuclear plant. Two types of ESR systems were used to measure the dose after exposure for one or two fuel cycles. The researchers concluded that alanine dosimeters could accurately estimate the dose values in nuclear power plants. The alanine dosimeter is also being considered by some European plants. However, no other instances of U.S. nuclear plant use of alanine dosimeters was found; so, using them in this manner is not clearly proven. With further investigation, an alanine dosimetry system could be a deemed useful way to measure radiation doses over an entire fuel cycle.

2.3 Combined Temperature and Radiation Monitoring Equipment

Table 2-7 identifies various temperature and radiation combined monitors that have been used to monitor temperature and radiation environments in support of commercial nuclear plant EQ considerations.

Table 2-7
Temperature and radiation combined monitors used in support of qualification activities

Monitoring Equipment: Manufacturer and Model	References in Which Cited *				
	[1]	[2]	[3]	[4]	[5]
Westinghouse LIFETIME monitor	✓	✓	✓	✓	✓

* **References**:
1. *Long-Term Operations: Normal Temperature and Radiation Dose to Installed Cable for U.S. Nuclear Power Plants in Containment*. EPRI, Palo Alto, CA: 2013. 3002000816.
2. *Plant Support Engineering: Nuclear Power Plant Equipment Qualification Reference Manual, Revision 1*. EPRI, Palo Alto, CA: 2010. 1021067.
3. *Guideline for the Management of Adverse Localized Equipment*. EPRI, Palo Alto, CA: 1999. 109619.
4. *Guide for Monitoring Equipment Environments During Nuclear Plant Operation*. EPRI, Palo Alto, CA: 1991. NP-7399.
5. Scientech Equipment Qualification Data Ban (EQDB) 2005 topical report, *Temperature/Radiation Monitoring Program Considerations*.

The Westinghouse LIFETIME monitor is a device that can contain several optional devices, each of which measures different ranges of environmental parameters [6]. Monitoring options include the following [4, p. II-3-2-1]:

- Peak temperature
- Integrated temperature
- Low- and high-range gamma ray dose
- Beta particle dose
- Neutron radiation

Advantages of the LIFETIME monitors include the following [4, p. II-3-2-3]:

- **Passive operation**. Operation of the monitor depends on reliable physical principles and is strictly passive, requiring no power or instrument cabling and no maintenance.
- **Availability**. The monitor can operate completely unattended for long time periods corresponding to one or more fuel cycles.
- **Compact size**. The standard enclosure measures only 2.5 x 2.3 x 1.3 in. (64 x 58 x 34 mm).

A disadvantage is that there is a delay of four to six weeks for results while the device is returned to Westinghouse for reading the recorded data [4, pp. I-3-4and I-3-5].

What may be the most important factor regarding the Westinghouse LIFETIME monitor is that it provides unique results. Other temperature or radiation monitors will record a parameter at a certain period of time, with an end result of a time versus parameter (temperature or radiation) graph. The Westinghouse LIFETIME monitor does not provide these same results; rather, the following methods are used: low-range gamma ray dose [4, p. II-3-2-4], where thermoluminescent dosimeters (TLDs) are read by heating the crystals and counting the thermoluminescence photons emitted when the trapped electrons and holes recombine, and integrated temperature [4, pp. II-3-2-5 and II-3-2-6], where the integrating thermal monitor (ITM) consists of materials whose optical properties change gradually as a function of both time and temperature. Based on the measured change in physical properties and the known time of exposure, an effective exposure temperature can be determined. This, in turn, permits an evaluation of component integrity. This effective exposure temperature is termed the *Arrhenius equivalent* temperature.

The degradation mechanisms that limit the life of equipment are usually treated as having a temperature dependence that conforms to the Arrhenius model. This model predicts that the time required to reach a given change in material property is an exponential function of exposure temperature and a material-specific constant, the activation energy. The rate of change in ITM optical properties is also described by Arrhenius functions of temperature using characteristic activation energies. Seven ITM materials have been calibrated spanning the range of activation energies typical of nuclear components (Note: typical activation energies of cables are defined later in this specification.). Combining the results from multiple ITMs allows the Arrhenius equivalent temperature to be plotted as a function of activation energy. This, in turn, allows the Arrhenius equivalent temperature to be determined for any component, regardless of its activation energy.

Accordingly, the Westinghouse LIFETIME equipment monitors will provide a total measured dose as opposed to a dose rate at a particular moment in time and will also provide an Arrhenius equivalent temperature versus selected activation energies rather than a specific temperature at a particular moment in time. Table 2-8 shows temperature and radiation monitor research.

Table 2-8
Temperature and radiation monitor research

Monitoring Equipment: Manufacturer and Model	Website	Catalog Available?	Available for Purchase?	Comment
Westinghouse LIFETIME monitor	http://westinghousenuclear.com/	http://www.westinghousenuclear.com/Portals/0/operating%20plant%20services/engineering/nsss%20system%20&%20component%20design/NS-ES-0061%20Equip%20Lifetime%20Monitors.pdf	Yes	Westinghouse provides a combined LIFETIME and CITM data sheet [6] rather than a catalog with specifications.

In addition, Westinghouse LIFETIME monitors were used in the EPRI's natural versus artificial aging series of reports, as follows:

- *Natural Versus Artificial Aging of Nuclear Power Plant Components*. EPRI, Palo Alto, CA: 1992. 100245 [24].
- *Natural Versus Artificial Aging of Electrical Components: Interim Report 1991–1995*. EPRI, Palo Alto, CA: 1997. 106845 [25].
- *Natural Versus Artificial Aging of Electrical Components: Interim Report 1996–2000*. EPRI, Palo Alto, CA: 2001. 1003062 [26].

Note: There were two other reports in this series of reports (NP-4997 from 1986 and 1011872 [*Long-Term Laboratory Aging of Nuclear Plant Cables*] from 2005); however, Westinghouse was not mentioned in either of these reports.

Westinghouse also provides CITMs, which are smaller than the LIFETIME monitor [6]. The CITM is typically just used to measure temperature but can optionally be provided with the capability for high range radiation measurements.

2.4 Monitor Mounting and Connection Equipment

Most nuclear power plants performing temperature and radiation monitoring for long-term operation of cables will be installing temperature and radiation monitoring equipment as temporary installations. Bolting or permanently attaching the monitors to plant structures will likely result in a significant administrative burden and added work process controls. Therefore, using tie wraps to attach monitors is an optimal solution for monitors such as the Westinghouse LIFETIME monitor. This vendor also provides mounting brackets and bolts; however, current nuclear plant practices, such as the use of generic tie wraps, are suggested. Note that a plant can have varying types of tie wraps depending on location, such as use inside or outside containment or the drywell.

Nuclear power plants using other types of monitors require other types of mounting as required by the nuclear plant and vendor requirements. Active monitors can also require an electrical connection or batteries as applicable.

Conclusion: based on the needs of this project, for the monitoring of temperature and radiation normal service conditions near cables, the monitors will be mounted using tie wraps.

2.5 Selection of Temperature and Radiation Monitors and Associated Mounting Equipment

In selecting temperature and radiation monitoring equipment for monitoring long-term operation of cables, many points must be considered. The processes for selection and procurement of data loggers (especially solid-state or microprocessor-based units) need to take into account the dose and dose/rate conditions at the location where they are to be used in order to minimize the potential loss of data that could result from an environmentally induced failure of the data logger.

Another consideration is whether the cost and installation requirements of a combined temperature and radiation monitor are much more involved than the cost and installation of singular temperature and radiation monitors installed in close proximity. Although the Westinghouse LIFETIME monitor is more costly, it also involves data research and a report by the vendor. Also, because the Westinghouse LIFETIME monitor is passive, it has significantly fewer installation requirements than other monitors. Accordingly, it is acceptable to procure just the Westinghouse LIFETIME monitors for combined temperature and radiation monitoring.

2.6 Conclusion

Based on the needs of this project, for the monitoring of temperature and radiation normal service conditions near cables for long-term operation, it was determined that the Westinghouse LIFETIME monitors were the best available option.

One caveat is that the Westinghouse LIFETIME monitors identify a total dose according to the time exposed rather than identification of actual plant dose rates at particular times. In a similar manner, the monitors identify an Arrhenius equivalent temperature rather than actual plant temperatures at particular times. Accordingly, if a utility or plant places more value on such results, equipment other than the Westinghouse LIFETIME monitors should be chosen for a particular utility or plant case.

3
MONITOR ADMINISTRATIVE PLANNING

This section covers administrative planning prior to installation research and planning, which is covered in Section 4 of this report. Major topics in this section include the following:

- **Plant cable aging temperature and radiation research**. This involves plant-specific research related to prior temperature and radiation plant monitoring or identified cable aging effects. The purpose of this section is to identify or highlight any potential adverse localized environments or areas that have repeatedly or continuously been monitored during the plant operation. Another purpose is to identify the current design basis or baseline normal temperature and radiation parameters.
- **Installation procedure considerations**. This section provides details on identification or selection of the appropriate plant procedure or guidance needed.
- **10CFR50.59 considerations**. This section provides details on addressing any NRC 10CFR50.59 considerations for the installation of monitors.
- **Work package considerations**. This section covers any topical areas that should be considered as part of the work package for the monitors' installation, such as planning considerations.
- **Calibration requirements**. This section covers identification of any calibration requirements that are required for the monitors that are selected for the activity.

3.1 Cable Aging: Temperature and Radiation Research

The following should be considered.

- **Identification of design basis or current temperature and radiation values**. Current and historical normal temperature and radiation data should be identified as a baseline. For example, EPRI report NP-7399 [4, Sections 2.1, 2.2, 4.1, and 4.2] provides background information on this topic.

  Overall, the following documents are suggested to be retrieved and reviewed prior to this effort, provided that they have been issued by the plant:

  - **EQ environmental service conditions report**. Environmental service conditions are typically maintained at a minimum by the EQ program. This may be a stand-alone report, part of an EQ program manual or design basis document, or sometimes part of the EQ section of the updated final safety analysis report. The reason for this prerequisite is that at a minimum it will provide EQ environmental service conditions and can also provide environmental service conditions for non-EQ locations or equipment. Caution is suggested when using EQ environmental data because the data may have additional margins unnecessary for the plant cables being evaluated or may include component-specific monitoring data that may not generically apply for a longer length of cable evaluated herein.

- **License renewal electrical cables aging management review report**. This type of report can provide cable location information, along with cable types and manufacture and model information, and possibly design environmental service conditions. An aging management review might also provide a review of network cable codes. A license renewal cable code process is typically developed as follows:

  1. Start with a list of cable codes.
  2. Remove all cable codes with no installed length.
  3. Delete fiber-optic and bare ground cable codes, because these types of cables have no significant temperature or radiation aging effects.
  4. Delete all cable code items with temperature thresholds above a high value, as determined at the plant, such as 150°F (65.5°C).
  5. Delete cable codes for materials such as cross-linked polyethylene (XLPE) power and control cables, which typically have a derating that maintains temperatures below 90°C.
  6. For remaining cables, delete cable codes that do not support license renewal loads.

  Because this process has multiple caveats, caution should be taken for this subsequent license renewal project to ensure that any differences between the license renewal cable list and the subsequent license renewal cable list (to be determined) are addressed.

- **License renewal cable and connection inspection NUREG-1801, Section XI.E1summary report**. This type of report can provide cable location information, along with cable types and manufacture and model information, and possibly design environmental service conditions. As mentioned previously, any differences between the license renewal and subsequent license renewal cable population may need to be addressed in order to use these data.

• **Availability of existing temperature and radiation monitoring near cables**. Efforts should be made to determine whether any prior historical or current temperature or radiation monitoring is available that can be used as a base foundation prior to any additional new monitoring. In addition, if such monitoring exists, efforts can be made to identify whether such monitoring is near any particular cable, cable trays, junction boxes, and so forth. The 1997 EPRI report *Cable Aging Management Program for D.C. Cook Nuclear Plant Units 1 and 2* (106687) [27, Part I, Section IV] offers an example of nuclear power plant monitoring identification.

• **Hot spot near cable research**. Efforts should be made to determine whether any adverse localized environments were ever walked down or identified, and, if so, whether such environments were near any specific cables. EPRI report 109619 [3] offers more information.

• **Site-specific operating experience (condition reports and so forth) that affected normal temperature or radiation near cables or created cable aging concerns from such environmental parameters**. Plant operating experience can be queried to identify any condition reports and so forth that relate to such topics as temperature monitoring, radiation monitoring, or cable aging.

- **History of major modifications that affected temperature or radiation near cables (and consideration of potential future modifications)**. Nuclear power plants undergo many modifications, some of which, such as power uprate or extended power uprates, are more significant and can affect normal temperature and radiation. Engineers may wish to determine whether any such activities occurred, when they occurred in the plant operating life, and whether any changes in normal temperature or radiation were either identified from a design standpoint to change or monitored and identified as having been changed.

  If a nuclear power plant uses design normal temperature and radiation values, such a backward review would be unnecessary, because each major modification would require evaluation at that time. If a nuclear power plant uses historical or recorded normal temperature and radiation data, a backward look at major modifications would be necessary only back to the time of the monitoring. Any major modification prior to the monitoring would already be factored into the actual monitoring.

- **Current plant normal temperature and radiation research conclusion**. Make a go/no -go decision if the information that is already available from the preceding steps is sufficient or if the process described in this report is necessary: in other words, is there sufficient existing plant information that can be collated and summarized to justify long-term operation of cables, from both a normal temperature and normal radiation standpoint? Typically this answer is *no*, because a *yes* answer would be based on having both temperature and radiation monitoring data representative of installed cable locations. In the case of this EPRI project, a similar go/no-go decision was made subsequent to the issuance of EPRI report 3002000816 [1].

  A secondary aspect of this consideration is to what extent any future temperature or radiation monitoring might be needed. Although the preceding answer may be *no*, data may exist indicating that either future temperature or radiation monitoring for cable may be unnecessary or certain plant locations with installed cables are already addressed sufficiently for temperature and/or radiation monitoring.

  The key point of this consideration is to consider all possible current and historical plant data that may be available prior to making plans for future temperature and radiation monitoring of cables for long-term operation.

- **Past industry research**. EPRI issued in the mid- to late 1980s a series of pilot plant life extension reports that were the precursor to license renewal research. These reports were grouped into the following three types:

  - Light water reactor reports (these were the initial reports of the series)
  - PWR reactor reports (with the Surry nuclear plant as the lead plant)
  - BWR reports (with the Monticello nuclear plant as the lead plant)

Further information on these reports as they relate to cable aging is provided in Appendix B in relation to value for this current project. Appendix B identifies the following relevant information:

- Both the BWR and PWR reports contain component and structure ranking lists for the lead plants.
- Both the BWR and PWR reports contain temperature and radiation monitoring location tables.
- The PWR reports have a series of tables providing inside and outside containment heat sources.
- The PWR reports have an outside containment cable concentration table.

There is some generic cable information in the reports on lead plant cable types and typical applications.

3.2 Installation Procedure Considerations

After a plant decision has been made to go ahead with installation of temperature and radiation monitors, the next decision point is to determine which plant installation procedures and processes need to be followed. If there is a current plant procedure for a specific type of monitor and that same type of monitor is to be used for the cable subsequent license renewal monitoring, the decision is simple: use the current plant procedure. However, there may be one or more available plant procedures dependent upon the type of monitor selected. Related plant installation procedures can range from generic housekeeping procedures to highly specialized and detailed installation procedures.

The selection of an appropriate plant procedure also depends upon the monitor type, because an active monitor requiring electrical power, batteries, or periodic download of data will have more plant requirements than a passive monitor, in which a material is being aged.

Accordingly, a monitoring program using passive monitors may be able to use plant procedures with fewer restrictions, such as procedures dealing with housekeeping or temporary modifications. Active monitors may also be able to use such procedures, but more limitations could be imposed based on their additional considerations. Discussions with owners of the applicable plant procedures are recommended in order to ensure that a consistent approach with sufficient technical justification is followed.

3.3 NRC 10CFR50.59 Considerations

The NRC 10CFR50.59 screening process or complete evaluation process may be required in order to install monitors for this specific purpose of long-term operation cable thermal and radiation monitoring.

One source for 10CFR50.59 background information is the 2007 EPRI report 1008254, *Plant Support Engineering: Guidelines for Optimizing the Engineering Change Process for Nuclear Power Plants, Revision 2* [28].

Plant procedures need to be followed in order to ensure that any required 10CFR50.59 screening or evaluation is completed in a technically sound engineering manner. If possible, examples from either of the host plants will be included in the final report on this project.

3.4 Work Package Considerations

Any work package for the installation of the temperature and radiation monitors to evaluate for cable aging for long-term operation needs to consider any other plant programs affected and any plant programs that may wish to obtain the resulting data.

Programs that possibly could be affected include the following:

- High-energy line break (HELB)/jet impingement[14]
- Seismic[15]
- NRC Generic Safety Issue GSI-191"Assessment of Debris Accumulation on Pressurized Water Reactor (PWR) Sump Performance," 2001 (sump issues)

At least one plant program may also wish to have a copy of the output data: EQ.

3.5 Calibration Requirements

Calibration requirements apply to all active temperature and radiation monitors. Passive temperature and radiation monitors, such as the Westinghouse LIFETIME and CITM monitors, are calibrated by the vendor (that is, Westinghouse) because even the data measurements are identified by the vendor, thereby using calibrated measuring equipment at the vendor facilities. For example, Westinghouse has identified that the ITM calibration database permits measurement of the Arrhenius equivalent temperature based on observable changes in material optical properties. In order to ensure its validity, calibration studies were carried out on a real-time, as well as on an accelerated, basis [4, p. II-3-2-6]. Also, Westinghouse radiation measurements as part of the LIFETIME monitor can be accurate to ±10%.

For monitors that record normal temperature and radiation values, EPRI report NP-7399 [4, pp. I-4-12 and I-4-13] states that the requirements for the calibration of instruments used to collect operating environmental data should be established. These requirements include calibration before instruments are placed, periodic calibration, and verification of instrument performance following the removal of instruments. The frequency of periodic calibration may be specified in the technical information literature for the monitoring devices. Calibration of devices that monitor safety-related equipment should be accomplished under a 10CFR50, Appendix B, Quality Assurance (QA) program. Acceptance criteria for equipment calibration should be clearly established.

In addition, the EQDB 2005 topical report [5] provides some guidance for establishing data acquisition criteria, as follows:

- Accuracy of data collection
- Retrievability of data
- Provisions for remote/local data collection
- Capability for data gathering through remote probes

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[14] For more information about jet impingement, see EPRI software product 1022977, *Engineering Technical Training Modules—Jet Impingement 1.0* [29].

[15] For more information about jet impingement, see EPRI software product 1007450, *Seismic Orientation Training Course Software, Version 11/2002* [30].

- Intended use and ease of use of data
- Compatibility with a PC for the storage and analysis of collected data
- Cost

The topical report said that verification of data integrity should have the applicable QA controls, including consideration of the following:

- Procedural controls
- Validation and verification of software
- Calibration of the measuring and test equipment
- Margin allowances
- Screening of corrupt data
- Independent verification

Finally, EPRI report 1021067 [2, p. 6-26] suggests that calibration of the data loggers should be confirmed before and after taking the data to ensure that the data are accurate.

Additional monitor-related items to consider prior to performing actions specific for installation include the following:

- Any materials and test equipment considerations, related to the calibration of the monitors
- Any software verification and validation that may be provided with the monitors
- Any electromagnetic interference/radio frequency interference (EMI/RFI) considerations of the monitors
- Any used monitor disposal or storage considerations (For monitors that measure aging, these monitors are typically owned by and shipped back to the manufacturer upon use. For monitors that measure temperature and radiation normal values, these monitors are owned by the plant and therefore appropriate adherence to plant procedures is required, along with consideration of any vendor recommendations. Consideration should also be provided to whether monitors can be reused in the future and, if so, any related storage requirements.)

Based on the preceding considerations, for this project, the following were recommended:

For passive monitors:

- Following the vendor calibration requirements (Vendor will most likely assume calibration responsibilities.)

For active monitors:

- Calibration according to a 10CFR50, Appendix B, QA program
- Acceptance criteria according to vendor recommendations
- Calibration pre-installation and post-removal according to vendor recommendations
- Verification during installation according to vendor recommendations, if possible
- Plant-specific calibration requirements for a 10CFR50, Appendix B, Program
- Miscellaneous concerns, such as software verification and validation, EMI/RFI considerations, materials and test equipment requirements, and monitor disposal considerations

4
MONITOR INSTALLATION PLANNING

This section covers required planning for thermal and radiation monitor installation for cables. Topics include the following:

- Considerations for total number of monitors
- Considerations for monitor placement
- Suggested temperature data logger placement
- Generic monitoring frequency
- Generic monitoring duration
- Installation accessibility and mounting adjustments

The purpose of this section is to identify the installation criteria for monitors and prior standard practices for installation criteria of monitors and explain how that information correlates with this specific purpose of long-term cable aging. Historically, EPRI report NP-7399 [4] provided installation criteria of monitoring. This new report considers the information from NP-7399 and any publicly available information subsequent to NP-7399 issuance. In parallel, EPRI has issued various cable aging management reports; accordingly, the information presented herein is the best correlation of monitoring practices to the topical areas of cable aging management for long-term operation.

This section considers generic planning considerations that relate to normal temperature and radiation monitoring impact on cable aging. Most citations herein are detailed to indicate whether they are referring specifically to temperature monitors, radiation monitors, or a combination of radiation and temperature monitors. In some of the sources cited, a reference is made specifically to temperature monitoring. However, in most such cases, similar considerations are applicable for radiation monitoring, and, therefore, determination of monitoring frequency and duration, for example, will be adequate for temperature and radiation monitoring.

4.1 Considerations for Total Number of Monitors

Before identifying proposed installation locations, research is necessary to identify how many temperature and radiation monitors nuclear power plants typically install and their overall location area (that is, entire plant or just containment/drywell). Another factor in the choice for the number of monitors is how the monitor is to be used, such as general area or room monitoring versus specific equipment monitoring. For example, many of the survey results from Phase I of this project [1] were for the plant EQ programs and, therefore, monitors were placed near specific EQ equipment, while this EPRI project is more focused on potential common cable areas, especially with high temperature or radiation potential.

Note that the total number of monitors that will be used partially depends on the type of monitoring equipment selected (for instance, Westinghouse LIFETIME monitors record Arrhenius weighted average temperature and total radiation dose). If a nuclear power plant wants dose rate data at a particular location, or peak temperatures at a particular location, additional non-Westinghouse LIFETIME monitors require purchase and installation. Conversely, if a plant prefers to use active temperature monitors, there may be plant locations where the radiation dose may be too severe for the monitors. In such cases, additional passive monitors, such as the Westinghouse LIFETIME monitor, may need to be purchased and installed.

Another consideration for the number of monitors needed can be the availability of existing temperature and radiation monitoring near cables and historical monitoring: credit may be able to be taken for some prior plant monitoring efforts.

In order to identify a representative number of monitors, the following temperature and radiation sources were collated from industry sources to determine the numbers of monitors that were used in various applications for comparison. However, these numbers of monitor examples were for plant-specific purposes other than the purpose herein of cable aging influences during long-term operation; accordingly, the following results are identified for comparison as a strong data point rather than a direct correlation with this specific purpose.

4.1.1 Number of Temperature Monitors

EPRI report NP-7399 [4] provides the following plant-specific cases of the total number of temperature monitors used for a particular project:

- "Reactor Building Temperature Reduction Project Data Acquisition, Evaluations and Proposed Actions Arkansas Nuclear One, Unit 1" [4, p. II-1-2-6]:
  - Reactor building: 72 temperature data points
  - 50 new data points
  - 16 existing resistance temperature detectors (integrated leak rate test)
  - Two resistance temperature detectors to control room (integrated leak rate test)
  - Two resistance temperature detectors to return air ductwork
- "Monitoring Actual Temperatures in Susquehanna SES Reactor Building" [4, pp. II-2-2-2 through II-2-2-3]:
  - Reactor building: 18+35 = 53 temperature data points
- "Monitoring Equipment Environment During Nuclear Plant Operation at Salem and Hope Creek Generating Station" [4, pp. II-2-3-3 through II-2-3-10]:
  - Salem pressurizer enclosure: six temperature data points
  - Hope Creek reactor building: 24 temperature data points
- Qualified Life Enhanced by Environmental Monitoring at Nine Mile Point Units 1 and 2 [4, pp. II-2-4-2, II-2-4-6 through II-2-4-12]:
  - Various: 29 temperature monitors in Unit 1 and 48 monitors throughout Unit 2

The 2013 EPRI report for Phase I of this project [1] provided various monitoring survey responses. Some survey response information included numbers of monitors, as follows:

- Plant 1, Unit A (PWR): 51 containment temperature monitors
- Plant 3, Unit C (PWR): 55 outside containment temperature monitors and 12 inside containment temperature monitors
- Plant 4, Unit D (BWR): 54 drywell monitors
- Plant 6, Unit H (PWR): seven containment temperature monitors at a minimum
- Plant 7, Unit K (BWR): approximately 85 temperature monitors throughout entire plant, with about 10 in each location that is, 10 in drywell)
- Plant 8, Units L and M (PWR): approximately 50 containment temperature monitors at a minimum
- Plant 9, Units N and O (BWR): approximately one monitor for each room or EQ component
- Plant 10, Unit P (PWR): approximately 25 reactor building temperature monitors
- Plant 11, Unit Q (BWR): approximately 24 drywell/containment temperature monitors
- Plant 12, Unit R (PWR): approximately 12 containment temperature monitors

EPRI report 106687 [27, pp. I-4-5 and I-4-6] says that 17 temperature monitors were used inside containment for a plant-specific cable aging program. The monitors were grouped as follows:

- Four in upper containment
- Four in lower containment
- Three in specific room
- One in instrument room
- One in pressurizer dog house roof
- Four in steam generator doghouse roof

EPRI report 106687 states the following for a plant-specific cable aging program:

> Long-term temperature measurements recorded inside containment … clearly demonstrated that the normal operating temperature is significantly less than the maximum design temperature. Since there is no set of temperature data yet for areas outside containment, a corresponding analysis cannot be made for those areas. Nonetheless, it is known (for certain areas, at least) that the temperature used in the calculations is never seen by the cable insulation … a discussion concerning specific areas (such as the control room and diesel generator room, among others) where the temperature either never reaches the design maximum (120°F [48.8C°] in the control room) or rarely would be at the design maximum (130°F [54.4C°] in the diesel generator room) [is provided]. [27, pp. I-4-5 and I-4-6]

Summarizing, these examples of plant temperature monitoring had a purpose to monitor all plant areas (typically harsh areas of the plant [as defined according to NRC EQ regulations and plant-specific definitions]) or had a purpose to measure specific equipment environments. For example, large numbers of monitors were used to ensure that a monitor was placed in most, if not all, auxiliary building rooms.

In the case of temperature monitoring on behalf of long-term operation cable aging, it is not required to identify temperatures in every single room or even monitor every single room with cables. Rather, the purpose is to provide a comprehensive example of how important cables are aging; therefore, a large number of rooms with insignificant normal temperature or radiation can be excluded if their actual room locations are already solidly documented. Some cables for this long-term operation cable aging monitoring are also anticipated to be monitored in multiple locations across their length (that is, monitoring at a cable location outside containment, at inboard and outboard penetrations, and at inside containment/drywell end device locations).

Therefore, based on the preceding **general area monitoring** examples (which is a different purpose from herein for long term-operation cable aging), the following temperature monitoring counts typically occurred:

- **BWR**. Drywell: 25 or more temperature monitors
  - Also recommend use in parallel of any ongoing drywell temperature monitoring for normal operation
  - Reactor building: one or more temperature monitors per selected room
- **PWR**. Containment: 25 or more temperature monitors
  - Also recommend use in parallel of any ongoing containment temperature monitoring for normal operation
  - Auxiliary building: one or more temperature monitors per selected room

This section concludes with a typical average number of monitors to be used for general area monitoring. The suggested minimum number of monitors needed for this long-term cable aging monitoring will be different because of its different purpose. Accordingly, the minimum number of monitors for this project will be further researched in the following sections with a conclusion then achieved.

4.1.2 Number of Radiation Monitors

The EPRI 2013 report for Phase I of this project [1] provided various monitoring survey responses, as follows:

- Plant 1, Unit A (PWR): four containment radiation monitors
- Plant 4, Unit D (BWR): 20 drywell radiation monitors
- Plant 6, Units H, I, and J (PWR): four containment radiation monitors at a minimum
- Plant 7, Unit K (BWR): approximately 12 drywell radiation monitors
- Plant 9, Units N and O (BWR): approximately one monitor per room or EQ component

Therefore, based on the preceding **general area monitoring** examples (which is a different purpose from herein for long-term operation cable aging), the following radiation monitoring counts typically occurred:

- **BWR**. Drywell: 20 or more radiation monitors
  - Also recommend use in parallel of the EPRI BWR Radiation Assessment and Control program, if possible
  - Reactor building: one or more radiation monitors for each room
- **PWR**. Containment: 20 or more radiation monitors
  - Also recommend use in parallel of the EPRI Standard Radiation Monitoring Program, if possible
  - Auxiliary building: one or more radiation monitors for each room

This section concludes with a typical average number of monitors to be used for general area monitoring. The suggested minimum number of monitors needed for this long-term cable aging monitoring will be different because of its different purpose. Accordingly, the minimum number of monitors for this project are further researched in the following sections with a conclusion then achieved.

The prior two sections of this report considered temperature monitoring and radiation monitoring separately. As a result of the monitor selection for this long-term operation cable aging research (Westinghouse LIFETIME monitor), both temperature and radiation monitoring will occur in parallel. Accordingly, there may be some selected locations that are more important for radiation than temperature or vice versa (as covered in the following section). Accordingly, the suggested minimum monitor counts will likely be even higher based on such needs.

4.2 Considerations for Monitor Placement

The obvious major locations for monitor placement relating to long-term operation cable aging include inside containment/drywell and assorted auxiliary building rooms/reactor building locations. Locations in other buildings or areas will typically have minor significance. However, if a known additional area, such as the turbine building, has any areas of concern, that additional building can also be addressed. But in such a case as this turbine building example, a more appropriate first monitoring approach may be an adverse localized environment review according to EPRI report 109619 [3] or a license renewal X1.E1 walkdown. Generally, a long-term operation cable aging monitoring project should focus on cable aging rather than identification of higher than normal or hot spot environments.

For more specific location considerations, the following excerpts from assorted reports provide additional considerations for monitoring placement as grouped under overall monitor location approach, suggested temperature monitor locations, suggested radiation monitor locations, suggested combined monitor locations, and site-specific supportive visual tools for monitor location consideration.

4.2.1 Overall Suggested Monitor Location Approach

Various EPRI reports describe a spaces approach regarding cable aging management programs. One example is in EPRI report 1003317 [31, pp. 7–8]. A spaces approach is one method of performing a walkdown related to cable aging management. Some of the principles of this method can also be applied to organizing a monitoring program for cables. Typically, the spaces approach includes the following actions that can apply to monitoring placement:

- Divide the nuclear plant into specific zones. The plant EQ program environmental service condition zones might already have completed this action.
- Identify any zones that do not have any cable installed. Disregard installing any monitoring equipment in zones that do not have cables within them.
- Identify within each remaining zone the cable tray locations in relation to the zone. The most likely monitoring installation locations will be near the cable trays.

IAEA report TECDOC-1188 [22, p. 37] likewise identifies that before an environmental monitoring program for cables is started, a classification list of cables should be available and should identify whether the cables serve normal or safety functions in the plant and identify their routing. In addition, further information on function and post-accident operation requirements are desired.

4.2.2 Suggested Temperature Monitor Location Considerations

IAEA report TECDOC-1188 [22] says that for the monitoring of the temperature in cable installations, it is important that the temperature be measured as close as possible to the cable position in order to avoid misinterpretation of the influences from nearby heat sources.

The IAEA report also says that bulk area temperature monitors exist for the containment of most nuclear power plants and possibly for steam tunnels; therefore, a first approach is for a plant to identify and obtain any existing temperature monitoring.

EPRI report NP-7399 [4, pp. I-2-3 through I-2-6] states that the following factors may provide incentives for enhancing the monitoring of particular areas:

- Areas with potentially adverse environments
- Areas prone to high temperatures, including the following
  - Areas with high-temperature process fluid piping
  - Areas with high-temperature equipment

High-temperature components are identified in Table 4-1.

Table 4-1
High-temperature components

PWRs	BWRs
Reactor pressure vessel	Reactor pressure vessel
Pressurizer	Recirculation pumps
Steam generator	Reactor water cleanup heat exchangers
Feedwater pumps	Feedwater pumps
Charging pumps	Reactor core isolation cooling turbine
Regenerative heat exchangers	
Letdown heat exchanger	
Reactor coolant pumps	

- Areas with limited ventilation

  EPRI report NP-7399 [4, pp. I-4-8 and I-4-9] cites temperature considerations for monitor placement. Temperature sensors should not be placed where heat sources can dominate the measured environment unless a specific objective is to provide conservative measurements of local temperature or an assessment of the temperatures affecting a particular piece of equipment. Temperature sensors should also not be located close to the discharge of ventilation systems, which could create an artificially low measurement of temperatures.

EPRI report 109619 [3, pp. 2-2 through 2-6] also identifies areas with high-temperature process fluid piping, including the following:

- Equipment near main steam isolation valves (MSIVs)
- Equipment in pressurized compartments
- Main steam pipe tunnels
- Compartments under turbines in BWRs
- Equipment adjacent to uninsulated process piping
- Areas with high-temperature equipment, including electrical cabinets
- Areas with limited ventilation, including upper drywell or containment regions

The 1996 EPRI report *Methodologies and Processes to Optimize Environmental Qualification Replacement Intervals* (104873) [32, p. 4-19] provides a listing of typical plant areas and the expected change in temperature during power operation and shutdown, as shown in Table 4-2.

Table 4-2
Typical plant temperature ranges

Area/Location	Temperature Range (Plant at Power)	Temperature Range (Plant Shutdown)
Containment	High	Medium
Turbine building	Medium to high	Low
Auxiliary building	Medium	Medium
Residual heat removal	Low to medium	High
Emergency core cooling system rooms	Low	Medium
MSIV tunnel	High	Medium to low

The EQDB 2005 topical report [5] provides the following installation location considerations, including temperature considerations:

- Crediting/using permanently installed temperature elements that typically store results in the plant computer
- Choosing locations near high-temperature or radiation equipment, cables, or piping
- Choosing locations in limited ventilation areas
- Photograph/videotaping all temperature/radiation sensor locations selected

Finally, EPRI report 106687 [27] actually provides an example of a cable aging management program for a particular nuclear power plant. For example, Part I, Section IV of this report provided environmental conditions for non-EQ cables. Section C.1 included 17 temperature sensor locations for inside containment that were considered appropriate for describing the range of temperature conditions therein.

4.2.3 Suggested Radiation Monitor Location Considerations

EPRI report NP-7399 [4, pp. I-2-3 through I-2-6] states that the following conditions may provide incentives for enhancing the monitoring of areas with potentially adverse environments and areas prone to high radiation.

Radiation considerations for monitor placement cited in EPRI report NP-7399 [4, pp. I-4-8 through I-4-9] are as follows: radiation monitors should not be located adjacent to significant radiation sources unless the objective is to obtain conservative representation of radiation environments or an assessment of radiation affecting a particular component. Consideration should also be given to potential radiation streaming in locating radiation monitors.

EPRI report 109619 [3, pp. 2-2 through 2-6] also identifies the following areas prone to elevated radiation levels:

- Areas near primary reactor-coolant-system piping or the reactor pressure vessel
- Areas near waste processing systems and equipment
- Areas subject to radiation streaming

The EQDB 2005 topical report [5] also provides location considerations including the following radiation considerations:

- Near high temperature or radiation equipment, cables or piping
- Photograph/videotaping all temperature/radiation sensor locations selected

For radiation monitoring, additional considerations include the following:

- Using the information collected by the Health Physics organization to identify candidate locations for radiation monitoring equipment
- Any radiation zone or dose maps
- Radiation monitoring in areas that may be subject to neutron radiation exposure during power operation

4.2.4 Suggested Combined Monitor Location Considerations

Combined temperature and radiation monitor placement considerations cited in EPRI report NP-7399 [4, pp. I-4-8 through I-4-9] are as follows:

- If sensors are placed in contact with components and ambient data are desired, adequate consideration must be given to effects from equipment operation. For example, self-heating because of energized cables or solenoid operators should be considered.
- Monitoring system components that require electrical power for operation must be located so that power can be provided.
- Placement of monitoring devices should consider seismic requirements.
- If safety-related equipment is in the area where the monitoring devices are located, the monitoring devices must be located or supported so that their failure will not adversely affect the performance of the safety-related components.
- The location of monitoring devices should also consider the need for access to the instruments to collect data or conduct periodic calibration.

4.2.5 Site-Specific Supportive Visual Tools for Monitor Location Considerations

After the general number of monitors is determined, more specific locations must be investigated. Ideally, the potential monitor locations would be walked down. However, this may not be possible for inside containment/drywell locations. Therefore, any available photos and videos should be reviewed to find potential locations. Walkdowns in conjunction with review of general arrangement and electrical drawings will ensure that monitors are located in areas with high concentration of cables.

Now that site-specific research on monitoring considerations and plant-specific monitoring methodologies have been provided herein, more detailed and more exact locations can be determined for specific nuclear power plants. There are two main ways to research potential site-specific monitor locations. The first is to conduct reviews of general arrangement drawings and conduit and cable tray drawings, in parallel to any cable information from the plant network, cable databases, and so forth that are applicable to proposed monitor locations. The second is to perform walkdowns of either the same unit where monitors are to be installed or a similar unit (during a prior shutdown) for hard-to-access areas, such as inside containment/drywell. For other accessible areas of the plant, walkdowns can occur as needed. Some plants also have video recordings of various plant locations that also can be used in order to limit radiation exposure.

The use of drawings and walkdowns can provide a more focused review of potential monitor locations, based on the background information provided herein. The following sections provide an overall figurative consideration for BWRs and PWRs, similar to a high-level general arrangement sectional drawing, in that they provide visual location information. One suggested tip is that potential monitor locations be marked up on general arrangement and conduit tray drawings, in order to determine whether there are any resulting concerns or changes needed.

Figure 4-1 provides a simplified drawing of a typical BWR; this drawing can be used to visually assist in general monitor placement before plant specific drawings are provided.

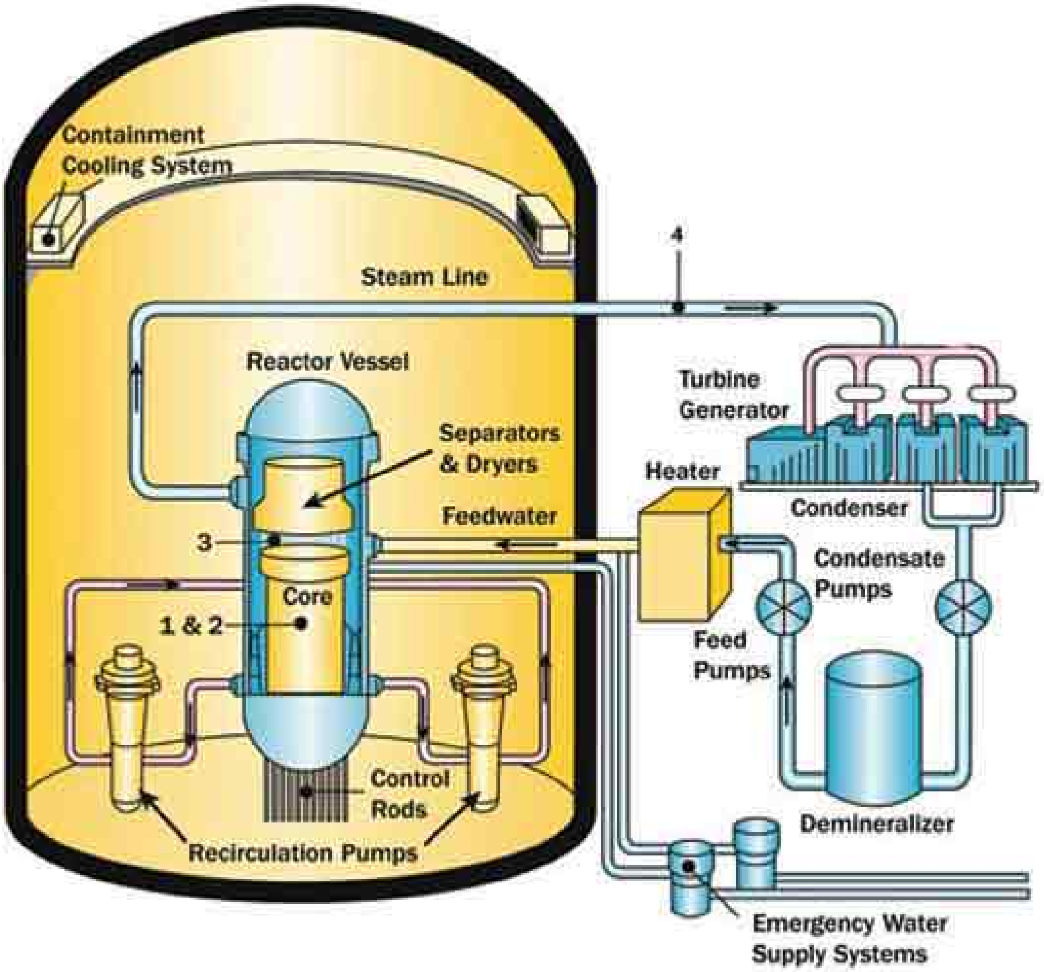

Figure 4-1
Typical BWR
Used with permission from the NRC

Figure 4-2 provides a simplified drawing of a typical PWR; this drawing can be used to visually assist in general monitor placement before plant specific drawings are provided.

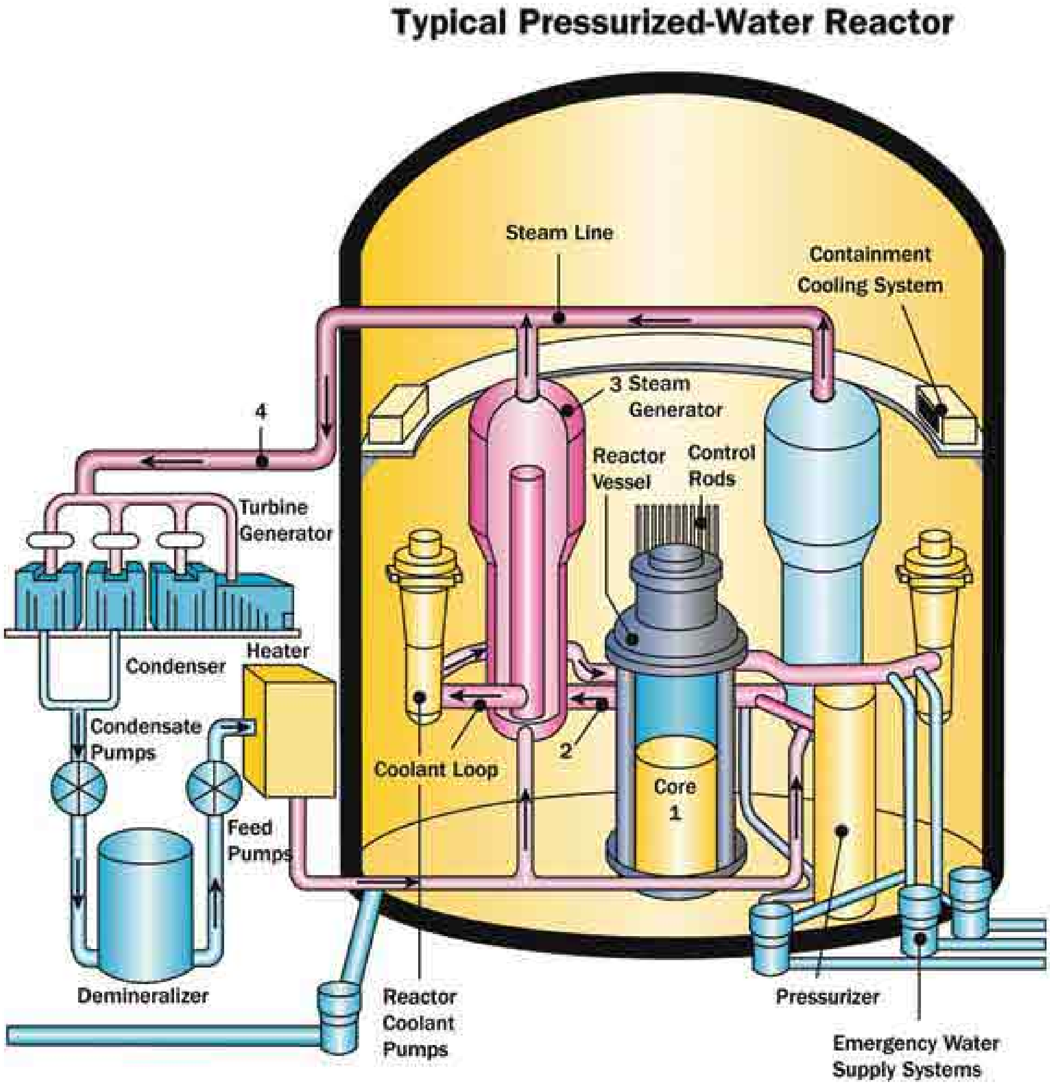

Figure 4-2
Typical PWR
Used with permission from the NRC

4.3 Suggested Monitor Placement

The previous sections identified how many monitors were used in various plant temperature and radiation examples. In addition, key focal points of monitor locations were generically provided from a variety of resources, so that key general monitoring locations in PWRs and BWRs were identified. Now, from all of this aforementioned background information, suggested monitor locations can be provided for BWR and PWR nuclear power plants for long-term operation cable aging purposes.

This new section takes all of the prior information and in Tables 4-3 through 4-6 identifies suggested total numbers and approximate locations of the environmental monitors for long-term operation cable aging. There are two tables for PWRs (one table for inside containment and one table for outside containment), and two tables for BWRs (one table for the drywell and one table for the reactor building).

Table 4-3 shows the suggested minimum number and locations of monitors for PWR inside containment.

Table 4-3
PWR inside containment monitor locations

Item No.	Area Description	Count
1	Reactor pressure vessel	2
2	Pressurizer	2
3	Steam generator	2
4	Reactor coolant pumps	2
5	Upper containment regions	2
6	Miscellaneous	10
	Total count	**20**

Therefore, a total of approximately 20 monitors is a minimum sufficient number of monitors to monitor a PWR inside containment.

Table 4-4 shows the suggested minimum number and locations of monitors for long-term operation cable aging for PWR outside containment.

Table 4-4
PWR outside containment monitor locations

Item No.	Area Description	Count
1	Demineralizer	2
2	Feed pump	2
3	Condensate pump	2
4	Heater	2
5	Emergency water supply system	2
6	Miscellaneous	10
	Total count	**20**

Table 4-5 shows the suggested minimum number and locations of monitors for long-term operation cable aging for the BWR drywell.

Table 4-5
BWR drywell monitor locations

Item No.	Area Description	Count
1	Feedwater lines	2
2	Reactor pressure vessel	2
3	Recirculation pumps	2
4	Upper drywell regions	2
5	Steam lines	2
6	Miscellaneous	10
	Total count	**20**

Therefore, a total of approximately 20 monitors is sufficient to monitor a BWR drywell. However, consideration may be provided to approximately doubling the number of monitors and place with a second train of equipment.

Table 4-6 shows the suggested minimum number and locations of monitors for long-term operation cable aging for the BWR reactor building.

Table 4-6
BWR reactor building monitor locations

Item No.	Area Description	Count
1	Demineralizer	2
2	Feed pump	2
3	Condensate pump	2
4	Heater	2
5	Emergency water supply system	2
6	Miscellaneous	10
	Total count	**20**

Based on the preceding research, a minimum of 20 monitors is suggested inside containment (PWR)/drywell (BWR) and a minimum of 20 monitors is suggested outside containment (PWR)/reactor building (BWR).

Use of additional monitors provides more justification of monitoring results (for example, use of redundant monitors: same room but opposing wall or same cable but at different locations, or use of diverse monitors, in that measurements are made of same cables, such as for reactor coolant pumps, but for different trains).

Use of lesser (or more) monitors can also depend on how much other monitoring is ongoing at the nuclear power plant; for example, if a large number of temperature and radiation monitors are already in use and can be applied toward the purpose of long-term operation cable aging monitoring, a smaller number of monitors may be possible.

These counts refer to one nuclear power plant unit. For multiunit sites, variances between the units need to be addressed, both from a design standpoint (that is, is the same BWR containment type used) and from an operating experience standpoint (that is, are any significantly different temperature or radiation areas observed applicable to only select units).

4.4 Installation Accessibility and Mounting Adjustments

Accessibility of monitor locations is also an important consideration. For example, needing a ladder, harness, or other equipment to access a monitoring location must be addressed. Even the size of a possible ladder will need to be addressed, because many cable trays are usually at high elevations from the floor level. Particularly in containment, it may require the installers to carefully place a ladder, room permitting. Accordingly, it may be useful to discuss with the planning department whether any particular work action is being performed nearby a potential monitoring location (that is, if a proposed monitor location is a short distance from some equipment work that also requires a ladder, possibly the ladder could be used at that time or the monitor could be moved close to the work location). Also to be considered is whether any confined space requires breaching in order to install a monitor, and, if so, whether the monitor location is that important to breach the confined space.

In addition, proposed monitor locations may have radiation restrictions (that is, high radiation, locked high radiation, and so forth). Even during a refuel outage when monitors can be installed, there may be a small window of opportunity for monitor installation in some radiological areas, resulting from the movement of fuel, reactor head, and so forth. Although optimal locations may be initially identified, they must be discussed with radiation protection, outage planning, and cable engineers, and so forth, to determine whether a more accessible location may meet the needs of the monitoring project.

Because cables terminate in junction, terminal, or penetration boxes, any monitors in those locations will necessitate opening the boxes. This is another case where coordination with the planning department can be useful prior to installation, because it can be learned which boxes can be potentially opened during an outage for maintenance of installing monitors inside such boxes would be easier than for boxes that are not scheduled to be opened for maintenance work. In all box opening activities, the nuclear power plant procedures and processes regarding opening of boxes need to be followed, because the plant may allow only certain individuals to open boxes.

Finally, the previously identified mounting method needs to be evaluated to ensure that it would be functional for all proposed locations. If tie wraps are used to mount the monitors, the location must be evaluated so it can be attached using a tie wrap. Note that a plant can have varying types of tie wraps dependent on location, such as use inside or outside containment or the drywell. This is where the use of pre-installation walkdowns is useful, because reviews of drawings would show cable trays but would not entirely identify the most practical places to install the monitors with tie wraps. Therefore, during the pre-installation walkdowns, consideration should be given as to where tie wraps can be used to locate the monitors.

4.5 Generic Monitoring Frequency

The suggested generic monitoring frequency (hourly, daily, and so forth) applies to active temperature and radiation monitors. Passive monitors, such as the Westinghouse LIFETIME monitors, are an exception because those monitors do not record periodically but are reviewed after removal to determine overall degradation values. Industry research on this topic is provided as follows.

EPRI report NP-7399 [4, pp. I-4-9 and I-4-10] provides suggestions for the frequency of data collection. The report states that data sampling rates used in current (as of 1989) utility programs varied from one point per hour to one point per minute. The report also states that, generally, monitoring at one point per hour appears to be a reasonable frequency, because infrequent, short duration transients will not have a significant effect on the average temperature.

EPRI report 3002000816 [1] identifies from surveys that plant monitoring frequencies occurs typically once a day, because the duration of monitoring was much longer than one year. Monitoring of approximately one year or less appeared to have more data points per day.

EPRI report 104873 [32, pp. 5-1 and 5-2] stated that that the frequency of monitoring can be important if there are significant daily temperature swings. The ideal would be to monitor frequently enough during the day to obtain the peak temperature for each day. However, if the daily temperature cycle has a small amplitude, measuring once each day would be sufficient. If the period of peak temperature during the day is known (for example, late afternoon), monitoring can be set to record at that time.

EPRI report 106687 [27, p. 1-4-6], describes a cable aging management program that provided temperature monitoring once each day on weekdays.

IAEA report NP-T-3.6 [33, p. 28] states that temperature measurement should preferably use sensors that allow for continuous recording during long periods of time, enabling detailed data analysis. Small self-contained temperature sensors with built-in data loggers are readily available commercially and are suitable for this purpose. Radiation doses can be measured with dosimeters installed in the areas with the highest doses. Dose measurements should cover long periods of time (that is, complete cycle between outages) in order to register potential transients or significant deviations in doses.

Based on the preceding considerations, for long-term operation cable aging monitoring, a recommended frequency of at least once a day is considered acceptable for active monitors. The actual data loggers selected should be examined to consider their memory capacity versus the monitoring duration covered as follows. If data capacity is available, monitoring of once an hour is suggested. The time of the monitoring can be conservatively assumed as late afternoon in case any external ambient temperatures affect plant service conditions.

For passive monitors, no monitoring frequency is required, because only total aging is recorded.

4.6 Generic Monitoring Duration

The suggested generic monitoring duration (that is—one year, one fuel cycle, and so forth) applies to **all** temperature and radiation monitors, active and passive. Industry research on this topic is provided as follows:

- EPRI report NP-7399 [4, pp. I-4-10 and I-4-11] provides suggestions for the duration of data collection. The report identifies that one fuel cycle duration appears to be the most appropriate duration because it will account for all of the normal operational events, outage, startup, full power operation, and end-of-cycle coast-down that affect equipment environments. This duration will also account for the effect that seasonal climate changes have on outside ambient air temperature and cooling water temperature. The report indicates that is may be necessary to monitor some locations for more than one refueling outage if an abnormal condition, such as an unusually hot or cold seasonal period, occurs.
- EPRI report 1021067 [2, p. 6-24] suggests that a one- to three-year period should be considered a minimum timeframe to ensure that seasonal and operational variations are adequately incorporated.
- EPRI report 104873 [32, pp. 5-2 and 5-3] says that the duration of the monitoring should be planned so that the peak expected temperature for the worst-case combination of cycles occurs during the elevated and low-temperature periods. Monitoring of temperatures through a complete yearly cycle and possibly an entire operating cycle is desirable for the areas with large swings.

- EPRI report 3002000816 [1] identifies from surveys plant monitoring duration of one or more years.
- EPRI report 106687 [27, p. 1-4-6] describes a cable aging management program that provided temperature monitoring data for seven years in containment.

Based on the preceding considerations, for long-term operation cable aging monitoring, a recommended duration of between one year and one refuel cycle is considered acceptable. Because of limited containment/drywell access during plant operation, a monitoring duration of one refuel cycle is recommended so that monitors can be installed and removed during refuel outages.

5
MONITOR DATA ANALYSIS

This section covers technical data retrieved from the monitors and how to analyze such data for a long-term operation cable aging research purpose. Major topics covered in this section include the following:

- **Data retrieval frequency**. This section involves how often to retrieve the monitor data.
- **Data type to be retrieved**. This section involves the type of data to be retrieved.
- **Data format**. This section involves the format of the data to be retrieved.
- **Plant monitoring data record sorting**. This section involves the types of sorting that are recommended for the retrieved data.
- **Determination of margin between the design and monitored temperature and radiation values**. This section involves identification from the data whether there is margin between the recorded data and the existing plant design or other currently used data.

5.1 Data Retrieval Frequency for Long-Term Operation Cable Aging Monitoring

The frequency of the data retrieval for long-term operation cable aging monitoring depends on many factors, including the following:

- **Type of monitor**. The type of monitor affects how often the data can be retrieved, as follows:
  - **Passive**. The monitor selected for this EPRI pilot project, the Westinghouse LIFETIME monitor, has the amount of aging determined at Westinghouse after removal from the plant. The monitors are typically left in place for one fuel cycle and then removed. The aged blocks can be replaced with new blocks that can then be left in place for another period of time. After the LIFETIME monitors are removed and evaluated by Westinghouse, a report is issued by Westinghouse.
  - **Active**. For other monitors that store and record data, the retrieval is based on various factors, such as the following:
    - The location of the monitor as it relates to accessibility to even have data retrieved.
    - The type of power supplied and whether that limits monitoring duration.
    - The size of the data storage versus the proposed monitoring duration.
    - Oppositely, overly conservative data retrieval introduces additional plant personnel into the plant and increases risks to monitor operability during the handling of the data download. For example, if a monitor is easily accessible and can store data for one year, there is no need to download data once a month because it introduces the potential or increased risk of having an accident damaging the monitor and can possibly lead to increased unnecessary dose exposure for plant personnel.

Data retrieval frequency is also covered in EPRI report NP-7399 [4, Part I, Section 4.5], which highlights factors such as the following:

- Storage capacity of the data logger
- Data download frequency
- Operational status of nearby equipment
- Data processing time
- The effect that time-related events could have on the data

Personnel should follow all plant procedures when removing the monitors, and make special note if any damage or issues are identified.

Based on the preceding considerations, for long-term operation cable aging monitoring, it is suggested that data be retrieved after one fuel cycle, which can be 12–24 months, depending on the particular nuclear power plant.

5.2 Data Type to Be Retrieved for Long-Term Operation Cable Aging Monitoring

This section refers to the type of data to be retrieved for long-term operation cable aging monitoring. The type of data will directly relate to how the data can be organized, sorted, and analyzed.

Active monitors evaluated herein typically provide data results in a series of time-dependent measurements of temperature and/or radiation over the duration of the monitoring period. The passive monitors evaluated herein (and used in this pilot project, such as the Westinghouse LIFETIME monitor), provide an Arrhenius equivalent weighted average temperature and a total radiation dose for the duration of the monitoring.

For this EPRI pilot project that uses Westinghouse LIFETIME monitors, according to EPRI report NP-7399 [4, pp. II-3-2-5 and II-3-2-6], the monitor actually contains an ITM, which consists of materials whose optical properties change gradually as a function of both time and temperature. Based on the measured change in physical properties and the known time of exposure, an effective exposure temperature can be determined, which is termed the *Arrhenius equivalent* temperature.

EPRI report NP-7399 continues that the degradation mechanisms that limit the life of equipment are usually treated as having a temperature dependence that conforms to the Arrhenius model. This model predicts that the time required to reach a given change in material property is an exponential function of exposure temperature and a material-specific constant, the activation energy. The rate of change in ITM optical properties is also described by Arrhenius functions of temperature using characteristic activation energies. Multiple ITM materials have been calibrated spanning the range of activation energies typical of nuclear components. Combining the results from multiple ITMs allows the Arrhenius equivalent temperature to be plotted as a function of activation energy. This, in turn, allows the Arrhenius equivalent temperature to be determined for any component, regardless of its activation energy.

For monitors that record time-dependent temperatures, thermal data are typically provided in a time versus temperature format.

For radiation data provided in all cases, the data are typically provided in a dose-over-time format with the following caveat. For passive monitors that measure radiation through aging dose identified to a particular material (for example, Westinghouse LIFETIME or CITM monitors), only a total dose for the installed monitor duration is available for retrieval. For example, EPRI report NP-7399 [4, pp. II-3-2-3 and II-3-2-4] states that the Westinghouse LIFETIME or CITM monitors contain optical crystals that are read by measuring the amount of optical absorbance at wavelengths that correspond to the various color centers of interest.

Based on the preceding considerations, for long-term operation cable aging monitoring, passive monitors will provide an Arrhenius equivalent weighted average temperature and a total radiation dose for the duration of the monitoring. Active monitors evaluated herein typically provide data results in a series of time-dependent measurements of temperature and/or radiation over the duration of the monitor.

5.3 Data Format for Long-Term Operation Cable Aging Monitoring

This section refers to the format of the data that are retrieved for long-term operation cable aging monitoring. Data can be provided in the following formats:

- Electronic or hard-copy printouts of time versus temperature or radiation
- Worst case values achieved
- Arrhenius equivalent weighted average temperature as provided by the monitor vendor
- Radiation dose as provided by the monitor vendor

Data availability is also dependent upon the data format. Any data that are directly downloaded from an active monitor would be available for immediate analysis by the nuclear power plant. Any data that require the vendor to read or measure change in material characteristics, such as various passive monitors, can take several months after the monitor removal to have data available.

For this EPRI pilot project that uses Westinghouse LIFETIME monitors, the data availability will be several months after the monitors' removal. This additional time for the vendor to review the data is not an issue because the purpose of this EPRI pilot project is to support subsequent license renewal; therefore, a pause of several months before data analysis is provided does not affect the project overall purpose.

Based on the preceding considerations, for long-term operation cable aging monitoring, it is suggested that data be provided or downloaded in electronic and hard-copy format. This includes, if possible, any data provided by the monitor vendor such as for passive monitors, so that any vendor-provided histograms or plots can be revised as necessary at the nuclear power plant, especially if any future adjustments or considerations are necessary.

5.4 Plant Monitoring Data Record Sorting for Long-Term Operation Cable Aging Monitoring

After the plant monitoring data have been collected from the long-term operation cable aging monitoring, they require collation and other sorting, in order for the data to be properly used and then compared to industry data.

The plant monitoring data record-sorting variability is dependent on the type of monitor used. The following should be considered:

- **Active temperature monitors that record time and temperature.** EPRI report 1021067 [2, p. 6-28] states that for temperature monitoring, conservative average or maximum design temperatures should be used, unless detailed information about the specific temperature profile in a particular plant area is available. When actual temperature information is used to define the normal thermal profile, the data should be representative of the specific equipment location and verified to be representative of existing conditions. Page 6-27 also suggests that when the actual temperature range is wide, the calculated qualified life using a temperature history can be significantly different from the value determined when a single (average or maximum) temperature is used and suggests the use of histograms.

  EPRI report 104873 [32, pp. 5-3 through 5-5] suggests that for areas with larger temperature swings, daily peak temperatures can be loaded into a spreadsheet for analysis. Sorting the temperatures by decreasing magnitude provides a stepped profile with duration for the period. This report provides more tips on how the histograms can be developed, including that three to six time steps are typically needed in a profile to provide a desired qualified life relief. Accordingly, a similar number of time steps may be necessary for the purpose of this particular project. Pages 4-20 through 4-22 provide a methodology that can also be used to some extent.

  The EQDB 2005 topical report [5] also suggests that caution should be exercised in applying data as representative of future plant operating conditions when it includes or is based on extended plant shutdowns, 18-month fuel cycles, or longer refueling outage durations compared with current/future plant operation.

  In addition, EPRI report 106687 [27, pp. 1-4-5 through 1-4-11], describes a cable aging management program that provided a specific use of containment temperature monitoring data analysis separated out in histogram format.

  For sorting purposes for active monitors, the report suggests recording temperature as a function of time: identify minimum, maximum, and average temperatures and mean arithmetic values, as deemed necessary, based on various sorts and computations. View histogram and determine whether worst-case temperature can be used as basis for plant normal temperature or whether another value is acceptable and identify its basis.

- **Passive temperature monitors that record Arrhenius equivalent temperature (for example, Westinghouse LIFETIME or CITM monitors)**. Passive temperature monitors that record Arrhenius equivalent temperature (for example, Westinghouse LIFETIME or CITM monitors) will not have a histogram because those types of monitors simply record the amount of aging. Westinghouse provides reading services for all of the devices in the LIFETIME monitor [4, p. II-3-2-9]. Results are provided in a detailed report summarizing the environment measured during the installed measurement period. Qualified life can be determined using Equation 4-16 of the 1980 EPRI report *A Review of Equipment Aging Theory and Technology* (NP-1558) [34]. This equation is used to calculate the time at the measured temperature that is equivalent to the original qualification time at the assumed qualification temperature using the critical activation energy for cable material of interest. Because only an Arrhenius equivalent weighted temperature is provided according to activation energy ranges, no additional sorting possibilities exist.

- **Active radiation monitors that record time and temperature**. These types of monitors can have data sorted on total dose and also other variables, such as peak dose recorded, depending on how frequent recordings occurred. For sorting purposes, it was recommended to record radiation as a function of time. Identify minimum, maximum, and average, temperatures and mean arithmetic values based on various sorts, and computations can be considered. View histogram, and determine whether a worst-case dose rate can be used as basis for plant normal radiation dose or whether another value is acceptable and identify its basis.
- **Passive radiation monitors that record total dose per duration (for example, Westinghouse LIFETIME or CITM monitors)**. Westinghouse provides reading services for all of the devices in the Lifetime Monitor [4, p. II-3-2-9]. Results are provided in a detailed report summarizing the environment measured during the installed measurement period.

  Because only a final radiation dose will be available based on the duration, a dose rate can be calculated based on duration of the monitor installation but no sorting possibilities exist.

Therefore, for the purposes of this specific pilot project, the plant monitoring data sorting is recommended to occur as follows:

- **Passive temperature monitors**. Only an Arrhenius equivalent weighted temperature is provided according to activation energy ranges. Therefore, no additional sorting possibilities exist.
- **Passive radiation monitors**. Only a final radiation dose will be available based on the duration. Next, a dose rate can be calculated based on duration of the monitor installation.
- **Active temperature monitors**. Temperature should be recorded as a function of time.
- **Active radiation monitors**. Radiation should be recorded as a function of time.

5.5 Determination of Conservatism Between the Design and Monitored Temperature and Radiation Values

When normal temperature and radiation monitoring data have been collected for this purpose of long-term operation cable aging, it is necessary to compare the monitoring data to the current plant design data or the in-use normal temperature and radiation values and then perform some type of evaluation or determine acceptance criteria. The purpose of an initial evaluation is to determine whether there is sufficient margin between the design service conditions or currently used plant normal radiation and temperature data that have been used and these new monitoring data so that cable life can be shown to extend to 80 yr. Basically, at this point a determination needs to be made as to whether there is sufficient benefit to the utility that additional engineering and financial resources should continue to be applied toward evaluation of the environmental monitoring data.

The answer to this overall primary question depends on how the utility controls and maintains cable and environmental service condition information. The following series of questions provides assistance in identifying the availability of currently used normal temperature and radiation data:

1. Are the design environmental service conditions (normal temperature and normal radiation) readily identified for the locations that have undergone monitoring?
2. Are the EQ files for cables readily identifiable?
3. Can the EQ files for cables be pared down to disregard any existing qualified lives greater than 80 yr?
4. Do the EQ files for cables readily identify installed cable locations, or is a worst-case location used for qualified life?
5. For the EQ files for cables, can a simple comparison between the design and monitored service conditions be performed, to identify a potential difference or conservatism?

   If the answer to the preceding question is *yes*, EPRI report NP-1558 [34, p. 4-9] identifies that for each 10°C increase in temperature, the life approximately doubles. Therefore, even a 5°C change in temperature can result in a significant qualified life difference.
6. For non-EQ cables, has any life analysis ever been performed and documented? For example, has the plant created any aging management reviews for cables?
7. For non-EQ cables, is there a cable database that identifies cable locations?
8. For non-EQ cables, can installed locations be identified on a manufacturer and model number basis? In addition, are cable insulation materials identified?
9. Has the plant performed any analyses based on guidance in Nuclear Regulatory Commission regulation (NUREG) 801 (the generic aging lessons learned Report [35]), Section XI.E1? Section X1.E1 describes a sampling program to manage aging for non-EQ insulated cable and connections within the scope of license renewal. These reports can be useful in identifying non-EQ cables.
10. For non-EQ cables, can a simple comparison between the design and monitored service conditions be performed to identify a potential difference or conservatism?
11. Are the cables installed in a cable tray in which additional temperature considerations might be necessary? For example, EPRI report NP-7399 [4, pp. II-3-4-3 and II-3-4-4] identifies multiple variables that need to be addressed for determining cable tray temperatures. Major topics include the following:
    - Basic design considerations
    - Conduit or tray geometry
    - Cable geometry
    - Thermal properties
    - Environmental conditions
    - Fire stop or penetration properties

Basically, this should be a simple effort to determine whether there is sufficient information to continue this evaluation process. The following examples can assist in this informal decision to continue the evaluation part of this process:

- An EQ Cable with a qualified life of 65 yr at a design temperature of 120°F (48.8°C) is shown to have actual monitoring temperatures below 100°F F (37.7°C) at all times. This large temperature difference should be further investigated because use of a lower temperature can increase the qualified life from 65 yr to greater than 80 yr.
- A non-EQ cable with a thermal or expected life of 30 yr at a design temperature of 120°F (48.8°C) is shown to have actual temperatures of 118°F (44.7°C). This insignificant temperature would be insufficient to increase the expected life so that only one replacement is required over 80 yr rather than the current two replacements (that is, increase of expected life from 30 yr to greater than 40 yr).
- Normal radiation monitoring identifies a difference between a design value and monitored value of 0.1E-06 rad per hour. Therefore, the change is too insignificant to pursue further calculations.

Also, consider any plant-specific factors that could affect the results in the future or could affect consideration for all BWR or PWR use. For example, EPRI report 1021067 [2, p. 6-26] identifies the following examples that could potentially result in higher ambient temperatures:

- Damage or removal of process piping insulation
- Degradation to heating, ventilation, and air conditioning coolers or ducts
- Increased normal heat loads
- Increase in plant thermal power as a result of power uprate

For radiation, it is suggested [2, p. 6-29] that normal radiation levels can increase because of radioactive crud buildup over the plant life.

In general, the more available a utility or plant has related information, the easier it is to consider this decision point.

After a decision to continue the process positively has occurred, a more orderly and specific evaluation criteria and methodology can be used, according to EPRI report 104873 [32, Section 4.8.3 Methodology, pp. 4-20 and 4-21 (Note: this EPRI report section is titled "Use of Actual Area and Component Temperature Data Instead of Design Temperature Values." However, the temperature methodology indicates in several steps that it is also applicable for radiation)]. Some of the steps of EPRI report 104873 [32] have been reproduced as follows for consideration:

1. Identify temperatures used as the basis of qualified life for the equipment under consideration.
2. If actual temperatures are known, evaluate the profile for the data and determine one of the following:
    a. For areas with nearly steady-state temperatures, determine the effective temperature of the room and document the basis.
    b. For areas with significant seasonal or unit mode temperature swings, determine an enveloping profile that conservatively approximates the periodic changes.

3. Two techniques might be possible for immediate, temporary relief:
    a. Review the calculations for the design basis normal temperatures to determine if local room temperatures are less severe than the generalized maximum.
    b. Determine if sufficient knowledge of the area conditions exists to provide a reduced, but conservative, temporary basis that is less severe than using the design temperatures.
4. To evaluate periodic changes in the environment, including radiation dose/rates, determine if a significant change in the environment related to operating mode or season occurs for the area under consideration. If so, determine the environmental conditions for least severe seasons, for refueling/maintenance outages, and for operating periods.
5. From historical records, determine the periods of power versus outage conditions. The seasonal effect on temperature should also be determined so that a conservative overall effect can be determined.
6. When the profile of the combined periodic changes is known, evaluate the effect of the profile on an incremental basis for the overall refueling/ maintenance cycle (e.g., 18 months).
7. Given the reduction in temperature from actual measurement or from qualitative or quantitative evaluation, the effect of the new temperature profile at the weak-link component must be evaluated for the device.

After it has been determined whether there is sufficient conservatism between assumed and actual parameters, the next step is to calculate new lives. Appendix A contains the steps for using the temperature and radiation data for extending cable lives. Understanding these steps is important because the end use of the data must be considered when determining which data should be collected.

Note: There is a difference between conservatism and margin; accordingly, *conservatism* is the more appropriate term to be used herein. Section 5.8 of EPRI report 1021067 notes this difference, which is that although they are seemingly synonymous terms, they have subtle different meanings in the area of qualification. Because only *conservatism* is used herein based on the definitions provided in EPRI report 1021067, only that definition will be repeated here: *conservatism* refers to any practices or assumptions that provide additional confidence in the conclusion that equipment is adequately qualified for the assumed service conditions and performance requirements.

Based on the preceding considerations, for the purposes of this specific pilot project, the following items have been recommended:

1. Determine whether there is a significant difference between the design or currently used plant environmental service condition (temperature and radiation) data and newly monitored values that could assist in extending cable life to 80 yr.
2. If not, no further actions using this methodology apply, unless the monitored data indicate that the plant is operating at higher than currently used data, in which case the corrective action process may need to be considered.
3. If yes, the following are recommended:
   - For EQ equipment, reevaluate thermal qualified lives and radiation total integrated dose comparison based on the monitored values.
   - For non-EQ equipment, evaluate thermal and/or radiation thresholds or lives as applicable based on material capability. Methodologies covered in Appendix A or others can be used as necessary.
   - Evaluation of the conservatisms between the histogram and the design normal maximum values can occur. Evaluations of the average recorded value and/or the maximum recorded value versus the design normal maximum value can also occur.

6
MONITOR DATA RECORDING AND RECORD KEEPING

This section covers how to store and maintain records and data that result from the long-term operation cable aging monitoring. Major topics covered in this section include the following:

- **Record keeping/data storage**. This section involves how to store the data resulting from the environmental monitors.
- **Data maintenance**. This section involves consideration for how plant modifications, changes, and so forth may require reevaluation or even reinstallation of monitoring equipment.
- **Maintainability of electronic records**. This section involves consideration of how the monitoring results data are maintained, typically on a software program basis, in order to ensure that the data are maintained current with software programs.

6.1 Record Keeping/Data Storage for Long-Term Operation Cable Aging Monitoring

EPRI report NP-7399 [4, p. I-4-13] provides suggestions for maintaining data, including data storage and record retention periods. It states that maintaining records of equipment environments is an important element of an effective monitoring program. Records of equipment environments should be maintained throughout the useful life of the equipment.

EPRI report NP-4926, *Review of Records Requirements Related to LWR Life Extension* [36], also summarizes requirements for records of inspection and operating performance data relevant to plant life extension. Appendix A of that report, based on NRC Regulatory Guide 1.28, states that design records, such as this type of monitoring, have a lifetime retention time.

Finally, the 1988 EPRI report *Guidelines for the Content of Records to Support Nuclear Power Plant Operation, Maintenance, and Modification (NCIG-08), Volumes 1 and 2* (NP-5653) [37, 38] also confirms this lifetime requirement. Specifically, Section 3.2 of Volume 1 [37, p. 3-1] states that records containing verification data should be retained for the lifetime of an item.

Based on the preceding considerations, for long-term operation cable aging monitoring, it is recommended that data collected by a utility for the verification of cable temperature and radiation environments be maintained for the lifetime of the plant. Consideration of all of the data collected and their storage is also necessary, because summary reports may not contain all of the applicable background data.

This record retention can include both paper and electronic storage of the data for potential future use or research, as required by the particular utility procedures and requirements, and should be processed with the appropriate plant document controls and retentions departments.

6.2 Data Maintenance for Long-Term Operation Cable Aging Monitoring

EPRI report NP-7399 [4, p. I-4-13] explains that routine trending of data provides a mechanism for identifying gradual adverse changes in environments. It also identifies that routine trending of data provides a mechanism for identifying gradual adverse changes in environments.

Therefore, consideration must be given to the length of time for monitoring data acceptability; in other words, for how long can the data be used as a technical justification? Most U.S. nuclear power plants have been in operation for many years and, therefore, are already well into their current operating license time period or into the initial license renewal period. In addition, most U.S. nuclear power plants have already performed any planned major modifications, such as power uprate or extended power uprate, that could affect a plant's normal temperature and radiation conditions.

Accordingly, the technical data recorded as part of such a project is acceptable for the lifetime of the plant, depending on consideration of any design changes, modifications, 10CFR50.59 screenings, or conditions reports, and so forth that can affect normal temperature or radiation conditions. Such processes typically include checklists and other line items that can lead to identification of potential normal temperature and radiation changes, which in turn can lead back to a reverification of the results obtained from this long-term operation temperature and radiation monitoring project.

Based on the preceding considerations, for long-term operation cable aging monitoring, the following are recommended:

- Any major plant changes, evaluated by 10CFR50.59 and so forth that affect normal temperature or radiation environments, may need to be considered in correlation with any long-term operations temperature and radiation monitoring and associated conclusions.
- Any condition reports or other deficiencies that similarly affect normal temperature or radiation environments may need to be considered in correlation with any long-term operations temperature and radiation monitoring and associated conclusions.

6.3 Maintainability of Electronic Records for Long-Term Operation Cable Aging Monitoring

EPRI report NP-7399 [4, p. I-4-13] states that data storage in digital format is a substantial benefit for future retrieval of information to support evaluation of equipment environments.

The 1989 EPRI report *Guidelines for Quality Records in Electronic Media for Nuclear Facilities (NCIG-10)* (NP-6295) [39] highlights such items as retention times, media lifetime (that is, the amount of time that data will function on a particular format, such as a digital video disk), storage format, and document source. In general for a data storage project such as herein, these considerations are necessary because the data are maintained for the duration of the plant lifetime. The following should be considered:

- For data stored on a floppy disk since the 1990s, plants may no longer have machines that can read the floppy disk; therefore, if data storage technology changes during the plant lifetime, the data from this type of project are best stored in a newer format (Typically, this is no longer a concern because of the use of nuclear power plant data servers; however, the concern is noted in case servers are not in use for such data). Some nuclear plants require all software use to be identified according to information technology (IT) records at a minimum, and having IT maintain such a list can be useful as software changes occur.

- Data from the 1990s may have used a non-Microsoft Excel spreadsheet program, such as Lotus 1-2-3, that might not be compatible with current software programs. This was more of a concern in prior years; however, this is typically not a current concern because newer software programs have conversion capabilities between software brands, even to the extent that Adobe Acrobat[16] can be used to convert information into spreadsheets.
- Some monitors use vendor-specific software; discussions should occur with the vendor to determine how the software is maintained and whether that requires additional costs at a minimum. The plant may even have to consider the monitoring company viability. For example, if a monitor is chosen from a small vendor and that software already is not maintained current for operating systems software, this could mean that the software could quickly become obsolete.

These maintainability concerns are more prevalent for active monitors. Active monitors can have issues if the electronic data are not periodically updated to the latest software version (for example, temperature monitoring data in the 1990s might have been issued in software that is now obsolete).

For passive monitors, such as the Westinghouse LIFETIME monitors, these maintainability concerns are non-existent because the monitors are for one-time use and require no software.

An additional although highly unlikely event is the issuance of an NRC 10CFR21 notification regarding the monitor used. Such a Part 21 notice would require evaluation to determine whether it affects the monitoring that has been performed by the plant.

Based on the preceding considerations, for long-term operation cable aging monitoring, the following is recommended:

- For active monitors, plant engineers should be cognizant of any software changes that could affect future use of the monitoring data.
- For passive monitors, no further actions are required.

[16] *Adobe Acrobat* is a registered trademark of Adobe Systems, Inc.

7 HOST PLANT INSTALLATION STATUS

This section covers the current status of the host plant installations and the steps that have occurred to this point in time, based on the generic research as suggested in the prior sections of this report. This section includes the following sections:

- **Introduction**. This section involves background related to the decision to go forward with selection of two host plants to install temperature and radiation monitors for one fuel cycle.
- **Host Plant Selections**. This section involves how host PWR and BWR host plants[17] were selected.
- **Pre-Installation Research**. This section covers any pre-installation research performed at the host plants.
- **Work Package Development**. This section covers the work package development for installation of the monitors at the host plants.
- **Monitor Installation**. This section covers the host plant monitor installation status.
- **Data Analysis**. This section covers forthcoming data analysis from the host plant monitoring—the schedules for when the data analysis will occur.

7.1 Introduction

EPRI report 3002000816 [1] was published in 2013, in support of the current plans of operating much of the existing fleet of nuclear power plants beyond 60 yr of service, in order to conduct research to assess the condition of the existing electrical cabling infrastructure. In order to operate through a subsequent licensing period (60–80 yr of operation), plants must demonstrate that the existing cabling has adequate margins remaining that ensure safe operation. The report provided the preliminary results of an effort to collect environmental service condition data during normal plant operations in plant locations where cables were installed. Specifically, temperature and radiation data were collected so that the effects on cable insulation thermal and radiation aging could be evaluated for long-term operation.

The collection of data was inadequate to reach any conclusions on the likelihood of cables being able to perform reliably during periods of extended operation. However, the radiation and temperature monitoring data that were provided did indicate that original plant design bases radiation and temperature values may have excessive margins as compared with typical plant conditions, with exceptions typically based on stratification, reactor and containment type, and elevation.

[17] All mentions of host plants are generic in nature. No exact plant names or specific distinguishing characteristics are identified. Leaving host plants unnamed supports one of the overall goals of this pilot project—that the steps taken by the host plants are generic in nature and follow the generic guidance provided herein, to the point that other nuclear power plants can follow the same processes.

Therefore, it was concluded that a more specific research and monitoring project be undertaken to gather conclusive evidence regarding this preliminary conclusion. This report provides the status on this more specific research and monitoring. The main purpose of this phase of the pilot project was to work with both a PWR and a BWR host plant in order to monitor normal thermal and radiation environments more closely as they relate to cable ambient service conditions. The host PWR and BWR plants would follow the methodologies, processes, and steps provided generically herein for the implementation of long-term operation cable aging monitoring.

7.2 Host Plant Selections

The host step plant selection was a step process, with most, if not all, U.S. nuclear plants contacted at first in a variety of means, as follows:

- Announcements to responsible nuclear plant cable engineers and cable industry groups
- Announcements at various industry conferences, such as for cable engineers and EQ engineers and radiation monitoring conferences
- Contacting plant personnel to provide preliminary background information

The second step in the process was for the responsible nuclear plant cable engineer to identify a desire to become a host plant and to initiate internal plant discussion. Critical to the success of having a plant become a host plant is having a sponsor in senior management to champion the project.

The third step in the process, if the initial internal plant discussion was positive, was that additional background information, such as presentations, was made available from EPRI for the responsible nuclear plant cable engineer to share internally.

A fourth step in the process was to arrange a conference call with EPRI and its representatives, along with the responsible nuclear plant cable engineer and other interested internal parties, in order to receive and answer any questions as necessary.

A fifth step, as necessary, was any follow-up conference calls or e-mails in order to provide further background on the plant questions received. Most questions related to how many plant person hours were needed to perform such an activity and, besides the positive attributes of performing monitoring, whether there are any possible negative attributes or contingency plans that may be necessary. Having senior management involved was important at this point in order to overcome any obstacles.

After a period of time had passed for plants to contemplate becoming host plants, all plants that had shown interest in being host plants were categorized. These categorizations included type of reactor at plant (PWR or BWR), how far along in the host step process the plant had achieved or was going to most likely achieve, the size of the plant, and year of operation. Another consideration was the scheduling of plant refueling outages and whether the outages would support timely issuance of the project final report. These types of characteristics were necessary in order to ensure that a fair selection of characteristic host plants would be selected using an independent process.[18]

Presently, a PWR host plant has been selected. This PWR is a multi-unit plant that is greater than 1000 MW.

Presently, a BWR host plant has not been selected, because all of the steps in the aforementioned process have not been achieved by a BWR nuclear plant. Further discussions are continuing with potential BWR host plants.

Accordingly, the following sections of this report only apply to the PWR host plant.

7.3 Pre-Installation Research

7.3.1 Kick-Off and Other Meetings

Multiple on-site kickoff meetings were held over the course of several days, in order to ensure that a diverse population of plant management, engineering, maintenance, outage, license renewal, EQ, and planning personnel would have background information and the availability to ask questions regarding the EPRI project.

7.3.2 Other Department Interactions

Discussions were held with the following groups at a minimum:

- **EQ**. The EQ program was questioned regarding any prior known temperature and radiation monitoring, any current monitoring, and any potential future monitoring.
- **Planning**. A meeting was held with several planners in order for the planners to do the following:
  - Suggest any monitor locations based on any particular concerns
  - Be apprised of the upcoming outage activity of monitor installation and any particular concerns
  - Be cognizant of the ability to work together, such as to recommend suggested replacement locations (that is, from a junction box not being already opened during a refuel outage to a similar junction box that was already scheduled to be opened during a refuel outage)
- **Outage planning**. Personnel associated with the upcoming outage had meetings in order to generically discuss the installation and removal of the monitors over the course of the next several fuel cycle outages, and to ensure that this monitoring will have no impact on outage activities.

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[18] One characteristic unconsidered between EPRI and the potential host plants was any perceived plant need for temperature and radiation monitoring beyond the scope of this monitoring, particularly for long-term operation cable aging. If a potential host plant had any required internal or external commitment to perform particular monitoring, that was unknown to EPRI as part of the host plant selection and, therefore, no additional weighting factor was applied, for example, to a plant that had such a commitment.

- **License renewal**. License renewal staff was also hosted because this project provides a direct benefit to subsequent license renewal.
- **Electrical/maintenance/cable program**. Meetings were held with appropriate maintenance staff. The plant fix-it-now team, although not addressed, was included in additional discussions because it could be involved in the actual installation. The plant cable program owner was chosen as the responsible point of contact to coordinate actions with EPRI and to be the lead on this project.

In addition, any plant or utility questions regarding the monitor's use, shipping, evaluation, and so forth also included information provided by the monitor vendor. Most of these questions dealt with caveats particular to these passive monitors, the Westinghouse LIFETIME monitors, such as how to handle potential X-rays of monitors, how to store monitors on site prior to use, and so forth. Westinghouse provided assembly drawings of the monitors, an installation and service procedure, and a material certification list, along with answering of various questions.

Note that the plant procurement program or department was not involved in this project because EPRI was the procurer of the monitors and Westinghouse shipped the monitors directly to the plant's responsible engineers; accordingly, there was no plant procurement involvement needed. However, any nuclear power plant that would be performing this long-term operation cable aging monitoring itself would need to have its plant procurement group involved in such a project in order to obtain the necessary monitors.

7.3.3 Reference Documents Researched

Based on the discussions with the various plant personnel covered in the preceding section, along with things to consider as mentioned in such documents as EPRI reports NP-7399 [4] and 109619 [3], various plant documents, such as EQ environmental service conditions, were obtained. An introduction to the plant cable network database was also provided. Drawings of locations of interest were also provided, such as general arrangement and conduit.

7.4 Work Package Development

7.4.1 Procedural Usage

The host PWR plant had performed prior EQ temperature monitoring using a detailed procedure specific for the temperature monitors. However, more recently, the plant had developed a general purpose housekeeping procedure that provided for situations such as temporary monitoring. Discussions with the plant owners and users of the housekeeping procedure identified that such a procedure is acceptable for the use of these temporary and passive environmental service condition monitors; therefore, the work package was addressed under the plant housekeeping procedure requirements.

7.4.2 Work Package Development

A work package was prepared to meet the needs of the host plant. In addition to installed locations and monitors to be used, topics included the following:

- **Seismic**. Any seismic effects of the monitors' installation needed to be evaluated and have been evaluated for the particular PWR host plant. Because the monitors to be installed are passive, extremely low weight, and of minimal size, the conclusion was that no seismic concerns existed.
- **HELB jet impingement**. The PWR host identified that there was no concern related to jet impingement post-HELB.
- **NRC Generic Safety Issue GSI-191"Assessment of Debris Accumulation on Pressurized Water Reactor (PWR) Sump Performance**.**"** The PWR host identified that there was no concern related to sump performance.
- **10CFR50.59 consideration**. The host PWR plant had performed prior EQ temperature monitoring that also included the issuance of a 10CFR50.59 evaluation. However, the newer plant housekeeping procedure does not require such an evaluation and, therefore, a 10CFR50.59 evaluation was unnecessary for this particular application.

Each nuclear power plant/utility would have to follow its own internal procedures and requirements regarding how to procedurally install such monitors and the use of a 10CFR50.59 screening or evaluation.

7.5 Monitor Installation

Because the PWR host plant was a multi-unit site, it was possible to perform a walkdown of a similar unit in a prior refuel outage, in order to visually inspect potential installation locations. Areas both inside and outside containment were walked down. Photos were taken of potential installation locations.

EPRI then reviewed photographs, drawings, and plant-specific documents, had discussions with plant personnel, and compared this information with the generic information provided in Section 4 of this report.

This particular plant has performed extensive temperature monitoring periodically for the EQ program and is currently undergoing extensive temperature monitoring for the EQ program. Accordingly, an additional consideration at this particular host plant was the location of the EQ program temperature monitors in correlation with the EPRI monitoring. The EPRI team and site cable programs staff coordinated with the plant EQ Program staff with regard to monitors, to the extent that in some locations the EQ program temperature monitors were complemented by the EPRI thermal and radiation monitors. This coordination provided an additional validation point of each monitor's temperature data and ensured that both EPRI and the EQ program had temperature and radiation monitoring data for select locations. This was an unexpected and unplanned benefit particular to this specific nuclear power plant. Each nuclear power plant performing similar long-term operation monitoring for cables needs to consider such plant-specific factors as ongoing temperature and/or radiation monitoring when identifying possible installation locations.

Accordingly, EPRI suggested the installation of approximately 50 monitors as follows:

- **Inside containment**. Approximately 35 monitors. Installation locations to highlight are the following:
  - Multiple monitors near pressurizer
  - Multiple monitors above reactor head (two monitors each per four banks of cables)
  - Multiple monitors near control rod drive mechanism
  - Inside and directly outside various penetration boxes
  - Various locations from penetration to termination for reactor coolant pump cables
  - Multiple locations near pressurizer
  - Miscellaneous locations with large number of cable tray runs
- **Outside containment**. Approximately 15 monitors. Installation locations to highlight are the following:
  - Multiple outboard penetration boxes and trays associated with the same cables monitored inside containment
  - Various outside containment rooms with higher than average normal radiation conditions, such as several pipe penetration rooms and valve areas
  - Multiple monitors near main steam valve area

Redundancy and diversity were considered and included as factors in the plant monitor locations as follows: redundancy by having multiple monitors measure similar functioning cables (for example, two monitors each for four banks of cables above reactor head), diversity by both measuring various types of cables (power, control, instrumentation, EQ and non-EQ) and by measuring singular cables along an entire cable run from outside containment all of the way through containment to their end points. As previously noted, because the purpose of the monitoring was for long-term operation cable aging, the total number of monitors used is considered sufficient for a typical plant approach to this specific purpose.

Installation of monitors occurred in October 2015.

7.6 Data Analysis

This particular host PWR has an 18-month fuel cycle; accordingly, the Westinghouse LIFETIME monitors will be removed 18 months after their installation, transported to the monitor vendor (Westinghouse) for results, and then further analyzed by EPRI and the host nuclear power plant. Accordingly, the host PWR monitoring data will be available in 2017.

8
CONCLUSIONS

This report provides inputs to be used for consideration of long-term operation cable aging radiation and temperature monitoring.

A PWR host plant has been selected with monitors installed in fall 2015 using the considerations herein.

The selection of a BWR host plant is still ongoing.

Based on reviews of available industry information, the following should be considered regarding the installation of temperature and radiation monitors:

- The Westinghouse LIFETIME equipment monitor has been chosen as the suggested monitoring device for this application and been installed in the PWR host plant. Other monitors can be used according to individual nuclear power plant preference.
- A minimum of 20 monitors may be needed inside containment (PWR)/drywell (BWR), and a minimum of 20 monitors may be needed outside containment (PWR)/reactor building (BWR).
- For the host PWR plant, slightly more than 50 monitors were used, although the host plant had a plant program that had performed periodic extensive temperature monitoring and was in parallel conducting additional equipment-specific and area temperature monitoring.
- For passive monitors, a recording frequency is not required. For active monitors, a recommended frequency of at least once a day is considered acceptable (for data logger type monitors).
- A monitoring duration of between one year and one refuel cycle is considered acceptable. Because of limited containment/drywell access, a monitoring duration of one refuel cycle is recommended.
- For passive monitors, all calibration is performed by the monitor vendor. For active monitors, the following calibration factors are recommended:
  - Calibration according to a 10CFR50 Appendix B QA program
  - Acceptance criteria according to vendor recommendations
  - Calibration pre-installation and post-removal according to vendor recommendations
  - Verification during installation, if possible, according to vendor recommendations
  - Any plant-specific calibration requirements for a 10CFR50 Appendix B program

- For passive monitors, data results will be an Arrhenius equivalent weighted average temperature and a total dose. For active monitors, the following normal temperature and radiation data evaluations are recommended to occur:
  - Identification of existing design normal maximum values
  - Identification of maximum recorded data
  - Derivation of average recorded data value
  - Derivation of a histogram that uses a probability distribution function
- Data analysis and data record keeping will occur after the monitors are removed from the host plants. The conclusions of the data analysis will be presented in a final report for this pilot project.

9
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A

METHODS FOR CALCULATING NEW CABLE LIVES BASED ON MONITORING DATA

After it has been determined whether there is sufficient margin between assumed and actual parameters, the next step would be to calculate new lives. The following are suggested steps that can be used with temperature and radiation data for extending cable lives. Because such criteria are different for temperature and radiation monitoring, the remainder of this section will separate the environmental criteria.

In addition, for EQ equipment, the new monitoring data would simply be substituted into the current existing applicable EQ thermal qualified life calculations and radiation total integrated dose comparisons to the tested dose.

For non-EQ equipment, the following criteria can be considered as appropriate:

A.1 Temperature Evaluation Criteria

- **Comparing installed cable material temperatures to industry thermal aging 80-yr thresholds**. Retrieve the previously collected identification of plant cable materials. Identify the highest recorded consistent plant temperatures (If only one temperature value is a peak versus the entire year's worth of data at much lower temperatures, the peak value may be an outlier. However, if there are periodic temperatures recorded near the peak value, that peak value is more valid.) The 1996 Sandia report *Aging Management Guideline for Commercial Nuclear Power Plants—Electrical Cable and Terminations* (SAND96-0344) [40, p. 4-17] from 1996 provides a table of recommended maximum ambient temperature for a 60-yr life under purely thermal aging conditions for various cable materials. These calculations were developed using the Arrhenius equation. Calculations can be performed as shown in Table A-1 to provide 80-yr results (an example calculation is shown at the end of this appendix). Therefore, the temperature per cable material can be compared with the installed cable materials and temperatures. If the installed temperatures are lower than the values shown in Table A-1, it is confirmed that the lives of the installed cables can achieve 80-yr life based on thermal aging.

Table A-1
Recommended maximum ambient temperature for an 80-yr life under purely thermal aging conditions

Generic Material Type	Activation Energy (eV)	Basis Temperature (°C)	Life Basis Temperature (yr)	Calculated Maximum Temperature (°C)*
Chlorosulfonated polyethylene (CSPE)	1.14	80	13.5	63.99
Ethylene propylene diene monomer (EPDM)	1.35	91	40	85.23
Ethylene propylene rubber (EPR)	1.2	135	0.2	74.03
Ethylene tetrafluoroethylene (ETFE)	0.9	148	11.4	118.83
Neoprene	0.94	80	2.5	44.37
Polyvinyl chloride (PVC)	0.99	120	0.2	53.11
Silicone	1.8	136	40	130.52
Viton A	1.17	200	1.7	144.01
XLPE/cross-linked polyolefin XLPO	1.24	150	0.1	80.49

* Calculated according this specification at the end of this appendix

- **Comparing installed cable materials to more refined industry thermal aging 80-yr thresholds**. Subsequent to the issuance of SAND96-0344 [40] in 1996, EPRI report 1013475 [41, pp. B-24 and B-25] in 2007 provided a similar table (see Table A-2) for 60-yr data, for a smaller list of various insulation materials. This EPRI report included more detailed thermal aging data, because some of the data were based on vendor or test laboratory thermal aging. Therefore, these data provide justification for longer lives than the data in SAND96-0344 [40].

Table A-2
Recommended maximum ambient temperature for a 80-yr life using EPRI report 1013475 data

Generic Material Type	Activation Energy (eV)	Intercept	60-yr Service Limiting Temperature (°C)	Calculated Maximum Temperature (°C) for 80 yr*
CSPE	1.14	-11.13	75.0	72.38
EPDM	1.35	-13.16	87.2	84.83
EPR	1.1	-10.51	75.0	72.29
Neoprene	1.14	-12.53	41.7	39.56
PVC	0.99	-10.00	44.2	41.70
XLPE/XLPO	1.35	-13.19	86.6	84.24

* Calculated according to this specification at the end of this appendix

Therefore, the same methodology in Step 1 can be used in Step 2 because the Step 2 data are simply a more refined set of values typically confirming possibly higher temperatures.

- **Comparing installed cable materials to more refined industry thermal aging 80-yr thresholds**. The methods of Steps 1 and 2 can be reapplied using any additional industry information. For example, EPRI report 1021067 [2, Appendix G] provides maximum, minimum, and average activation energy data for various materials that can be potentially used in expected life calculations. The plant EQ program may also have access to industry databases that provide material aging information.
- **Comparing installed cable materials to more refined test report thermal aging 80-yr qualified lives**. This step is based on vendor-specific thermal aging data, most notably from test reports. Typically, the plant EQ program would have this information. This material specific information can only be used if the manufacturer/model cable information in the plant test report is comparable[19] to the installed plant cable materials. For example, EPRI report 106687 [27, Table V-2, p. 1-5-7, and Table II-1, p. 2-2-11] provides thermal life calculations of various cable manufacturers and materials, based on specific test data. Table V-2 provides results as expected thermal lives at 104°F (40°C), at 122°F (50°C), at 140°F (60°C), at 158°F (70°C), and at 169°F (76°C), while Table II-1 provides 40- and 60-yr life temperatures based on test thermal aging. Depending on the installed plant cable manufacturer and material type, the EPRI report data may be sufficient unto themselves. Otherwise, calculations would have to be developed to provide the maximum 80-yr temperature.

A.2 Additional Considerations for Passive Monitors

A.2.1 Westinghouse Lifetime Monitor Temperature Measurement

ITMs consist of glass solid-state track recorders that contain latent fission fragment tracks introduced into the material during manufacture. These latent tracks undergo thermal annealing while the ITMs are installed in LIFETIME monitors in the plant. Following thermal annealing in the plant, the ITMs are again exposed to the fission source. At this point, the ITM contains annealed and unannealed latent tracks. To read the ITM, these latent tracks are developed by chemical etching to a size that can be measured using an optical microscope. Based on the measured ratio of track diameters, the annealed track diameter divided by the unannealed track diameter, and the known time of exposure, an effective exposure temperature and activation energy can be determined from the calibration data. The effective exposure temperature is the Arrhenius equivalent temperature, that constant temperature over the time period of interest that produces the same effect as the actual varying temperature over the time period.

[19] The term *similar* in EQ terminology has a specific meaning and requirements; accordingly; therefore, because this specification represents a plant population of cables more encompassing than just EQ cables, the term *comparable* is used herein.

The annealing of latent tracks in an ITM is also described by an Arrhenius function of temperature using a characteristic activation energy. The combination of the seven ITM materials that are used and the amount of annealing that occurs in each ITM yields data over a broad range of activation energies typical of nuclear components. Combining the results from multiple ITMs allows the Arrhenius equivalent temperature to be plotted as a function of activation energy, which allows the Arrhenius equivalent temperature to be determined for any component regardless of its activation energy.

The EPRI EQ reference manual [2, p. E-8] provides a formula for degradation-weighted average temperature or Arrhenius equivalent temperature by applying the Arrhenius equation successively over n time intervals, t_i, with midpoint temperatures T_i, and then equating the result to the qualified life at an Arrhenius equivalent constant temperature, T_e. This process gives the following:

$$T_e = -\frac{\emptyset}{k}\left[\ln\left(\frac{1}{t_s}\sum_{i=1}^{n} t_i e^{-\emptyset/kT_i}\right)\right]^{-1} \quad \textbf{Eq. A-1}$$

Because of the nonlinear (exponential) relationship between chemical reaction rate and temperature, Te is always greater than the arithmetic or linear average. Therefore, the actual temperature history always gives more degradation than predicted on the basis of the arithmetic average temperature. The difference becomes greater as the temperature range in the actual history increases. When using an Arrhenius equivalent temperature for a general plant area or EQ zone, it is conservative to select an activation energy that is sufficiently high (for example, 2.0 eV or greater) so that it bounds the range of activation energies for the equipment in the area. This results in an Arrhenius equivalent temperature, which can be considered to be independent from the various activation energies associated with the components located in the area of interest. As seen in Table A-1, cable insulation activation energy values typically range from 0.9 to 1.8 eV.

For passive monitors, a monitored Arrhenius equivalent temperature can be used in the preceding temperature evaluation criteria steps as necessary.

A.3 Radiation Environmental Criteria (Non-Westinghouse LIFETIME Monitors)

- **Comparing installed cable material radiation dose rates to industry thermal aging 80-yr thresholds**. Retrieve the previously collected identification of plant cable materials. Identify the highest recorded consistent plant dose rate (If only one radiation dose rate value is a peak versus the entire worth of data at much lower dose rates, the peak value may be an outlier. However, if there are periodic dose rates recorded near the peak value, that peak value is more valid.) Sandia report SAND96-0344 [40, Table 4-7, p. 4-47] from 1996 provides a table of **lowest** reported threshold dose. From this value, a calculated 80-yr dose rate can be determined.

  Next, the cable materials, if possible, need to be further separated between those materials with an accident function and those without an accident function. If a cable material has an accident function, the postulated plant accident dose must be removed from the threshold before recalculating the remaining available dose to be used for an 80-yr normal dose rate.

Therefore, the SAND96-0344 [40] radiation dose rate per cable material can be compared with the installed cable materials and associated dose rate. If the installed radiation dose rates are lower than the values shown in Table A-3, it is confirmed that the lives of the installed cables can achieve 80-yr life based on radiation.

However, note that the Sandia report SAND96-0344 [40] values are based on the **lowest** material threshold and are therefore extremely overly conservative for this approach. For example, Tables A1 and A2 in IEEE 323-1974, provide an accident dose of 1.5E+08 rads for PWRs and 2.6E+07 rads for BWRs. These accident doses, without even considering the normal dose, are much higher than the thresholds shown in Table A-3. Note that these PWR and BWR accident values are based on 1-yr post-accident operating time terms and also include beta radiation. Because most plants have a post-accident operating time of 30 days or six months, and because various beta radiation reduction factors are available to substantially reduce a cable's beta radiation dosage, the actual plant terms may become much more manageable.

Table A-3
Recommended cable material 80-yr dose rate maximum values

Material Category	Material Name	Cable AMG Table 4-7 Dose (rad)	Cable AMG Maximum 80-yr Dose Rate (rad/h)*	EPRI Elec. LR Handbook Table 10-1 60-yr Limiting Dose (rad)	EPRI Elec. LR Handbook Maximum 80-yr Dose Rate (rad/h)*
Elastomers	EPR/EPDM	1.00E+06	1.43	5.00E+07	71.30
	Neoprene	1.00E+06	1.43	2.00E+06	2.85
	CSPE	5.00E+05	0.71	2.00E+06	2.85
	Nitrile (Buna N)	1.00E+06	1.43	Not identified	N/A
	Butyl	7.00E+05	1.00	5.00E+06	7.13
	Viton	1.00E+05	0.14	Not identified	N/A
	Silicone	1.00E+06	1.43	Not identified	N/A
Thermoplastics	XLPE/XLPO	1.00E+06	1.43	1.00E+08	142.60
	PVC	1.00E+05	0.14	2.00E+07	28.52
	Polyethylene	3.80E+05	0.54	2.00E+07	28.52
	ETFE (Tefzel)	1.00E+06	1.43	3.00E+07	42.78
Thermosets	Epoxy resins	2.00E+08	285.19	Not identified	N/A
	Polyimide (Kapton)	1.00E+07	14.26	2.00E+06	2.85
	Phenolic resins	3.00E+05	0.43	Not identified	N/A
	Furanic resins	3.00E+08	427.79	Not identified	N/A

Table A-3 (continued)
Recommended cable material 80-yr dose rate maximum values

Material Category	Material Name	Cable AMG Table 4-7 Dose (rad)	Cable AMG Maximum 80-yr Dose Rate (rad/h)*	EPRI Elec. LR Handbook Table 10-1 60-yr Limiting Dose (rad)	EPRI Elec. LR Handbook Maximum 80-yr Dose Rate (rad/h)*
Thermosets (continued)	Polyester resins	1.00E+05	0.14	Not identified	N/A
	Melamine formaldehyde	6.70E+06	9.55	Not identified	N/A

* Calculated according to this specification by dividing the dose by 80 yr (701,280 h)
LR = license renewal
AMG = American Wire Gauge

- **Comparing installed cable materials to more refined industry radiation dose rates**. The methods of Step 1 can be reapplied using any additional industry information. The plant EQ program may also have access to industry databases that provide material aging information.

  For example, EPRI report 1021067 [2, Appendix G] provides low, medium, and high magnitudes of material degradation based on percent property change for various materials.

- **Comparing installed cable materials to more refined test report thermal aging 80-yr qualified lives**. This step is based on vendor-specific thermal aging data, most notably from test reports. Typically, the plant EQ program would have this information.

A.4 Additional Considerations for Passive Monitors

A.4.1 Westinghouse LIFETIME Monitor Radiation Measurements

The high range gamma ray dose optical crystals have a range of 1.0E+04 rad to 1.0E+10 rads. The lower limit is the commonly accepted threshold for radiation damage to typical organic materials. The upper limit exceeds typical one-year post-accident containment doses resulting from the radioactive decay of released fission products. Westinghouse reads these optical crystals by measuring the amount of optical absorbance at wavelengths that correspond to the various color centers of interest.

The low range gamma ray dose measurement below 1.0E+05 rads is provided by TLDs. These crystals are similar to the devices commonly used in personnel dosimetry, which rely on the displacement of electrons by incident radiation, and production of corresponding holes. TLDs are read by heating the crystals and counting the thermoluminescence photons emitted when the trapped electrons and holes recombine.

The results from the Westinghouse LIFETIME monitor can be used in the same way as other radiation monitoring by determining whether there is a significant difference between the design and monitored values that could assist extending cable life to 80 yr.

Sample Calculation for Table A-1:

The data in Table A-1 were obtained from Sandia report SAND96-0344 [40, p. 4-17]. In the first row as an example, a cable with CSPE insulation had a calculated qualified life of 13.5 yr at 80°C. Using an equivalency form of the Arrhenius equation from the EPRI EQ reference manual [2, p. E-9] (see Equation A-2), the maximum temperature for an 80-yr life can be calculated as follows:

$$L_1 = L_2 e^{\left(\frac{\varphi}{k}\right)\left(\frac{1}{T_1}-\frac{1}{T_2}\right)} \quad \textbf{Eq. A-2}$$

where:

L_1 = Life (hours) at temperature T_1 (K)

L_2 = Life (hours) at temperature T_2 (K)

φ = Activation energy (eV)

k = 8.617E-5 eV/K

Solving for T_1, Equation A-2 becomes:

$$T_1 = \frac{1}{\frac{1}{T_2}+\left(\frac{k}{\varphi}\right)\ln\left(\frac{L_1}{L_2}\right)} \quad \textbf{Eq. A-3}$$

where:

L_1 = 80 yr = 701,280 h

L_2 = 13.5 yr = 118,341 h

T_2 = 80°C = 353.15 K

φ = 1.14 eV

k = 8.617E-5 eV/K

T_1=337.14 K = 63.99°C

Sample Calculation for Table A-2:

The data in Table A-2 were obtained from EPRI report 1013475 [41, pp. B-24 and B-25]. In the first row was an example, a cable with CSPE insulation had a 60-yr life of at 75°C. Using the Arrhenius equation (see Equation A-3), the maximum temperature for an 80-yr life can be calculated as follows:

$$T_1 = \frac{1}{\frac{1}{T_2} + \left(\frac{\mathrm{k}}{\varphi}\right)\ln\left(\frac{L_1}{L_2}\right)} \qquad \textbf{Eq. A-4}$$

Using the values from the example from Table A-2,

L_1 = 80 yr = 701,280 h

L_2 = 60 yr = 525,960 h

T_2 = 75°C = 348.15 K

φ = 1.14 eV

k = 8.617E-5 eV/K

T_1=345.53 K = 72.38°C

B

APPLICABLE LESSONS LEARNED FROM EPRI PILOT PLANT LIFE EXTENSION REPORT SERIES

EPRI issued in the mid- to late 1980s a series of pilot plant life extension reports that were the precursor to license renewal research. These reports were grouped into the following three types:

- Light water reactor reports (these were the initial reports of the series)
- PWR reactor reports (with the Surry nuclear plant as the lead plant)
- BWR reports (with the Monticello nuclear plant as the lead plant)

Note: The PWR and BWR report series were completed in parallel.

The reports are identified in the following lists:

- LWR reports, as follows:
  - *Review of Records Requirements Related to LWR Life Extension*. EPRI, Palo Alto, CA: 1986. NP-4926.
  - *LWR Plant Life Extension*. EPRI, Palo Alto, CA: 1986. NP-5002.
- PWR reports, as follows:
  - *PWR Pilot Plant Life Extension Study at Surry Unit 1: Phase 1*. EPRI, Palo Alto, CA: 1987. NP-5289-P
  - *PWR Pilot Plant Life Extension Study at Surry Unit 1: Phase 2*. EPRI, Palo Alto, CA: 1989 NP-6232-SD.
  - *PWR Pilot Plant Life Extension Study at Surry Unit 1: Phase 2*. EPRI report NP-6232-M, 1989.
- BWR reports, as follows:
  - *BWR Pilot Plant Life Extension Study at the Monticello Plant: Phase 1*. EPRI, Palo Alto, CA: 1987. NP-5181-M.
  - *BWR Pilot Plant Life Extension Study at the Monticello Plant: Phase 1, Volume 1: Appendices*. EPRI, Palo Alto, CA: 1987. NP-5181-SPV1.
  - *BWR Pilot Plant Life Extension Study at the Monticello Plant: Phase 1, Volume 2: Appendices*. EPRI, Palo Alto, CA: 1987. NP-5181-SPV2.
  - *BWR Pilot Plant Life Extension Study at the Monticello Plant: Interim Phase 2*. EPRI, Palo Alto, CA: 1988. NP-5836-M.
  - *BWR Pilot Plant Life Extension Study at the Monticello Plant: Interim Phase 2, Volume 1: Appendices*. EPRI, Palo Alto, CA: 1988. NP-5836-SV1.
  - *BWR Pilot Plant Life Extension Study at the Monticello Plant: Interim Phase 2, Volume 2: Appendices*. EPRI, Palo Alto, CA: 1988. NP-5836-SV2.

- *BWR Pilot Plant Life Extension Study at the Monticello Plant: Interim Phase 2, Volume 3: Appendices*. EPRI, Palo Alto, CA: 1988. NP-5836-SV3.
- *BWR Pilot Plant Life Extension Study at the Monticello Plant: Phase 2*. EPRI, Palo Alto, CA: 1989. NP-6541-M.
- *BWR Pilot Plant Life Extension Study at the Monticello Plant: Phase 2, Volume 1: Appendices*. EPRI, Palo Alto, CA: 1989. NP-6541-SDV1.
- *BWR Pilot Plant Life Extension Study at the Monticello Plant: Phase 2, Volume 2: Appendices*. EPRI, Palo Alto, CA: 1989. NP-6541-SDV2.
- *BWR Pilot Plant Life Extension Study at the Monticello Plant: Phase 2, Volume 3: Appendices*. EPRI, Palo Alto, CA: 1989. NP-6541-SDV3.

Although these reports were completed more than 25 yr ago, they do have relevance to this current EPRI project, as follows:

- Both the BWR and PWR reports contain component and structure ranking lists for the lead plants (for example, BWR: Report NP-5181M, Table 4-2; PWR: Report NP-5289, Tables 1 and 3-1). Therefore, these ranking lists can be examined by nuclear power plants to identify generic components or structures for which monitoring may prudent for subsequent license renewal. In addition, although these rankings are lengthy, a similar BWR or PWR plant can take a focused look at the top 10 or top 25 items, for example, to ensure that they have monitoring coverage at such locations as deemed necessary.
- The BWR and PWR reports contain temperature and radiation monitoring location tables (for example, BWR: Report NP-6541-SDV2, Table 1; PWR: Report NP-6232-SD, Section D, Attachment A). When a similar BWR or PWR determines the need for monitoring, these lead plant monitoring location lists can be used for historical comparison. Note that the number of proposed lead plant monitors from 25 yr ago can differ from any other similar BWR or PWR current or future monitoring practice.
- The PWR reports have a series of tables providing inside and outside containment heat sources (PWR: Report NP-6232-SD, Tables 1 and G-2). For similar PWR plants these heat sources can be generically considered when placing monitors (and possibly to a smaller extent be considered for BWRs as applicable).
- The PWR reports have an outside containment cable concentration table—that is, where were the locations where the most cables were run—PWR: Report NP-5289, Table 5-20, Report NP-6232-SD, Section G, Attachment A). For similar PWR plants these cable runs can be generically considered when placing monitors (and possibly to a smaller extent be considered for BWRs as applicable).
- There is some generic cable information in the reports on lead plant cable types and typical applications (BWR: Report NP-5836-V2, Appendix N, Table 3-1) and insulation and jacket materials (BWR: Report NP-5836-V2, Appendix N, Table 5-1, Report NP-5836-M, Table 3.13-2) that may be useful, although more recent information is available in the many related EPRI reports published subsequently and cited herein.

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