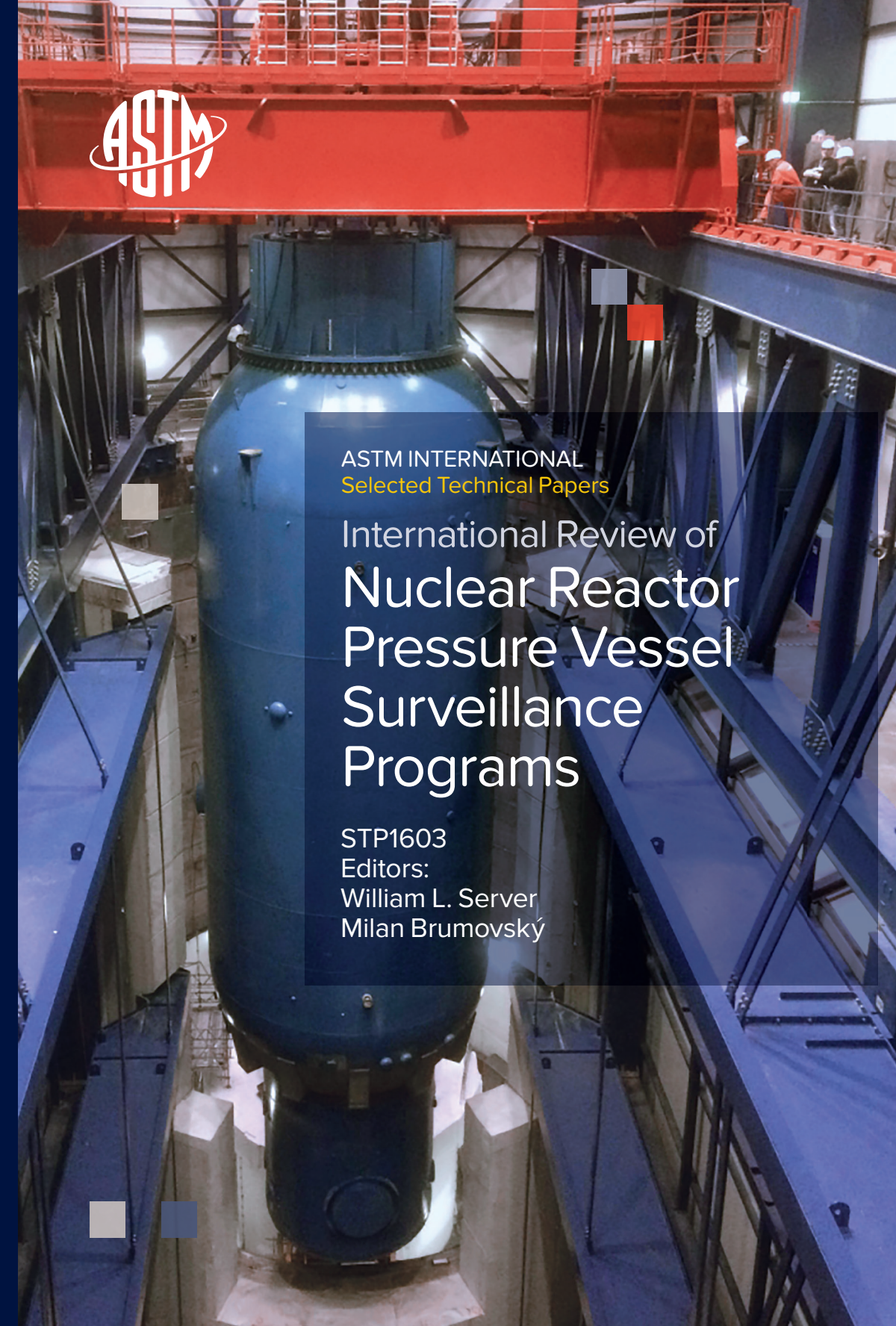

ASTM INTERNATIONAL
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International Review of Nuclear Reactor Pressure Vessel Surveillance Programs

STP1603
Editors:
William L. Server
Milan Brumovský

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Foreword

THIS COMPILATION OF Selected Technical Papers, STP1603, *International Review of Nuclear Reactor Pressure Vessel Surveillance Programs*, contains peer-reviewed papers that were presented at a workshop held June 29, 2016, in Chicago, Illinois, USA. The workshop was sponsored by ASTM International Committee E10 on Nuclear Technology and Applications, and Subcommittee E10.02 on Behavior and Use of Nuclear Structural Materials.

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Overview

The reactor pressure vessel (RPV) is generally considered to be the most important component in a nuclear power plant in terms of safety and overall structural integrity. An RPV is not considered to be a replaceable component, and, thus, the monitoring of the material toughness properties during long-term operation is of crucial importance. RPV surveillance programs are almost always applied for such monitoring, and the design of the capsules, operations to install and remove capsules, and testing of irradiated specimens is governed by international/national codes and standards and can differ between individual reactor designs, as well as requirements/methodologies used in different countries. Results from testing actual RPV material specimens irradiated in the surveillance capsules serve to the assessment of current and future degradation levels of RPV material toughness properties. Thus, the surveillance program results provide needed input for RPV integrity evaluations and future operating lifetime determination.

A special publication dealing only with RPV surveillance programs was initiated by the Metal Properties Council of the USA and prepared by L. E. Steele and C. Z. Serpan, Jr. This very detailed survey was published in 1970 in ASTM STP481, *Analysis of Reactor Vessel Radiation Effects Surveillance Programs*. This publication explains in six chapters the effects of radiation on vessel materials, describes the surveillance programs for commercial reactors, (as well as for army type reactors), reviews existing experience through the 1960s, and provides some recommendations.

A related publication, ASTM STP784, *Status of USA Nuclear Reactor Pressure Vessel Surveillance for Radiation Effects*, was issued in 1983 under the editing of L. E. Steele. This publication contained papers prepared by different authors describing in detail individual RPV surveillance programs for the different types of reactors designed and manufactured in the USA.

Results on design and testing of RPV surveillance programs were presented in many technical meetings concentrated on radiation effects in reactor materials. Primarily there were bi-annual ASTM symposia on *Irradiation Effects in Structural Materials and Alloys* beginning in 1960 and then published as separate ASTM STPs. Simultaneously, workshops on *Irradiation Effects in Reactor Pressure Vessel Steels* (or similar titles) were irregularly conducted in four- to five-year time intervals organized by the International Atomic Energy Agency (IAEA) in different countries and generally published as IAEA-TECDOC reports.

A recent initiative to summarize the progress in RPV surveillance programs was conducted in an international workshop on *RPV Embrittlement and Surveillance Programmes* organized by UJV Řež on October 13–15, 2015 in Prague, Czech Republic. The presentations from this workshop provided an impetus for further international collaboration to produce a more focused workshop and publication devoted to an update on world-wide RPV surveillance programs.

Consequently, under the auspices of ASTM Subcommittee E10.02 on Behavior and Use of Nuclear Structural Materials, a *Workshop on Nuclear Reactor Pressure Vessel Surveillance Programs* was held on June 29, 2016 in Chicago, IL, USA. The main objective of the workshop was to document the international knowledge and experience gained from current surveillance programs. This experience includes actual surveillance capsule testing and associated results, applications for evaluating the irradiated material toughness results, and identification of problem areas identified from conducting the international surveillance programs. The workshop was organized in such a way that invited presenters would cover all light water reactors (LWRs) operated in the world. These LWRs include pressurized water reactors (PWRs) and boiling water reactors (BWRs) that were designed and manufactured following the essence or slightly modified versions of the ASME Boiler and Pressure Vessel Code and Water-Water-Energy-Reactors (WWERs) similar to PWR but designed and manufactured according to Russian rules and standards. Papers that have been derived from the detailed presentations from this workshop are now included in this ASTM STP1603.

Together 24 technical papers are divided into 5 categories for ASTM STP1603:

1) Bases for RPV Surveillance Programs (4 papers)
   The requirements for design and operation of RPV surveillance programs are described as they were developed in conjunction with the individual reactor designs. The knowledge and possibilities at the time of initial design and manufacturing were somewhat fixed, but codes and standards continuously evolved developing to cover the latest developments in radiation damage in RPV materials. The surveillance program approach between PWR/BWR and WWER designs used different standards and requirements. The main differences between PWR/BWR and WWER programs are in the values of lead factor, use of static fracture toughness specimens, and utilization of thermal ageing specimens. A comprehensive overview of neutron and thermal embrittlement in reactor pressure vessel materials serves as fundamental support for surveillance program existence and design, including modern methods of characterization of vessel materials degradation.

2) Neutron Dosimetry for Surveillance Programs (2 papers)
   Neutron dosimetry is the non-separable part of all surveillance specimen programs since it is mandatory to determine the most important irradiation parameter neutron fluence. The main principles and procedures are presented for the two different surveillance programs for PWRs and for WWERs. Even

though both LWR methodologies are practically identical (using the same ASTM standards), their numerical results are quite different. The key difference is the neutron fluence characterization for the two dosimetry approaches in setting the neutron threshold energy: 1 MeV for PWRs and BWRs while 0.5 MeV for all WWERs. This difference which was selected in the beginning of reactor design makes comparison of material neutron embrittlement very complicated or even impossible although general conversions are often used for convenience.

3) National Surveillance Programs (12 papers)
The papers in this category describe unique and special differences between surveillance programs conducted in individual countries, depending on the reactor design organization and national codes and standards. Papers covering almost all LWR operating countries from the USA, Europe (France, Germany, UK, Spain, Sweden, Belgium) and Asia (Japan, Korea) are included as well as two other papers describing surveillance programs for all WWER models, both 440 and 1000 types. The main principles for the surveillance program design and methodology for testing the surveillance specimens are described, as well as some typical results which can depend on national codes. Problems with adjusting surveillance programs for license renewal and long-term operation are identified.

4) Surveillance for Long-Term Operation (2 papers)
Long-Term Operation (LTO) of operating reactors from the typical 40 years of operation to more than 60–80 years creates new problems for any changes and/or organization of existing surveillance programs. There can be the need to design/modify and insert new capsules with the aim to obtain key information about behavior of RPV materials after irradiation at neutron fluences beyond the original design. Approaches used in the USA and Europe are described in the papers. One simple way is to delay the removal of some surveillance capsules to a later time to obtain higher fluences. Another way is use of an integrated surveillance program (ISP) and/or a supplemental surveillance program (SSP) using irradiation of many materials realized in one or more reactors using archive materials or reconstitution of already tested surveillance specimens and reinserting them in a new capsule.

5) Experience from Surveillance Programs (4 papers)
The main experience and important lessons learned from surveillance programs are analyzed and delineated. The issues identified can be compared to the original capsule design and potential application for the reactor pressure vessel assessment of integrity and long-term operation. Emphasis is given to the special work done by ASTM E10.02 for the development of the embrittlement trend curve (ETC) in ASTM E900-16 in which all available PWR and BWR results from the USA and elsewhere were compiled, analyzed and a new ETC proposed. Additionally, specific work has been devoted to WWER steels in developing the comparison of existing ETCs for WWER type materials

with actual results from several decommissioned RPVs. It is expected that the information presented in ASTM STP1603 can be used to identify potential weaknesses in some existing surveillance programs and lead to modifications as needed in the future.

In closing, the editors would like to express gratitude to Mr. L. E. Steele for his first fundamental work in stressing the critical importance of surveillance programs and documenting the early activities in the 1960s and extending into the 1980s and implications based on the surveillance program results. It is our opinion that this new publication for the first time effectively covers the current world-wide description of experience, problems, and critical results of surveillance programs from the last 30 years. This compilation should help all readers (students, engineers, designers, technicians, researchers, and regulators) to better understand all key aspects of surveillance programs and the direct connection with RPV integrity and long-term lifetime assessment.

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