



Designation: E1214 – 11^{ε1}

Standard Guide for Use of Melt Wire Temperature Monitors for Reactor Vessel Surveillance¹

This standard is issued under the fixed designation E1214; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

^{ε1} NOTE—The title of this guide and the Referenced Documents were updated editorially in May 2017.

1. Scope

1.1 This guide describes the application of melt wire temperature monitors and their use for reactor vessel surveillance of light-water power reactors as called for in Practices **E185** and **E2215**.

1.2 The purpose of this guide is to recommend the selection and use of the common melt wire technique where the correspondence between melting temperature and composition of different alloys is used as a passive temperature monitor. Guidelines are provided for the selection and calibration of monitor materials; design, fabrication, and assembly of monitor and container; post-irradiation examinations; interpretation of the results; and estimation of uncertainties.

1.3 The values stated in SI units are to be regarded as standard. The values given in parentheses are mathematical conversions to inch-pound units that are provided for information only and are not considered standard.

1.4 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use. (See **Note 1**.)*

1.5 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

¹ This guide is under the jurisdiction of ASTM Committee **E10** on Nuclear Technology and Applications and is the direct responsibility of Subcommittee **E10.02** on Behavior and Use of Nuclear Structural Materials.

Current edition approved July 1, 2011. Published September 2011. Originally approved in 1987. Last previous edition approved in 2006 as E1214–06. DOI: 10.1520/E1214-11E01.

2. Referenced Documents

2.1 *ASTM Standards*:²

- E185** Practice for Design of Surveillance Programs for Light-Water Moderated Nuclear Power Reactor Vessels
- E706** Master Matrix for Light-Water Reactor Pressure Vessel Surveillance Standards
- E794** Test Method for Melting And Crystallization Temperatures By Thermal Analysis
- E900** Guide for Predicting Radiation-Induced Transition Temperature Shift in Reactor Vessel Materials
- E2215** Practice for Evaluation of Surveillance Capsules from Light-Water Moderated Nuclear Power Reactor Vessels

3. Significance and Use

3.1 Temperature monitors are used in surveillance capsules in accordance with Practice **E2215** to estimate the maximum value of the surveillance specimen irradiation temperature. Temperature monitors are needed to give evidence of overheating of surveillance specimens beyond the expected temperature. Because overheating causes a reduction in the amount of neutron radiation damage to the surveillance specimens, this overheating could result in a change in the measured properties of the surveillance specimens that would lead to an unconservative prediction of damage to the reactor vessel material.

3.2 The magnitude of the reduction of radiation damage with overheating depends on the composition of the material and time at temperature. Guide **E900** provides an accepted method for quantifying the temperature effect. Because the evidence from melt wire monitors gives no indication of the duration of overheating above the expected temperature as

² For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

indicated by melting of the monitor, the significance of overheating events cannot be quantified on the basis of temperature monitors alone. Indication of overheating does serve to alert the user of the data to further evaluate the irradiation temperature exposure history of the surveillance capsule.

3.3 This guide is included in Master Matrix **E706** that relates several standards used for irradiation surveillance of light water reactor vessel materials. It is intended primarily to amplify the requirements of Practice **E185** in the design of temperature monitors for the surveillance program. It may also be used in conjunction with Practice **E2215** to evaluate the post-irradiation test measurements.

4. Selection and Calibration of Monitor Materials

4.1 Selection of Monitor Materials:

4.1.1 Materials selected for temperature monitors shall possess unique melting temperatures. Since composition, and particularly the presence of impurities, strongly influence melting temperature, the fabricated monitor materials shall consist of either metals of purity 99.9 % or greater or eutectic alloys such that the measured melting temperature is within $\pm 3^{\circ}\text{C}$ ($\pm 5^{\circ}\text{F}$) of the recognized melting temperature. Transmutation-induced changes of the monitor materials suggested in 4.1.2 are not considered significant for fluence exposures up to 1×10^{20} n/cm² ($E > 1$ MeV) relative to the goal of these temperature monitors in flagging deviations from expected temperatures.

4.1.2 The monitor materials in **Table 1** provide temperature indications in the range of 266 to 327°C (511 to 621°F). Other metals or alloys may be selected for the temperatures of interest provided the monitor materials meet the technical requirements of this guide.

4.1.3 The chosen monitor materials shall be carefully evaluated for radiological health hazards.

NOTE 1—It is beyond the scope of this guide to provide safety and health criteria, and the user is cautioned to seek further guidance.

4.2 *Calibration of Monitor Materials*— Each lot of monitor materials shall be calibrated by melting tests to establish the actual melting temperatures. The melting temperature tests shall be conducted in accordance with Test Method **E794**. If an alternate method of calibration is used, the procedure and equipment must be described, the resultant mean values and uncertainties must be reported, and traceability to standards must be declared.

TABLE 1 Monitor Material Melting Temperatures

Monitor Material, Weight %	Melting Temperature, °C	Melting Temperature, °F
Cd-17.4 Zn	266	511
Au-20.0 Sn	280	536
Pb-5.0 Ag-5.0 Sn	292	558
Pb-2.5 Ag	304	579
Pb-1.5 Ag-1.0 Sn	309	588
Pb-1.75 Ag-0.75 Sn	310	590
Cd-1.2 Cu	314	597
Cd	321	610
Pb	327	621

5. Design, Fabrication, and Assembly of Monitor and Container

5.1 The design of the monitor and its container shall ensure that the maximum temperature of the surveillance specimens is determined within $\pm 10^{\circ}\text{C}$ ($\pm 18^{\circ}\text{F}$).

5.2 The design shall provide for a minimum of one set of monitors for each surveillance capsule. Additional sets of monitors are recommended to characterize the in-service axial temperature profiles necessary to determine the maximum temperature of each surveillance specimen.

5.3 The design of the monitor and its container shall ensure that the monitor will readily sense the environmental temperature of the surveillance specimens and yet not be subject to any influences from fabrication or assembly or even post-service examination. The monitors typically consist of melt wires positioned adjacent to or among the surveillance specimens.

5.4 The quantity of monitors within each set shall be adequate to identify any temperature excursion of 10°C (18°F) up to the highest potential temperature, such as 330°C (626°F). It is recommended that monitors be selected to measure temperature at intervals of 5 to 12°C (9 to 22°F). At least one monitor shall remain intact throughout the service life; therefore the highest temperature monitor shall possess a melting temperature greater than the highest anticipated temperature.

5.5 Fabrication and assembly of the monitors and containers shall protect and maintain the integrity of each temperature monitor and its ability to respond by melting at the environmental temperature of the surveillance specimens corresponding to the monitors' melting temperature. The monitors and containers shall be designed, fabricated and assembled to ensure that the monitors melt at a temperature within $\pm 3^{\circ}\text{C}$ (5°F) of the environmental temperature of the specimens.

5.6 Identification of each monitor, its material and melting temperature, and its orientation and location in the surveillance capsule shall be maintained. Provision for means of verification shall be done by design.

6. Post-Irradiation Examination

6.1 Following irradiation, the temperature monitors shall be examined for evidence of melting to establish the maximum exposure temperature of the encapsulated surveillance specimens. Precautions should be taken while recovering the monitors from the surveillance capsule and during subsequent examination.

6.1.1 The monitor design and method of encapsulation shall be considered in the recovery procedure to ensure that the monitors are not damaged and that the original identity of individual monitors and their location is maintained.

6.1.2 Recovery and examination of the monitors should be performed remotely or with sufficient shielding to protect the operator from unnecessary radiation exposure.

6.2 Evaluation of the temperature monitors after service for evidence of melting should be performed using suitable equipment that is dependent on the design of the monitor container and the examination facility. When visual inspection of the monitors is possible, such as with periscopes, each monitor

shall be examined and the results recorded. When possible, photographic records should be made of each monitor or set of monitors. When visual inspection is not practical or conclusive, radiography or metallographic examination may be necessary. Destructive examination should be performed only if further confirmation of the melting temperature is necessary.

6.3 The monitors shall be evaluated on the following basis:

6.3.1 *Unmelted*—No evidence of melting of any portion of the monitor.

6.3.2 *Partially Melted*—Any evidence of any melting of any portion of the monitor.

6.3.3 *Fully Melted*—Evidence that the entire monitor was subject to melting.

6.4 If there is reason to question the results, monitors should be reevaluated after completion of the post-irradiation examination to ensure that there was no change in the melting temperature. This verification of melting temperature may be performed as described in 4.2.

7. Interpretation

7.1 The design of the melt wire configuration should prevent ambiguities as to incipient melting. However, there may be circumstances where melting is questionable. Change in shape, slumping, and segmenting are indications of melting. When initial examination results are uncertain, this shall be documented. Further nondestructive and destructive examinations may be performed if warranted to verify the condition of the monitor.

7.2 The condition of the monitors should be consistent according to axial position and expected relative temperatures.

7.3 The range of possible maximum service temperatures of the surveillance specimen shall be estimated and documented, based upon the indications provided by the temperature monitors. The temperature estimate should consider the design of the monitor and container, the location of specimens relative to the monitors, and potential temperature gradients.

7.4 Discrepancies between the temperature monitor results and historical service conditions shall be assessed and described.

8. Estimation of Uncertainties

8.1 Uncertainties arise from limitations in precision and bias in determining the initial melting temperatures of each monitor,

the ability of the monitor to accurately indicate the environmental temperature, the relationship in temperature between the monitors and the specimens, and the bias in discriminating melting.

8.2 All known and estimated uncertainties, including a description of their determination, shall be reported with the estimated maximum exposure temperatures.

8.3 Uncertainties resulting from unresolved ambiguities shall be described. Probable causes and subsequent implications should be stated.

9. Report

9.1 In addition to the reporting requirements of Practices E185 and E2215, the following information shall be reported:

9.1.1 Description of the temperature monitors including chemical composition of the monitor melt wires and their respective melting temperatures with uncertainties, container design, identification, and location in the irradiation capsule.

9.1.2 Results of the post-service evaluation in which each monitor condition is characterized as unmelted, partially melted, or fully melted.

9.1.3 The estimated maximum exposure temperature range of the surveillance specimens and the associated uncertainties.

9.1.4 The agreement between the temperature monitor results and the historical service conditions and description of any anomalies found while recovering, examining, or evaluating the monitors.

9.1.5 Results of any additional examinations, if performed, to resolve inconsistent monitor results.

9.2 The following additional documentation should be reported if available:

9.2.1 Photographs of each irradiated temperature monitor that document the visual observations.

9.2.2 Preirradiation test results used to certify the melting temperatures of each monitor type.

9.2.3 Test results, if performed, verifying post-irradiation melting temperature for each monitor.

10. Keywords

10.1 nuclear reactor vessels; neutron irradiation; surveillance (of nuclear reactor vessels)

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