УДК 621.039.53

INTEGRATED SURVEILLANCE SPECIMEN PROGRAM FOR WWER-1000/V-320 REACTOR PRESSURE VESSELS

M. Brumovský, J. Brynda, M. Kytka, P. Novosad, J.Žďárek
Nuclear Research Institute Rez plc, 250 68 Rez, Czech Republic

Surveillance specimen programs play an important role in reactor pressure vessel lifetime assessment as they should monitor changes in pressure vessel materials, mainly their irradiation embrittlement. Standard surveillance programs in WWER-1000/V-320 reactor pressure vessels have some deficiencies resulting from their design – nonuniformity of neutron field and even within individual specimen sets, large gradient in neutron flux between specimens and containers, lack of neutron monitors in most of containers and no suitable temperature monitors. Moreover, location of surveillance specimens does not assure similar conditions as the beltline region of reactor pressure vessels. Thus, Modified surveillance program for WWER-1000/V-320C type reactors was designed and realized in two units of NPP Temelin, Czech Republic. In this program, large flat type containers are located on inner wall of reactor pressure vessel in the beltline region that assures their practically identical irradiation conditions with critical vessel materials. These containers with inner dimensions of 210x300 mm have two layers of specimens; using inserts (10x10x14 mm) instead of fully Charpy size specimens allows irradiation of materials from several pressure vessels at once in one container. This design advantage has been used for the creation of the Integrated Surveillance Program for several WWER-1000 units – Temelin 1 + 2, Belene (Bulgaria), Rovno 3 + 4, Khmelnick 2, Zaporozhie 6 (Ukraine) and Kalinin 3 (Russia). Irradiation of these archive materials together with the IAEA reference steel JRQ (of ASTM A 533-B type) and reference steel VVER-1000 will allow to compare irradiation embrittlement of these materials and to obtain more reliable and objective results as no reliable predictive formulae exist up to no due to a higher content of nickel in welds. Irradiation of specimens from cladding region will help in the evaluation of resistance of pressure vessels against PTS regimes.

1. INTRODUCTION

Reactor pressure vessels (RPV) are components with the highest importance for the reactor safety and operation as they contain practically whole inventory of fission material but they are damaged/aged during their operation by an intensive reactor radiation.

Surveillance specimen programs are the best method for monitoring changes in mechanical properties of reactor pressure vessel materials if they are designed and operated in such a way that they are located in conditions close to those of the vessels. Reactor Codes and standards usually included requirements and conditions for such programs to assure proper vessel monitoring [1-3].

WWER reactor pressure vessels are designed according to former Russian Codes and rules with somewhat different requirements using different materials comparing e.g. with ASME Code.

Standard surveillance programs in WWER-1000/V-320 reactor pressure vessels have some deficiencies resulting from their design – nonuniformity of neutron field and even within individual specimen sets, large gradient in neutron flux between specimens and containers, lack of neutron monitors in most of containers and no suitable temperature monitors. Moreover, location of surveillance specimens does not assure similar conditions as the beltline region of reactor pressure vessels.

Prediction of radiation damage/embrittlement in weld metals of these type of vessels has been put into great interest when first results from Standard surveillance programs (SSP) were obtained – it looks that some of these weld metals showed higher irradiation embrittlement than was predicted with the use of the standard [4]. One of the reasons could be a fact that weld metals in most of these vessels contain higher content of nickel as it was tested within the Qualification tests of this vessel material – 15Kh2NMFA(A). In these tests nickel content was lower than 1.5 mass % but later Technical specification for the weld metal was changed and some of weld have as much as 1.9 mass % of nickel while no representative irradiation tests were performed. This situation can be seen in Fig. 1 where results from some first tests of SSP specimen are summarized.

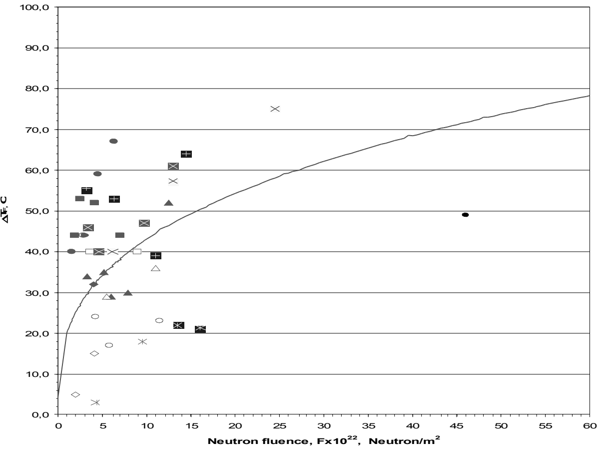

Fig. 1. Shift of the shift in the critical temperature of brittleness, T_k of WWER-1000 RPV weld material due to irradiation. Results of surveillance specimen testing

2. MODIFICATION OF THE STANDARD SURVEILLANCE PROGRAM

Main disadvantage of the original SSP is that it is not capable to provide the monitoring of RPV material properties in a reliable way. Therefore, a modification of the program was elaborated in SKODA Nuclear Machinery, Plzen, Czech Republic for NPP with WWER-1000/V-320C type reactors for Belene (Bulgaria) and Temelin (Czech republic).

Main principles of the design was chosen in such a way to solve problems of the Standard Surveillance Program, mainly:

- location of containers should well monitor the conditions of reactor pressure vessel wall in beltline region, i.e. specimens temperature should be as close as possible (containers must be washed by a cold inlet water) and lead factor should be less than 5;
- whole set of specimens for one testing curve should be located in identical neutron fluence position;
- as much as possible sets of specimens should be located in similar/close neutron fluence to be able to compare behaviour of different materials;
- withdrawal scheme of containers should assure monitoring pressure vessel material as well as neutron fluence during the whole RPV lifetime;
- neutron monitoring should assure determination of neutron fluence to each of test specimens for every container;
- temperature monitoring should be performed using melting temperature monitors with a appropriate range of melting temperatures;
- cladding materials should be also included in the containers;
- reference material should be added for an objective comparison of results;
- spare containers should be added to monitor vessel annealing as well as further re-embrittlement if necessary.

Design of such a program was performed and supported by a set of calculations (neutron physics, thermal-hydraulics) as well as experiments in a scale 1:1 (thermal-hydraulic characteristics measured in a hydraulic channel of a pressure loop in SKODA, thermal fatigue tests of container holders on pressure vessel wall).

Main characteristics of this Modified Surveillance Program are as follows:

CONTAINERS

Containers are of flat type with inner dimensions approx. 200 x 300 x 25 mm, are made from austenitic stainless steels plates welded on a frame. They contain special holders for location on pressure vessel wall – see Fig. 2 to 4.

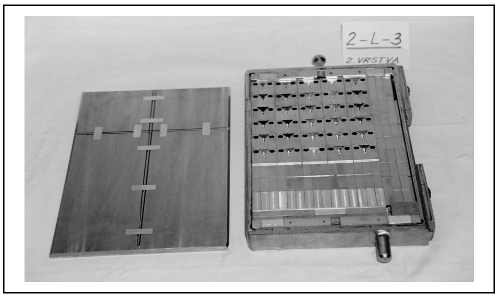

Fig. 2. Upper floor of the container of the Modified Surveillance Programme with wire type neutron fluence monitors on the container cover

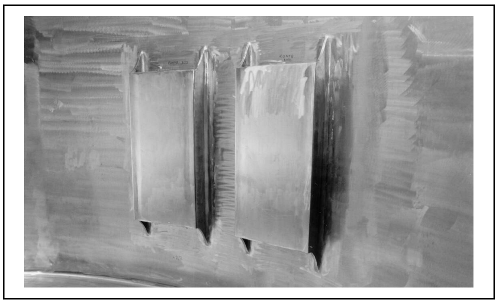

Fig. 3. Container of the Modified/Integrated Surveillance Program in NPP Temelin

Fig. 4. Container of the Modified/Integrated Surveillance Program with inserts

3. INTEGRATED SURVEILLANCE PROGRAM FOR WWER-1000/V320C TYPE RPVS

In principle, it exists a possibility to use this reactor of WWER-1000/V-320C as a “host” reactor for those V-1000 units that are supplied by the Standard Surveillance Program and thus reliability of obtained results is not very high. Possibility of incorporation materials also from other reactors is given by the fact that containers of flat type are sufficiently large as they were designed for full size Charpy type specimens but now, application of reconstitution technique allows to include practically four times more specimens if inserts of dimensions 10 x 10 x 14 mm are used – see Fig. 5.

Fig. 5. Hardware support for the Modified Surveillance Programme in NRI
(container weight is more than 15 kg)

Integrated surveillance program for several similar reactors can be realized in accordance with the [2] if the following main requirements are fulfilled:

– reactors are similar in design and operation;
– neutron fluence determination on all RPV wall is assured for the whole reactor lifetime;
– operation of the "host reactor" is assured for the whole operation of reactors within the family.

A proper and reliable monitoring radiation damage in materials for WWER-1000/320 units is now under high study and interest as it was determined that in some welds with high nickel content (in some cases up to 1.88 mass %) radiation embrittlement can be much larger than that obtained from predicted formula given in [4]. Qualification tests for materials of WWER-1000 RPVs were performed on welds with nickel content below 1.5 mass %, but later the nickel content was increased (in most of V-1000 units) to get better fracture toughness properties but no further study of radiation embrittlement was performed.

Thus, using the opportunity that NPP was delayed in its start-up due to changes in I&C system, it was possible to modified content of some containers (for Unit 2) in such a way that specimens from archive materials of the following units were incorporated into the program: Khmelnitsky Unit No 2, Rovno Units No 3 and 4, Zaporozhye Unit No 6 (Ukraine) and Kalinin Unit 3 (Russia), as nickel content in all these weldment is well over 1.5 mass %. In this first part of the program only weld metals from this RPVs were included. From all materials, 12 specimens for impact notch toughness and 12 specimens for static fracture toughness tests are included. It is necessary to mention that all these RPVs contain their original Standard surveillance program.

In this time, second part of this Integrated surveillance program is under final realization. New six containers are manufactured that will replace containers from the first part in both units in NPP Temelin (design of container holders and containers itself allows inserting of new containers during reactors shut down where reactor internals are removed). Base metals from all abovementioned RPVs will be included in these containers together with base and weld metals from the NPP Belene. Moreover, standard IAEA reference material JRQ as well as IAEA reference V-1000 materials are also included for mutual comparison with results of the first part as well as for better and more objective evaluation of results (there exist a large database of the behaviour of JRQ steel, e.g. within the IAEA Co-ordinated programs and its database).

Realization of such Integrated Surveillance Program will substantially improve knowledge about behaviour of WWER-1000 RPV materials during their operation, i.e. about radiation damage – embrittlement. Comparison of results from different RPVs also allows to assess the behaviour of materials from other RPVs with only Standard surveillance program – based on comparison of chemical composition and operational conditions. It also allows comparison and analysis of results from testing their SSP and propose a correction coefficients (taking into account different irradiation conditions) if necessary. Results from this Integrated Surveillance Program also will enlarge existing database of radiation embrittlement data of this type of materials in a more objective manner.

4. CONCLUSIONS

Modified Surveillance Program for reactor pressure vessels of NPP Temelin with WWER-1000/V-320C type reactors is used for the Integrated Surveillance Program for several RPVs of NPPs in Ukraine, Russia, Bulgaria and Czech Republic as the Standard Surveillance Programs in WWER-1000/V-320 type reactors do not fulfil requirements given by codes and standards.

Such Integrated Surveillance Program allows to obtain reliable information about radiation embrittlement of materials in tested reactors pressure vessels that will be also correlated with the IAEA reference steel JRQ to get more objective results.

Realization of this Integrated Surveillance Program increases information about the behaviour of RPV materials of this type of reactors that have only Standard Surveillance Program. Moreover, it allows correlation of results from these Standard Surveillance Programs with those from other vessels not included in this Program that also increase reliability of such results. Generally, this Integrated Surveillance Program will increase safety of operating WWER-1000/V-320 type reactors operated in these countries.

REFERENCES

1. Us Code of Federal Regulation, Nuclear Regulatory Commission, Part 50 (10CFR50) – Domestic Licensing of Production and Utilization Facilities, Appendix H – Reactor Vessel Material Surveillance Program Requirements.
2. *Правила устройства и безопасной эксплуатации оборудования и трубопроводов атомных энергетических установок ПН АЭ Г-7-008-89*. M., 1990 (Rules for Design and Safe Operation of Components and Piping of Nuclear Power Plants, Experimental and Research Nuclear Reactors and Stations, PN AE G-7-008-89, M., 1990), that for surveillance programs are practically identical with *Правила устройства и безопасной эксплуатации обородувания атомных электростанций опытных и исследовательских ядерных*

реакторов и установок. М., 1973 (Rules for Design and Safe Operation of Components of Nuclear Power Plants, Experimental and Research Nuclear Reactors and Stations, M., 1973).

3. ASTM Standard Practice for Conducting Surveillance Tests for Light-Water Cooled Nuclear Power Reactor Vessels, E 706 (IF), ASTM E-185.
4. *Нормы расчета на прочность оборудования и трубопроводов атомных энергетических установок ПН АЭ Г-7-002-86.* М., 1989 (Standards for Strength Calculations of Components and Piping in NPPs, PN AE G-7-002-86, M., 1989).

КОМПЛЕКСНАЯ ПРОГРАММА ДЛЯ ОБРАЗЦОВ-СВИДЕТЕЛЕЙ КОРПУСОВ ВЫСОКОГО ДАВЛЕНИЯ РЕАКТОРА ВВЭР-1000/V-320

М. Брумовский, Ю. Бринда, М. Китка, П. Новосад, Ю.Ждярек

Программы для образцов-свидетелей играют незаменимую роль при оценке продолжительности эксплуатации корпуса высокого давления реактора (КР), так как они должны контролировать изменения в материалах КР, в основном их радиационное охрупчивание. Стандартные программы для корпусов высокого давления реактора ВВЭР-1000/V-320 имеют некоторые недостатки, причиной которых является их конструкция – неоднородность нейтронного поля даже внутри отдельных наборов образцов, большой градиент нейтронного потока между образцами и контейнерами, отсутствие нейтронных мониторов в большей части контейнеров, а также соответствующих температурных мониторов. Кроме того, расположение образцов-свидетелей не гарантирует условий, соответствующих условиям облучения центральной обечайки КР. Модифицированная программа для реакторов типа ВВЭР-1000/V-320С была разработана и реализована в двух блоках АЭС Темелин, Чехия. По этой программе большие плоские контейнеры располагаются на внутренней стенке КР в зоне центральной обечайки, что обеспечивает практически идентичные условия облучения с критичными корпусными материалами. Такие контейнеры с внутренними размерами 210х300 мм имеют два слоя образцов; использование вкладышей (10х10х14 мм) вместо полноразмерных образцов Шарпи даёт возможность облучать материалы нескольких корпусов одновременно в одном контейнере. Это преимущество конструкции использовалось при создании Комплексной Программы для нескольких блоков ВВЭР-1000 – Темелин 1 + 2, Белене (Болгария), Ровно 3 + 4, Хмельник 2, Запорожье 6 (Украина) и Калинин 3 (Россия). Облучение этих архивных материалов вместе с эталонными сталями JRQ МАГАТЭ (типа ASTM A 533-B) и ВВЭР-1000 позволит сравнить радиационное охрупчивание данных материалов и получить более надёжные и объективные результаты, так как до сих пор не существует достоверных прогнозируемых формул при наиболее высоком содержании никеля в сварных соединениях. Облучение образцов из зоны оболочки поможет при оценке сопротивления корпуса давления режимам PTS.

КОМПЛЕКСНА ПРОГРАМА ДЛЯ ЗРАЗКІВ-СВІДКІВ КОРПУСІВ ВИСОКОГО ТИСКУ РЕАКТОРА ВВЭР-1000/ V-320

М. Брумовський, Ю. Бринда, М. Кітка, П. Новосад, Ю.Ждярек

Програми для зразків-свідків відіграють незамінну роль при оцінці тривалості експлуатації корпуса високого тиску реактора (КР), тому що вони повинні контролювати зміни в матеріалах КР, в основному їх радіаційне окрихчення. Стандартні програми для корпусів високого тиску реактора ВВЭР-1000/V-320 мають деякі недоліки, причиною яких є їхня конструкція – неоднорідність нейтронного поля навіть усередині окремих наборів зразків, великий градієнт нейтронного потоку між зразками й контейнерами, відсутність нейтронних моніторів у більшій частині контейнерів, а також відповідних температурних моніторів. Крім того, розташування зразків-свідків не гарантує умов, що відповідають умовам опромінення центральної обечайки КР. Модифікована програма для реакторів типу ВВЭР-1000/V-320С була розроблена й реалізована у двох блоках АЕС Темі-Лин, Чехія. По цій програмі більші плоскі контейнери розташовуються на внутрішній стінці КР у зоні центральної обечайки, що забезпечує практично ідентичні умови опромінення із критичними корпусними матеріалами. Такі контейнери внутрішніми розмірами 210х300 мм мають два шари зразків; використання вкладишів (10х10х14 мм) замість півнорозмірних зразків Шарпи дає можливість опромінювати матеріали декількох корпусів одночасно в одному контейнері. Ця перевага конструкції використовувалася при створенні Комплексної Програми для декількох блоків ВВЕР-1000 – Темелин 1 + 2, Белене (Болгарія), Рівне 3 + 4, Хмільник 2, Запоріжжя 6 (Україна) і Калінін 3 (Росія). Опромінення цих архівних матеріалів разом з еталонними сталями JRQ МАГАТЕ (типу ASTM A 533- B) і еталонною сталлю ВВЕР-1000 дозволить зрівняти радіаційне охрихчування даних матеріалів і одержати більш надійні й об'єктивні результати, тому що дотепер не існує достовірних прогнозованих формул при найбільш високому змісті нікелю у зварених з'єднаннях. Опромінення зразків із зони оболонки допоможе при оцінці опору корпуса тиску режимам PTS.