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Surveillance Extension Experience at WWER-440 Type Reactors.

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ABSTRACT

SURVEILLANCE EXTENSION EXPERIENCE at WWER-440 TYPE REACTORS.

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ABSTRACT.

In WWER-440 reactors the surveillance specimens are located in accelerated irradiation positions. After five years all specimens are withdrawn and the operational changes are not monitored. At Paks NPP a new surveillance program extension is started to eliminate of this disadvantage of the original program, and obtaining further data for plant lifetime management.
The paper is includes:
- Research performed to prepare the surveillance extension programme.
- The elaborated surveillance extension programme
- The evaluation method prepared for the surveillance extension programme.
- The first results.

Keywords: surveillance, radiation embrittlement, RPV integrity.

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1.Introduction

The second generation of the of WWER-440-s, the so-called V-213 type, has a uniq surveillance programme. Such units are operated in Hungary at Paks site. The task of the surveillance testing is to verify the operational safety, to supply data for PTS analysis and for evaluation of the exact lifetime. To fulfil these requirements the original surveillance program of the V-213 reactors had to be extended.

2.The original surveillance program of the WWER-440-s

To understand the extended surveillance program a short review of the original surveillance is necessary.

Specimen sets

Each WWER-440 V213 unit has 6 sets of specimens for surveillance testing. Each set contains specimen series made from base material, HAZ, and the weld. Each series consists of 12 Charpy V specimens, 12 Charpy size TPB specimens and 6 tensile specimens. This means a total of 90 irradiated specimens in each set. Two sets also contain specimens for studying thermal embrittlement. Every set has Fe, Ni, Co, and Cb foils for dosimetry.

The specimens are located between the core and the vessel wall in pipes welded to the outer side of the core barrel. The specimens are encapsulated in stainless steel capsules. FIG. 1. The Charpy size specimens are encapsulated two by two, and the tensile specimens are encapsulated six by six, and 19 or 20 capsules are connected together as a chain. Two chains form a complete set of specimens. Since the chains are quite long, the first and last capsules are out of the maximum flux. The Charpy specimens are located in the middle of the sets, the tensile specimens are in one capsule, and give reliable results, but the COD specimens are irradiated by different fluences. Since the small ligaments of these specimens also give confusing results generally only the results obtained on weld material can be accepted as valid fracture toughness values.

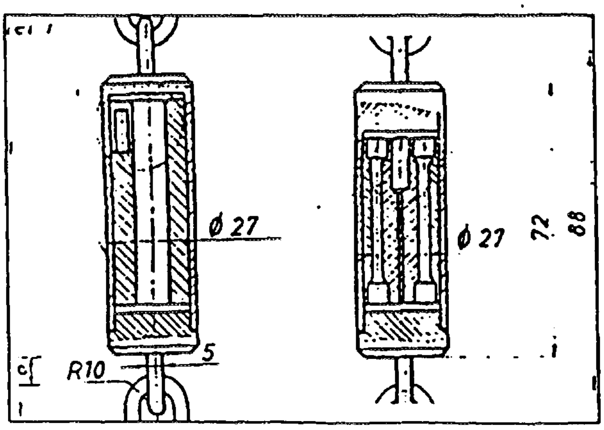


FIG.1.Specimen capsules in the WWER-440-s

The specimens are cut from below 1/4 depth of the wall thickness, from four or in some cases five different layers.

The layers are named D, G, I, E, K as it is shown in FIG. 2.

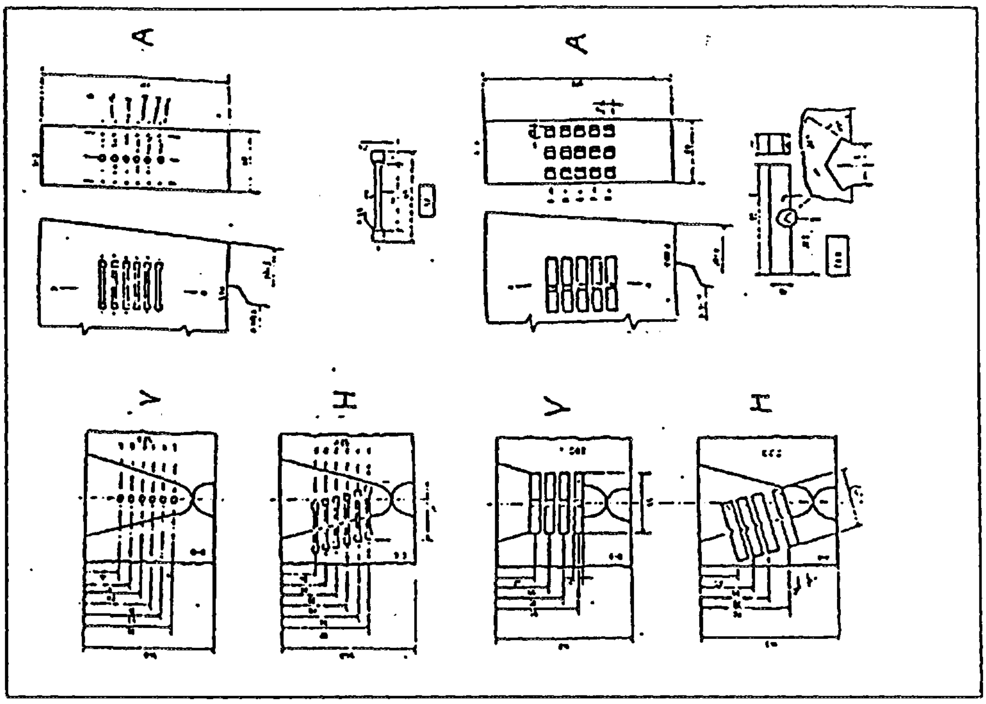
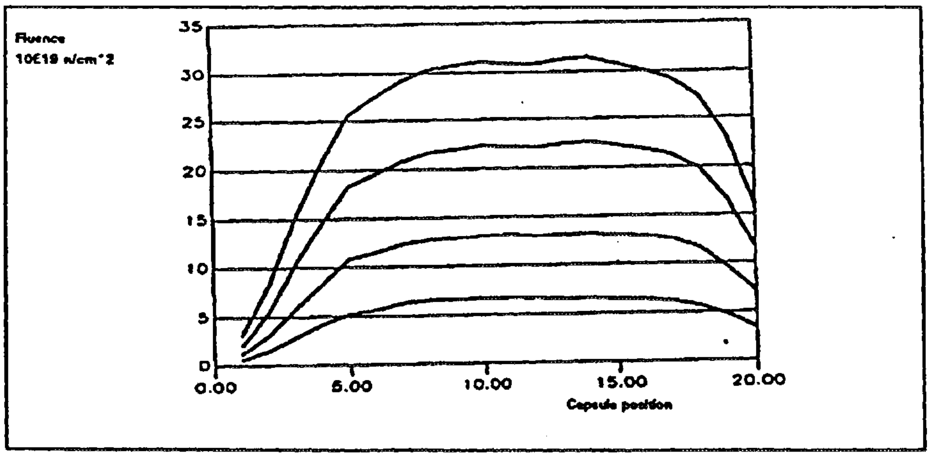


FIG.2. Specimen cut plan of WWER-440-s

Dosimetry

The accuracy of dosimetric measurements and calculations is strongly influenced by the facts that flux and fluence change with the burning of the fuel and with refuelling; great fluences cause saturation effect, and some foils (e. g. Cb) may be activated by gamma radiation which does not cause embrittlement in the wall. The distribution of the flux changes along the active zone, too. Figure 3. shows the results of the measurements performed in the first unit of the Paks Nuclear Power Station.



.FIG.3 . Fluence distribution in Paks unit 3

The Charpy (ISO V) specimens, which are the source of the most important information for the surveillance, are situated in neighbouring capsules facing the centre of the active zone and thus the divergence of the flux is small. A more significant divergence is caused as there are two Charpy specimens in one capsule and - depending on their position as compared to the active zone - they shield each other or themselves. The divergence of fluence between the farther surfaces of the two specimens may reach 40%. Because of the irregularities of the fluence the specimens are used in random order during testing.

Withdrawal schedules

Since the surveillance specimens in WWER-440 V-213 units are relatively far from the vessel wall the lead factor is about 11.8 for the base material and about 18 for the weld metal as the welds are below or above the core level. The high lead factors imply that the specimens are withdrawn in the first 5 years. The withdrawal schedules applied in Hungary are shown in TABLE 1.

TABLE 1. Surveillance itinerary at Paks

Unit	Capacity[MWe]	Supplier	First operation	Specimen set withdrawn year
Paks1	440	Skoda	1982	84, 85, 86(2), 87
Paks2	440	Skoda	1984	85, 86, 87(2), 88
Paks3	470	Skoda	1986	87, 88(2), 89, 90
Paks4	460	Skoda	1987	88, 89(2), 90, 91

One set of specimens in every unit stays for a long period (minimum 10 years) to study the thermal embrittlement.

3. The extended surveillance program

The surveillance testing of WWER-s is different from that prescribed in the ASTM E-185 standard. Difficulties in the evaluation of this type of surveillance are caused by the high lead factor, by the fact that there is no direct thermocouple for temperature measurement of the capsules (diamond powder is used as temperature monitor) and by the self-shielding of the specimens. The small size COD specimens can only be used to obtain valid fracture toughness values at a very low temperature. On the other hand the large number of the specimens allows statistical evaluation, even the low temperature fracture toughness values give extra information on the material performance and because the results are obtained in an early stage the utility has an extended period for plant lifetime management.

To avoid the disadvantages and to satisfy fully the requirements of the ASTM-E-185 standard an extended surveillance program has been elaborated in Hungary and it has been accepted by the Hungarian authority. The new specimens are placed into the empty surveillance channels.

The new specimen sets

The new specimen sets consist of three different types of forged (base) material. The materials are: a special heat of the 15H2MFA material, the IAEA reference material JRQ, and the original archive material of every unit.

Every specimen set consists of 12-20 Charpy and 6 tensile specimens of each of the above mentioned materials. The extended surveillance specimen sets are shown in FIG.4.

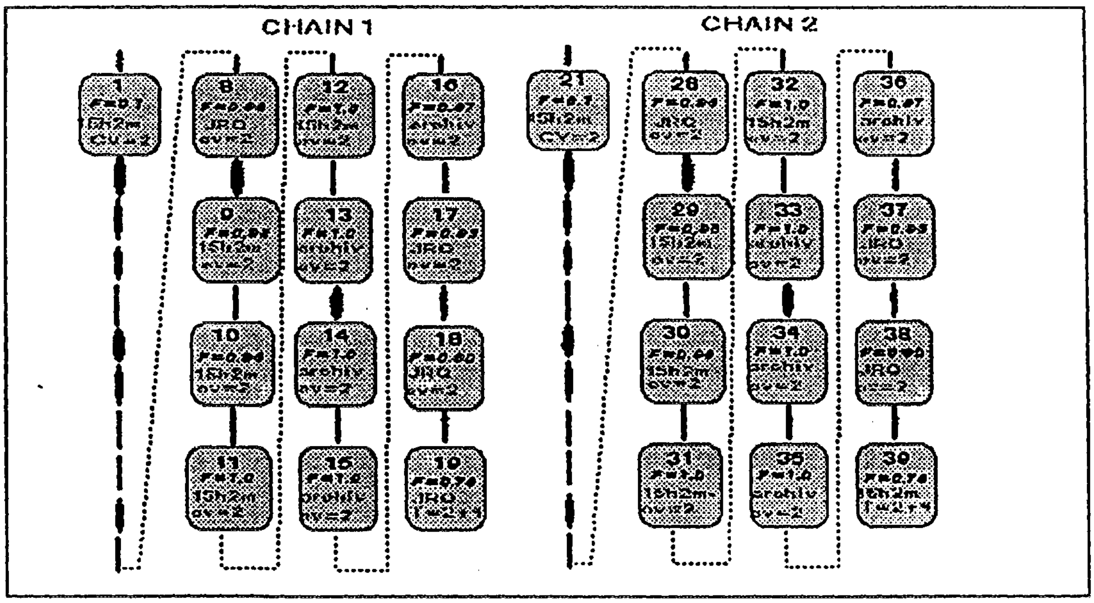


FIG.4. Specimen sets for extended surveillance program at NPP Paks
F= relativ fluence (max=1), 15h2m=15H2MFA reference steel, archiv=reconstituted Charpy specimens made from archive material (remnants of 0 level testing), JRQ=IAEA reference steel, CV= Charpy V notched specimen, T= round tensile specimen (2 smooth and 4 notched in 1 capsule).

For a forty year operation period every unit requires about 150 uniform Charpy and 60 uniform tensile specimens plus specimens for zero level testing from every material. All of the specimens are located against the middle of the core to be exposed with the same irradiation fluence, with the exception of 4 Charpy specimens in every set, which are located in low flux positions. These specimens will be collected from the four units, and they will be used to evaluate the flux rate effect, which may affect the surveillance results.

Production of the specimens

In case of reference materials the requirement is to use specimens cut from the same specific layer of the material, since the material properties especially in case of the IAEA reference material JRQ are changing in the function of distance from the surface (depth).

Due to the limited availability of archive materials (practically only the remnants of specimens used for zero level testing are available) reconstituted type specimens are used. Electron beam or laser welding is used for the reconstitution. Instead of individual welding the remnants of the archive Charpy specimens are welded together with two metal blocks, called "combs" due to their shape. See Fig. 5. The thickness of the combs is a bit more than the thickness of the Charpy remnants, so there is no crater at the edge of the welding. Eight-twelve specimens and two combs are welded together.

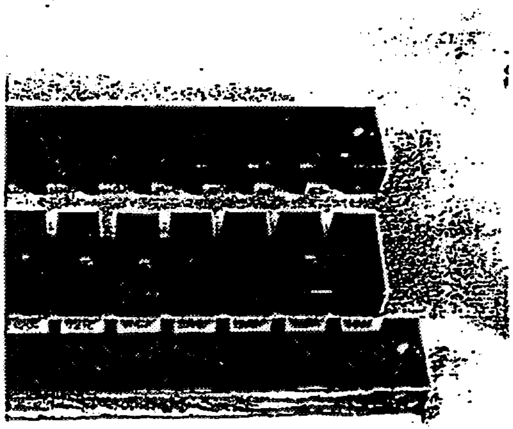


FIG. 5 Charpy remnants and "comb" cut for welding

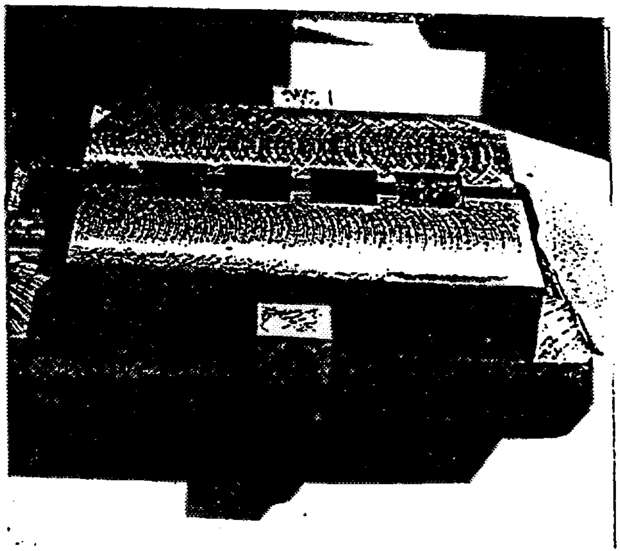


FIG. 6 Pieces fixed into a rig, before welding

Before the welding the pieces are placed into a special rig. See FIG. 6. The rig is made from copper to assist heat removal. To avoid the forming of martensitic structures in the weld or in the HAZ, preheating suitable to the material type is necessary. The welding parameters are carefully selected to ensure defectless seams and a small heat affected zone at the same time. A computer model to calculate the heat distribution during welding in the function of the technology parameters has been elaborated. FIG.7 shows the calculated sizes of the differently heat affected zones made by electron-beam welding.

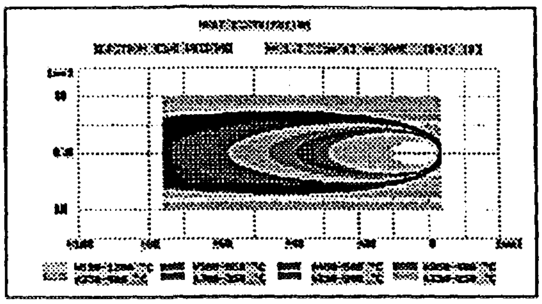


FIG.7. Calculated size of the heat affected zone during EB welding

The model has been verified by thermocouple measurements during welding and by metallography (FIG 8. shows a metallography picture on an electron-beam welded specimen), by hardness testing on the welded pieces.

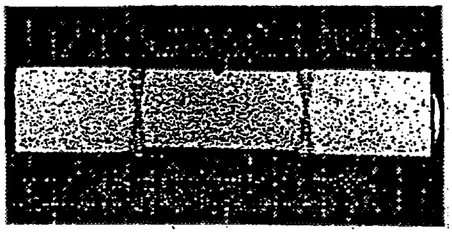


FIG.8. Cross section of an electron beam welded Charpy specimen.

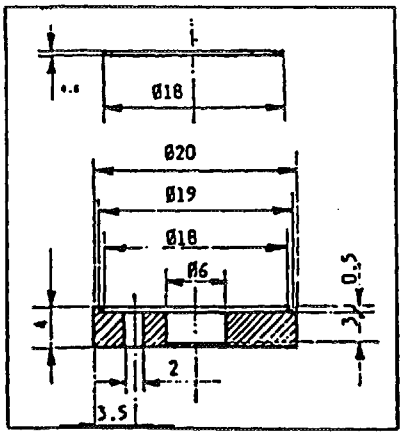
Finally careful machining and control of the specimen size are the last steps of the specimen production.

According to the tests performed until now these specimens gave the same results as the original ones. For further verification we participate in the ASTM Round-Robin program on reconstituted Charpy specimen production.

Every specimen got a specific number engraved on both ends by laser beam. This technology gives good visibility without destroying any part of the specimens.

Dosimetry

In the original surveillance program the dosimetry foils are located in an eccentric position. Since the specimen holder chain can turn around during location into the irradiation channels, the self shielding increases the scatter of the results. In the extended surveillance program centrally located foil holders are used.



The shielding effect of the wall of the foil holders is equivalent to the shielding effect of a half thickness of a Charpy specimen. See FIG. 9. The foil holders are in the head of the selected capsules. There are 6-10 dosimetry foil sets are in every extended surveillance set. The foils used in the extended surveillance programme are: Cb; Fe54; Cu, Co.

FIG.9. The new foil holder

d. Encapsulation

The specimens are encapsulated into stainless steel capsules, which are the same design as the original surveillance capsules. The materials for capsule production are carefully selected, they have quality guarantee by the producer. The sealing of the capsules is made by TIG welding in argon gas. The weld technology and quality satisfy the requirements for nuclear pressurised components. Every capsule is leak tested. The geometry and flexibility of the complete sets are also checked.

Every set of specimens including material properties, cut plan, specimen geometry, location in the chains, location, mass, material of the dosimetry foils are carefully documented. The national authority checks the documentation and permits the utility to reload the specimens.

Preparation of the surveillance extension program

Four sets of specimens were used to prepare this surveillance extension program. These sets are similar to the sets which will be used in the future, but they contain more dosimetry foils. In the first two sets JFL, JRQ, JWP, and JWO materials were also irradiated for the IAEA co-ordinated irradiation research program.

In the reserach sets irradiated for 1 year Ti, and U238 dosimetry foils are also used. This extended foil set gives a better estimation on spectra of Paks unit 2, meaning an increase of the accuracy of dosimetry results and EOL calculation.

These research sets had been placed into the empty surveillance channels of Paks unit 2, for 1, 1, 2, and 3 years of irradiation. This made it possible to develop the standard technology of the production of the new specimen sets, and permits better comparison with the previous surveillance results.

Irradiation schedule

Every specimen set will be irradiated for four years in the reactor. Table 2. shows the schedule for the extended surveillance sets at NPP Paks. Until this year 4 preparation (research) sets and 3 extended surveillance sets have been reloaded.

TABLE 2. Surveillance extension reloading itinerary at Paks

Unit	Capacity [MWe]	First operation	Extended specimen set reloading year
Paks1	440	1982	94, 98,2002, 06,10,14,18
Paks2	440	1984	89*,91*,91,92*,92*,95,99,2003,07,11,15,19
Paks3	470	1986	92,96,2000,04,08,12,16,20,24
Paks4	460	1987	93,97,2001,05,09,13,17,21,25

* Remark: preparation sets for research purpose
The bold numbers indicate the sets already reloaded.

Results obtained from the first two research sets

The first two research sets have already been withdrawn and tested.

The purposes of installing the research sets were:

-to get experience in designing , production and reloading of specimen sets and to test the manipulating technology.

- to check the maximum temperature of the specimens during irradiation.

- to get informations on the radiation embrittlement behaviour of the materials used in the extended surveillance program

- to get further dosimetry results.

No difficulties arised during the production, reloading and withdrawal of the first research set. During irradiation 3 capsules became inhermetic, and the surface of the specimens slightly corroded.

In WWER-s the maximum capsule temperature is determined by the measurement of the lattice parameter of diamond powder irradated together with the specimens. Due to the high flux the gamma heating is a considerable factor affecting the specimen temperature. In the original surveillance program the diamond powder is located avay from the specimens, which that means it tests the temperature of itself. Also there is some uncertanity during the measurement and evaluation of the lattice parameter. In the research specimen set small holes were drilled into the end of some specimens and into some of the aluminium heat conduction elements contained in every capsule, and melting temperature monitors were inserted into the holes. See Fig. 13.

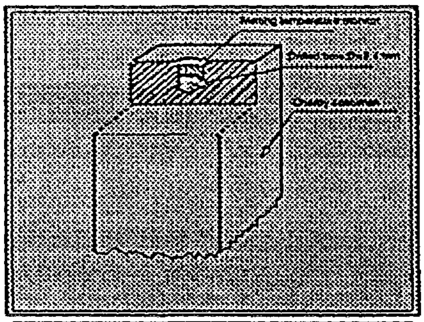


FIG. 13. Cavity for melting temperature monitor in Charpy specimen.

Only two monitors with melting a temperature of max 290 °C were melted. (FIG. 14.). Since the melting monitor alloys contain several elements (like lead, cadmium..) having very high cross section values a high quantity of gamma heat is generated in them. This means that the specimen temperature remained below 290 °C in every case, in good agreement with the thermocouple measurement results performed by VTT (Finnland) in similar type capsules.

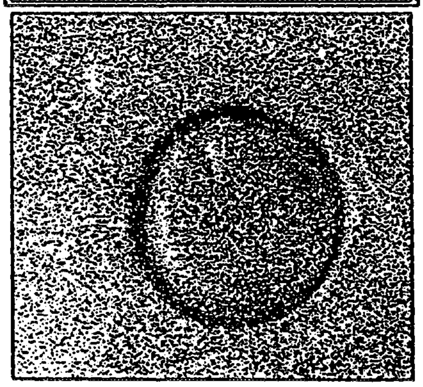


FIG.14. Melted temperature monitor in Charpy specimen

The Charpy results of materials tested in Paks unit 2 are shown on Fig.15. Table 3. and 4. shows the hardness testing and tensile testing results.

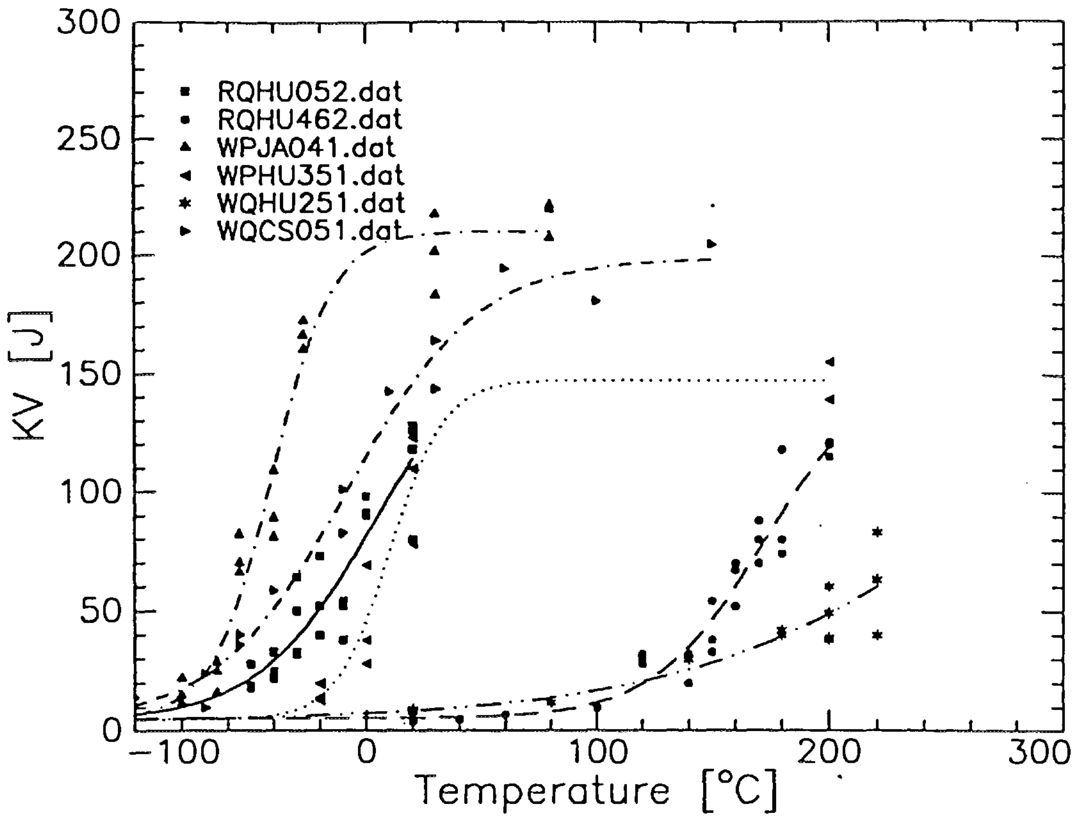


FIG.15. Charpy results obtained on JRQ, JWQ, JWP and materials.
(Zero level and 1 year irradiated specimens. Fluence $3*10^{19}$ n/cm^2 E>1 MeV)

TABLE 3. Tensile results on JFL and JRQ material.

Code	Testing temp [°C]	Yield stress [MPa]	Ultimate stress [MPA]	True fracture stress [MPa]	Reduction of area [%]	ASFE [MJ/m^3]
JRQ01	20	698	794	1423	62	1026
JRQ02	20	702	803	1345	58	887
JRQ03	100	691	787	1154	51	654
JRQ04	100	675	751	1097	44	517
JRQ05	300	623	746	952	32	301
JRQ06	300	626	744	1247	58	803
JFL01	20	587	707	1087	60	774
JFL02	20	558	674	1023	64	799
JFL03	100	530	644	915	53	547
JFL04	100	513	616	928	62	705
JFL05	300	505	653	738	42	334
JFL06	300	500	636	697	53	547

Evaluation

After every four year period the results of every unit will be compared with the original surveillance results. If the new results differ greatly from the original ones, the EOL calculated from the original surveillance program results will be modified. The modification will be performed by the use of the following formula1.

$$E_m = E_t - C - \sum_{1}^{n} 4 * K * \frac{\Delta T_{k[n]}}{\Delta T_{k[1]}} \quad 1$$

where E_m is the remaining lifetime, E_t is the full lifetime, calculated from the original surveillance program), C is the number of operational years until the loading of the first new surveillance set, n is the serial number of the new sets in the unit, K is a correlation factor characterizing the relationship between the original and the first extended surveillance period finally $\Delta T_{k(n)}$ is the transition temperature shift (in K) measured on the n. sets of new specimens. K is evaluated from the operational hystory, its value generally is 1. If in case of any extended set the value of: $\frac{\Delta T_{k[n]}}{\Delta T_{k[1]}} > 1.5$ the utility must study why the embrittlement rate increased.

5.Summary

The surveillance program extension at NPP Paks will complete the original surveillance program and eliminate all its disadvantages. The surveillance programs with the extensions at the Paks units satisfy the requirements of ASTM E-185 standard, supports life time management of the PWR-s, and will give more data for PTS calculations.

6.Acknowledgement

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The following scientists and their institutes participated in the work beside the authors: Dr. J. Rittinger (ERÖKAR), Dr. A. Fehérváry (VASKUT), Dr. É. Zsolnay (Technical Univ. of Budapest)

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