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ASTM Standards for Reactor Dosimetry and Pressure Vessel Surveillance²

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ABSTRACT: The ASTM standards provide guidance and instruction on how to field and interpret reactor dosimetry. They provide a roadmap towards understanding the current "state-of-the-art" in reactor dosimetry, as reflected by the technical community. The consensus basis to the ASTM standards assures the user of an unbiased presentation of technical procedures and interpretations of the measurements. Some insight into the types of standards and the way in which they are organized can assist one in using them in an expeditious manner. Two example are presented to help orient new users to the breadth and interrelationship between the ASTM nuclear metrology standards. One example involves the testing of a new "widget" to verify the radiation hardness. The second example involves quantifying the radiation damage at a pressure vessel critical weld location through surveillance dosimetry and calculation.

KEYWORDS: Dosimetry, standards, guide, practice, test method, ASTM, "how to", PV Surveillance

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INTRODUCTION

The American Society for Testing and Materials has been promoting technical standards for over one hundred years. During the centennial celebration many of ASTM's customers expressed their appreciation [1] for the support it provides in the areas of reactor technology and energy research. The role of the ASTM E-10 committee is to promote standards in the area of Nuclear Technology while the E10.05 subcommittee has the mission to develop standards in the area of Nuclear Radiation Metrology. Four different types

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of standards are produced: Test Methods, Practices, Guides, and Matrix Standards. These different types of standards cover the range from a prescriptive test method to very general guide which suggests an approach to a technical area. What distinguishes the ASTM standards is that they represent a "consensus" of the technical community. The standards are formulated by a committee with technical expertise and a balanced membership. A "consensus" must be reached before a standard can be endorsed.

The ASTM standards on nuclear metrology are intended to be a roadmap towards understanding the current "state-of-the-art" as reflected by the technical community. As with any navigational aid, the utility of this roadmap is greatly enhanced if one is trained or experienced in its use. The purpose of this paper is to describe the landscape covered by the ASTM standards on neutron metrology and to introduce some of the landmark standards which can help orient the novice user to the landscape.

The relevant nuclear metrology standards can be configured in different ways to support users coming from different perspectives. One of the best ways to gain a familiarity with a navigational tool is to use it on a training course. Towards this end, this paper will use two training examples to try to describe the organization of the standards. The first example is a researcher testing a new widget in a research reactor environment in order to determine and if it is susceptible to radiation damage. The second example is nuclear power utility trying to predict the radiation damage to a critical weld in a reactor pressure vessel. This second example presents a very complex terrain. In this talk we will examine this second case from two perspectives: from a top-down approach where we start with the general orientation provided by the E706 matrix standard on pressure vessel surveillance standards and then follow the guidance to the specifics detailed in the lower level test methods and practices; and from a bottom/up perspective where we start by identifying the standards which quantify the nuclear environment at the critical weld and then proceed to find the current technical consensus on how to relate this neutron environment to a pressure vessel damage metric.

The standard walk-thru as demonstrated in these two examples should serve to orient the new user to the breadth and interrelationship between the ASTM nuclear metrology standards. The standards development activity provides a fundamental support to the nuclear metrology community. Users of the standards should not only look to the standards for guidance nuclear metrology, but they should join their local standards societies and contribute towards the development of new standards in area where they have technical expertise and assist in the updating of the current standards so that they continue to reflect the state-of-the art and represent a true technical consensus.

U.S. Standards on Nuclear Technology

Several organizations within the U.S. assist in the development of standards within the generic area of "Nuclear Technology". These organization include the ASTM, American National Standards Institute (ANSI), American Nuclear Society (ANS), IEEE, and ASME among others. These standards organization generally cooperate in the area of standards development and avoid duplication of effort. Due to the interests and expertise of each organization patterns have developed in the responsibility for development of standards in a particular topical area. The ANS, for example, tends to take responsibility for standards in

the areas of nuclear criticality and radiation protection. The ASTM has tended to take responsibility for the development of standards relating to LWR pressure vessel surveillance. ANSI is the official U.S. voice in the international standards community. ANSI frequently adopts standards developed by the other organizations. ISO is the international standards organization.

Several different ASTM committees are involved with the development of nuclear standards. The committee most directly involved with LWR pressure vessel surveillance is E10, on Nuclear Technology and Application. Other committees have related standards. C26, for example takes responsibility for standards on the nuclear fuel cycle. Within E10 subcommittee E10.05 takes responsibility for the standards relating to Nuclear Radiation Metrology; E10.02 has responsibility for the Behavior and Use of Nuclear Structural Materials; E10.03 has responsibility for Radiological Protection for Decontamination and Decommissioning of Nuclear Facilities and Components, E10.07 has responsibility for Radiation Dosimetry for Radiation Effects on Materials and Devices, and E10.08 takes responsibility for standards on Neutron Radiation Damage Simulation. These different subcommittees weave a web of expertise which form the technical underpinning for the current U. S. position on LWR pressure vessel surveillance. The standards organization do not function in a regulatory role. Within the U.S. the regulatory authority is contained within the Nuclear Regulatory Agency (NRC). The ASTM and other nuclear standards organizations just provide the "community consensus" technical foundation which can be drawn upon by the regulatory bodies.

Organization of ASTM Standards for Pressure Vessel Surveillance

Even when one limits his scope to the ASTM, just one of the U.S. standards organizations, the web of interlocking standard guides, practices and methods can be very confusing to the user. One purpose for this paper is to try and shed some light on how the ASTM standards on pressure vessel surveillance are organized and how the user can navigate this web to support his needs.

One approach to understanding the interrelationships between the standards is to categorize them. Several different categorization schemes are possible. One useful categorization¹ is to divide the relevant standards in three general areas with the indicated subcategories:

- environmental characterization (E)
 - measurements (m)
 - calculation (c)
 - interpretation of radiation exposure (i)
- materials effects (M)
 - test methods to establish material properties (p)
 - supporting standards (s)
- correlation of material effects and environmental characterization (C)
 - design of tests (d)

1. Proposed by P. Lippincott and documented in E10.05 Minutes from the June 1999 meeting in Seattle WA.

- interpretation of tests (i)

Another useful categorization is by the type of standard; a test method, practice, or a guide. A concise way to differentiate between the three types of standards¹ is:

Guide (G) - A compendium of information which does not recommend a specific course of action

Practice (P) - A definitive set of instructions for performing one or more specific operations that does not produce a test result.

Test Method (T) - A definitive procedure that does produce a test result.

Another type of standard includes a master matrix standard (X), a reference or guide to the preparation, revision, and use of a series of standards with respect to a particular application. There also exist standard specifications (S) and standard terminology (D) standards.

How to Use Standards

A user often first seeks help from the standards when he is new to a technical area and is trying to tackle his first major project. If he is persistent in the endeavor and successful in navigating the Book of Standards he will have acquired a tool which he will use repeatedly throughout his professional career. The initial encounter with standards can be very intimidating to the unprepared novice. One purpose of this paper is to orient the new user to the ASTM standards and to make his next encounter less intimidating.

When you are faced with the intimidating array of standards and are searching for specific guidance on a narrow topic, one approach is to do a keyword search of the standards to locate the ones most relevant to your objective. Standards are listed by subject in the beginning of each volume of standards and an index of keyword appears at the end of each volume. The most important volume for reactor metrology is Volume 12.02 [3]. A more general keyword search can also be performed at the ASTM website.

When beginning a search for relevant standards particular attention should be given to the type of standard where you begin your investigation. Matrix standards and guides will provide the most general perspective from which to narrow your attention to the specific topic of concern.

Once you have a starting point within the standards system, the "Referenced Documents" section of the standard will provide a good cross reference to other relevant ASTM standards, standards by other standards bodies, and other general reference documents such as the International Commission on Radiation Units and Measurements (ICRU) reports. Finding the proper standards is only part of the task. After locating the relevant standard the reader needs to digest the material and ensure that he/she has understood how to implement the recommended procedure. The "Reference" section at the end of every standard provides a citation of general technical reports that form the basis for the consensus-based practice or test method. This material will typically detail the rationale for the recommended procedure and document/validate the procedure for benchmark problems.

1. Proposed by F. Quinzi in summary of the authoritative definitions provided in Reference [2].

Example Applications of ASTM Standards

Searching the ASTM standards gets easier as you gain experience with the procedure. As an introduction to the standards the following two sections pose a problem and show how the standards can provide guidance in the search for the proper nuclear metrology technique. The ASTM standards do

Widget Testing in a Research Reactor

The first example is an inventor who has just developed a brand new “widget”. The widget could be a gauge that can be used as an in-core reactor sensor, an electronics component for a satellite, or an accident sensor for use as a nuclear criticality alarm. What these new “widgets” have in common is their need to survive in a radiation environment. The inventors dilemma is to certify the “widget” survival in the radiation environment so that it can satisfy the customer vulnerability concerns. To begin the search the researcher needs to select a keyword. The best starting point is the damage metric of interest, e.g. 1-MeV(Si) displacement damage, ionizing dose, or thermal neutron flux. Suppose that the selected metric of concern is the 1-MeV(Si) equivalent displacement damage fluence. A keyword search immediate locates Practice E722 on Characterizing Neutron Energy Fluence Spectra in Terms of an Equivalent Monoenergetic Neutron Fluence for Radiation Hardness Testing of Electronics and Practice E1854 on Ensuring Test Consistency in Neutron Displacement Damage of Electronic Parts. A check of standards cross referenced in these two standards highlights E496 on the use of DT neutron sources, E264 on monitoring fast neutron fluence, and E1855 on the use of transistors as displacement monitors. Figure 1 shows a hierarchical view of how these and other relevant cross referenced standards are related.

FIGURE 1. Some Relevant Standards for Widget Testing to Radiation

Figure 1 also shows some starting points where alternate damage metrics would have led. Some standards highlighted by the cross reference address the simulation of displacement damage with charged particles.

After this hierarchy of standards is uncovered by the researcher, he is better able to proceed to plan and execute a test protocol. Practice E1854 provides all the cautions and details the roles of parties when reactor testing is performed with displacement damage as the metric of interest. If the “widget” survival specification is appropriate then the E1855 Test Method on the use of 2N2222 transistors provides a direct metric of the test environment. If this dosimeter cannot be used, then standards E721, E722, E720, and E264 describe how to monitor an irradiation with an activation foil, how to characterize the neutron spectrum in the test field relative the selected monitor foil, and how to relate the spectrum and monitor foil activation to a 1-MeV(Si) equivalent fluence. Executing the test is not a trivial matter, but the inventor now has a roadmap which details how to proceed to verify the survival of his “widget” to the radiation environment.

Prediction of Radiation Damage in Pressure Vessel Weld

For the second example we address the nuclear power plant analyst who is trying to determine a procedure to validate compliance of his light water reactor (LWR) pressure vessel (PV) to Criterion 31 of 10CFR50, fracture prevention of reactor coolant boundaries. A keyword search finds many relevant ASTM standards, but the E706 Matrix Standard should stand out to the analyst just because it is a matrix standard. Figure 2 shows how, for purposes of validating compliance with the pressure vessel embrittlement requirements, various standards highlighted in the keyword search and in the E706 cross reference section are related.

FIGURE 2. Some Relevant Standards for RPV Surveillance Damage

We have to assume that the power plant analyst has some background on the regulatory requirements and the physics of the damage process before he searches the standards [4]. The CFR regulations require that the boundary, the pressure vessel, behave in a non-brittle manner. Non-brittle behavior is defined in terms of the nil-ductility transition temperature (NDTT) as measured by the drop weight test detailed in Test Method E208. The fracture toughness is defined as the lower bound of the region where the stress field around commonly observed flaws can propagate (crack initiation). The damage analysis must reflect the effects of radiation on the material properties. Fast neutron displacement damage has been correlated with a shift in the nil-ductility transition (NDT) temperature for materials. Several methods are available to establish the fracture toughness of PV materials, see Test Method E399, but since the size of samples is too large to place material samples within most reactors. Consequently procedures have been established to relate the reference temperature for NDT as determined by the drop test to the Charpy impact test (E23, E900 and E1253). Power plants use a surveillance program with test specimen of the PV material to ensure that the properties of their PV materials under radiation are sufficient to comply with the Criterion 31. The surveillance capsules are placed close to the core so that they are irradiated more intensely than the PV. The behavior of the surveillance capsule test samples is then related to the cumulative neutron fluence seen at critical locations of the PV. This procedure is used to determine the remaining lifetime for the pressure vessel.

The process of proving to a regulatory agency compliance with the Criterion 31 of 10CFR50 can seem appear to the analyst to be an inquisition. The ASTM standards provide guidelines on how to prepare for and execute the dosimetry needed to support the community-consensus approach to estimating the PV damage metric at the 1/4T location and to determine the remaining PV lifetime. Even with guidance from the standards this process of demonstrating compliance can be tedious, complex, and time-consuming.

A review of the E706 Master Matrix guidance provides a top-down perspective on the PV damage determination. Standardized procedures for conducting the surveillance program are detailed in Practice E185, Conducting Surveillance Tests for LW Cooled Nuclear Power Reactor Vessels, and compliance with certain editions of this standard is required by Appendix H of 10CFR50. By reference to other standards E185 provides detailed guidance on the surveillance process. practice E853, Analysis and Interpretation of LWR Surveillance Results, details the how to use the results of the surveillance program. Guide E900, Predicting Neutron Radiation Damage to Reactor Vessel Materials, describes how to predict the radiation-induce shifts in the reference transition temperature based on the chemistry factor the material, the irradiation temperature, and the neutron fluence.

It is useful to also consider a bottom-up analysis of the standards role as detailed in the E706 Master Matrix. From a detailed perspective Guide E844 describes the design of a sensor set for irradiation in the surveillance capsule with respect towards providing a experimental reaction rates to characterize the neutron spectrum at this location. Guide E482 describes the use of radiation transport methods to calculate the neutron spectrum at the surveillance capsule and at the critical PV weld locations. Guide E944 describes how to use the reaction rate measurements to adjust the calculated spectrum and obtain the "best estimate" of the neutron fluence at the critical locations. Practice E693 describes how to convert the neutron fluence into an iron dpa which physics considerations indicates will provide the best correlation with material embrittlement.

The underpinnings of the neutron spectrum characterization is also detailed in the E706 master Matrix. Guide E2006 describes guidance on the benchmark testing of LWR calculation and describes the benchmark experiments which form the foundation for the consensus approach. Guide E2005 describes the benchmark testing of the basic dosimetry which has been conducted in standard and reference fields (such as the ^{252}Cf and ^{235}U thermal fission fields) and is an underpinning for the spectrum characterization of the LWR experimental testbeds.

CONCLUSION

This paper has tried to introduce the reader to the scope, breadth, and in particular the utility of the ASTM standards for reactor dosimetry. These standards reflect a community-consensus on the reactor dosimetry and should be an important resource for guidance for the new as well as the experienced metrologist. Two examples have been provided to illustrate ways to find and navigate the standards of interest to the user. These examples were selected as items felt to be of interest to the general audience at this meeting and because they illustrated the breadth and power of the existing standards database. Standards may not exist to address every issue of interest to members of this audience. If a standard does not exist in a mature area where you see a need and where you have expertise, please contact the relevant ASTM subcommittee and help us to see that a proper standard is prepared. The ASTM standards are consensus-based. I encourage all members of this symposium to become active in supporting and maintaining these standards. We need your participation to continue to ensure that the standards reflect the changing state-of-the-art in the reactor dosimetry community.

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