

Complex treatment of erosion-corrosion issues for piping

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Abstract. Erosion-corrosion damages piping sufficiently affect safety and economic efficiency of NPP long-term operation up. Due to the multifactorial nature of the damage mechanism under consideration, an integrated approach is required to minimize its negative effects.

Erosion-corrosion (E-C) or Flow Accelerated Corrosion (FAC) damages of piping and equipment made from low-carbon and low alloy steels are typical for nuclear power plants (NPPs) in Russia and abroad.

The damages have significant impact on NPP safety and economic efficiency.

E-C damages are known from NPP operation experience as severe degradation processes leading to leaks and double-end-guillotine breaks [1-2], which is unacceptable in compartments with working personnel.

Water chemistry (WC) parameters have sufficient influence on E-C damage intensity. Nevertheless, E-C issue cannot be solved by means of WC optimization only. It is well known from publications and operational experience that about ~ 10÷15 essential parameters need to be assessed for E-C damage analysis [3].

Complex treatment of E-C issues for NPP equipment and pipelines should be based on structural integrity methodology [4] through conservative strength maintenance of damaged piping element operation on the basis of effective In-service Inspection (ISI), on-line load monitoring and technical state evaluation.

Zones of NPP piping welds are the most complicated objects for revealing local E-C damages [5-6] by means of ISI.

As applied to equipment and pipelines of auxiliary NPP systems it is desirable to obtain forecast estimates of wall thinning rates taking into account the indicators of the corrosive environment effect on structural materials: using chemical control or corrosion monitoring systems [7-8].

The measures should be based on proper materials selection and fixation of initial technical state parameters, including:

- selection of construction materials that are not susceptible to E-C;
- predictive analysis of general and local E-C damages (by special Codes and/or CFD-Codes);
- fitness-for-purpose analysis to substantiate acceptable minimum wall thickness for zones of local E-C;
- use of passive defense against water hammer occasion in piping;

- water chemistry and corrosion monitoring;
- wall thickness measurement by NDE means (selected areas with 100% covering measurements as well as specific locations, e.g., under weld caps using time-diffraction technology);
- instrumental fixation of "as built" piping geometry and bends ovality;
- measurement of chemical composition of piping base metal;
- load monitoring of piping;

The paper deals with current implementation of complex measures mentioned above at RF NPPs. All nuclear industry programs for elimination of E-C damages developed by Rosenergoatom Utility in the years of 2007-2016 were unfortunately lacking complex approach.

Selection of "15X1M1Φ" type steel (which contains more than 1% of chromium) for main steam and feed water piping of NPP Unit with VVER-TOI reactor facility is an example of proper material selection to avoid E-C damages during long-term operation.

Secondary system piping of NPP Units "AES-2006" series have been manufactured from the same materials as similar piping of VVER-1000 NPPs for which operation experience give examples of E-C damages (as well as for VVER-440 NPPs) [3]. That is, at the design stage of the NPPs of "AES-2006" series, no systematic measures were taken to ensure "cloudless" long-term operation [9].

Computational forecasting of zones and intensity of local erosion-corrosion in relation to RF NPP piping and equipment is carried out using of the RAMEK series software tools, which do not guarantee conservatism of calculations [10-11]. For example, Figure 1 from the RAMEK certification passport [11] shows a scattering diagram of calculated rates of erosion and corrosion wear according to RAMEK-1 and ISI data.

Certification passports for software tools of the RAMEK series are available now only for feed water and condensate piping of NPPs with VVER-440/1000 and fast breeder reactor BN-600 [10-11].

Applicability of RAMEK series tools for E-C forecasting for conditions of two-phase flow of the

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working medium, as well for the piping and equipment of NPP units with VVER-1200/TOI is not currently confirmed by the relevant certification passports.

Indicators of RAMEK series tools that characterize the effectiveness of calculated forecast of the E-C cannot be considered acceptable.

The largest in the world Utility – EdF (France) – shows an example of unified application of software tool BRT-CICERO [2, 12-13] for computational forecast of piping wall thinning at all 58 NPP Units in operation.

According to [14-15], periodic reassessments of conservatism of E-C intensity forecasts performed using the BRT-CICERO code showed a fairly high level of conservatism, which varies in the range from 99.3% to 99.8%, depending on the processing of additional thickness measurement results obtained from all NPP Units.

Currently, CFD-class Codes are also used for calculating the intensity of E-C damages.

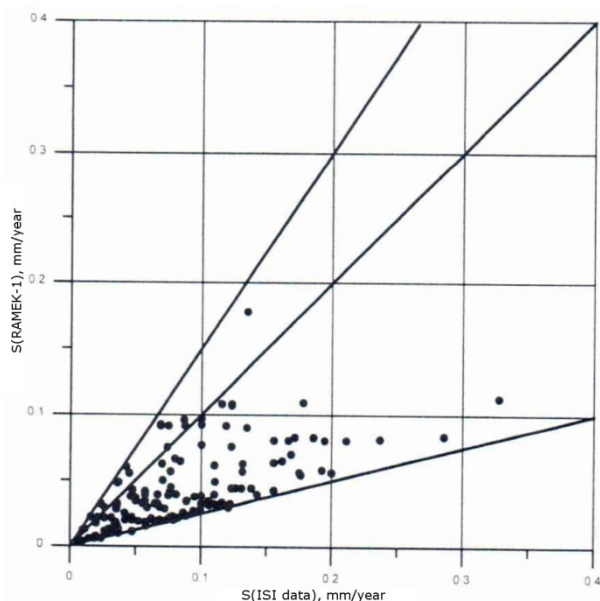


Fig. 1. Scattering diagram of the results of calculations of the rate of erosion and corrosion wear according to RAMEK-1 and ISI data.

Taking into account the active export of Russian nuclear technologies abroad, we can recommend either the direct use of foreign codes for predicting the E-C at new NPP units, such as BRT-CICERO or COMSY, or the parallel use of Russian calculation codes [10-11] in combination with the specified foreign ones to adjust the calculation models and obtain guaranteed conservative estimates of the E-C intensity.

For certification of any software tool for calculating E-C rates in the certification Council at the Federal Budget Institution “Scientific and Technical Center for Nuclear and Radiologic Safety” SEC NRS), the bank of verification examples must be representative and objective. Currently there is currently no such Bank of verification examples at SEC NRS disposal.

All verification reports for certification of software tools of the RAMEK series contained only part of examples selected by the developers themselves from a

larger population of thickness measurement results obtained from the NPPs which could not be accepted as a true ‘fair-play’.

Values of allowable minimum wall thickness for zones of local E-C should take into account not only internal pressure, but also other operational and unexpected loads, such as preloads due to construction and/or possible water hammer (if no specific measures to exclude its influence are undertaken).

Allowable minimum wall thicknesses obtained using minimum guaranteed properties of metal pipes and bends, for many cases, can provide an excessively conservative assessments for further operation.

The actual guidance document of RF Utility [16] is intended for performing estimates of the allowable minimum wall thicknesses of elements applicable to local areas of wall thinning. However, the document [16] does not specify the loads that are taken into account when justifying minimum allowable thicknesses, which distinguishes it from previous document [17].

The methodology used in the document [17] was presented ten years earlier [18-19] and corresponds to well-known foreign approaches [20].

The most correct approach is when the allowable minimum wall thicknesses will be determined individually for various geometries of defects in the form of wall thinning, taking into account the actual load spectrum and based on the methodology for ensuring structural integrity [4].

Passive protection against possible water hammer in pipeline systems subjected to E-C damages can be provided, for example, by using special protection devices [21].

For Russian NPPs in order to provide systematic work on improvement of water-chemical regimes under leadership of JSC “VNIIAES” an information-analytical system “Center for chemical support of NPPs” is under development, allowing to accumulate and to systematize the results of monitored parameters of water chemistry [22].

Chemical control or corrosion monitoring systems [8] are not yet used in new NPP Units, but they are promising and effective means of corrosion damage monitoring at NPP piping and equipment.

A set of NDE procedures has been developed for the RF NPPs including measurements in the zones of butt welded joints of perlitic pipelines $DN \geq 150$ mm [23]: thickness measurement in the area of the welded joint is provided without taking into account the height of the joint reinforcement according to the combined TOFD scheme in combination with the use of phased arrays. The volume of practical application of the developed thickness measurement technology at nuclear power plants is still significantly less compared to the methods of manual non-destructive testing (NDT).

As of the beginning of 2020, nondestructive testing systems (including thickness measurement systems) used at Russian nuclear power plants have not passed the qualification (conformity assessment) according to the requirements of item 61 of NP-084-15 [24]. This shortcoming is to be eliminated in the nearest future.

After qualification of the thickness measurement systems, it will be possible to correctly perform points 137-146 of NP-084-15 [24] for a more effective solution of the E-C problem.

Suggestions for monitoring pipeline tracing and actual geometry of elements (including measurements of bend ovality) have been presented in conference papers [25-26]. However, these proposals have not yet been fully implemented in the design documentation for construction and commissioning of new NPP Units.

Monitoring of the chemical composition of the base metal of pipelines and equipment subject to E-C damages is performed at NPPs using portable devices. The results of the control allow to differentiate thickness measurement zones and identify groups of zones with different levels of relative risk of E-C damage.

Monitoring of pipeline loading should be performed in accordance with the requirements of NP-089-15 [27]. However, the requirements of paragraph 230 of NP-089-15 do not apply to all pipelines that may be subject to E-C. Therefore, it is necessary to forecast E-C damage for piping and equipment of the NPP Unit and make a decision on equipping the actual load monitoring systems for those elements where the risk of intensive E-C will be associated with the risk of guillotine break.

It is also important to take into account possible unrevealed mounting preloads in pipeline systems, which can provoke unpredictable destruction of pipeline elements with undetected wall thinning. To identify non-project loads, the acoustoelasticity method can be used [28].

For new NPP units at the stages of design, construction, installation and commissioning of equipment and pipelines that are potentially subject to E-C damages, it is necessary to provide a set of measures to fix the parameters of the initial technical condition [25].

In conclusion, it is necessary to note once again the effectiveness of E-C problem complex treatment to ensure safe long-term operation of NPP piping and equipment.

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