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METHODS AND RESULTS OF PROBABILISTIC ANALYSIS OF LEAKS AND BREAKS OF NPP EQUIPMENT ELEMENTS

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The paper presents a brief description of a procedure for calculation of the probability of leaks and breaks onset in the high pressure vessel such as the pipes, reactor vessels, steam generators etc.,developed at the RRC "Kurchatov Institute". The procedure and the code MAVR-2.1 created on its basis can be used for the analysis of a wide spectrum of operation, technological parameters for the strength reliability and service of the nuclear power plant.

The procedure is based on the mathematical modelling of the kinetics of defect development with allowance for the spread in the data on the initial size, concentration and the rate of subcritical growth as well as on the probabilistic distribution of defect control and repair, heat, stress and radiation loads.

In the primary circuit elements of the nuclear power plants a number of the crack growth mechanisms, such as low-cycle and many-cycle fatigue, stress corrosion cracking, corrosion fatigue etc.,can occur. Each mechanism has a different dependence determining the crack growth rate.

In the general case for the subcritical crack growth, the following dependence can be used:

$$X = A * q_1(\sigma,\Delta\sigma,t,N,PH) * f(x) \qquad (1)$$

were: σ, $\Delta\sigma$ are the stress and the stress amplitude, respectively;

t is the temperature;

N is the loading frequency;

PH is the water-chemical regime characteristic.

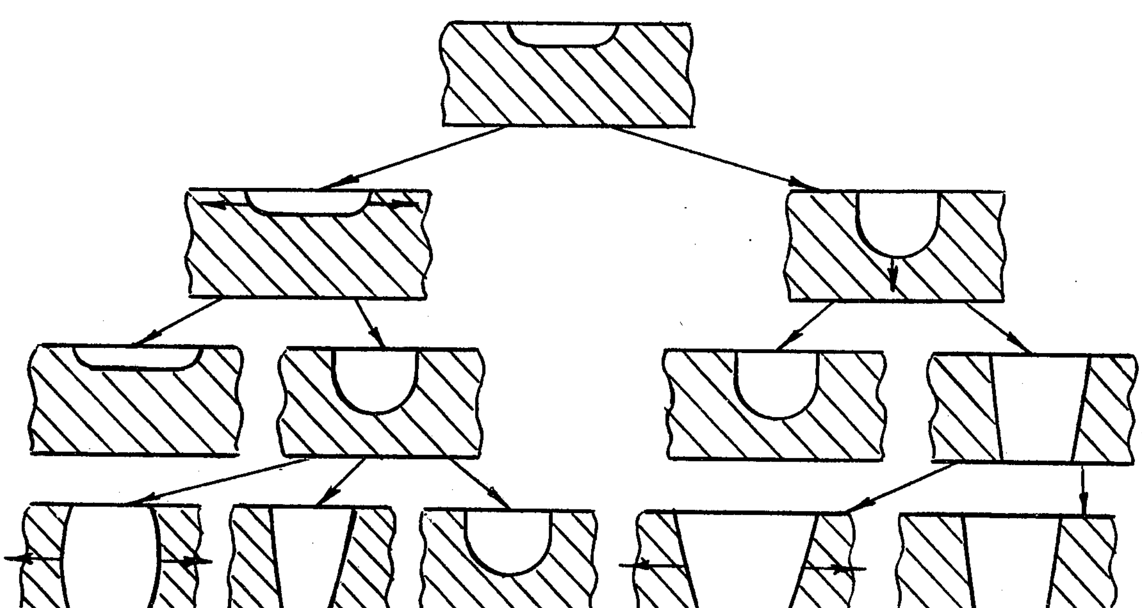
The form of the q and f function is specified after choosing the dependence for calculation of the coefficient stress intensity taking into account of the geometry of the structure calculated.

The current crack size is calculated using the iteration method.

The algorithm for the calculation of the statistical distribution of defects in sizes with allowance for their subcritical growth has been developed both for the case when the coefficients in formula (1) are deterministic and for the case when these coefficients take the random values.

In the process of the subcritical growth of the cracks they may reach the size equal to the pipe wall thickness, which means the initiation of leak. For calculating the probability of this event the function $\Psi(A, a, b, \Delta\tau, \sigma_{ij}, \Delta\sigma_{ij}, t, N_i, PH, \ldots)$ is introduced, which becomes equal to unity when at the parameters given in brackets, the crack of depth "a" will penetrate for a time $\Delta\tau$ through the wall; otherwise, function Ψ becomes zero. Here A is the coefficient in the formula of subcritical growth of cracks; a,b are the current values of the defect depth and length, respectively; τ_{ij}, $\Delta\tau_{ij}$, N_i are the stresses, theiramplitude and the frequence of loading cycles for the i-th operation regime in the j-th sequence of regimes.

The following possible scenarios of the initial crack propagation are considered (Fig.1) in the procedure.



For the calculation of the probabilities of leak and break onset in the case of the avalance-type penetration of the crack into the pressure vessel wall or in its starting along the wall the dependence of linear and non-linear fracture mechanism are used. The probability of the failure or depressurization of the structure having "n" cracks is calculated as an addition to intersecting of "n" independent random events involved to non-destruction of the structure with one crack.

The procedure contains a method for determination of the size of the leak resulting from the opening of the crack taking into account the associated dynamical effects.

The ultimate aim of a design for a strength of pipelines and pressure vessel is an estimation of a surface area having opened as a result of a occurence at a through crack. A way for determining this area has been developed in the method at predetermined length and trajectory of the crack propagation with allowance for dynamic effects. The following possible trends of investigation can be singled out using the mentioned:

1. Assessment of leak and break probabilities for various elements of NPF concrete units.

2. Analysis of realization of concept "leak before break" for pipelines and vessel.

3. Varying of input parameter characteristics in order to arrange them in degrees of influences on a final result.

4. Optimization of a time-limits of testing RP high pressure vessel (hydraulic pressing, hydraulic tests, nondestructive control).

Calculation of the probability function of the cracks' critical sizes in the startup and shutdown for various operation modes with allowance for statistical spread of the mechanical characteristics.

To check whethere the procedure can adequately describe the actual processes and mechanisms leading to destriction of the structures and onset of leaks and breaks, the calculation of the failure probabilities of the SG heat exchanger tubes in the technological channels of the RBMK reactors under normal operation conditions was carried out. The astimates obtained were compared with the available statistical failure data for such leaking elements.

Fig.2 and 3 presents the comparision results showing a reasonable agreement between the calculations and the experimental data.

In order to check the MAVR-2.1 code availability in the

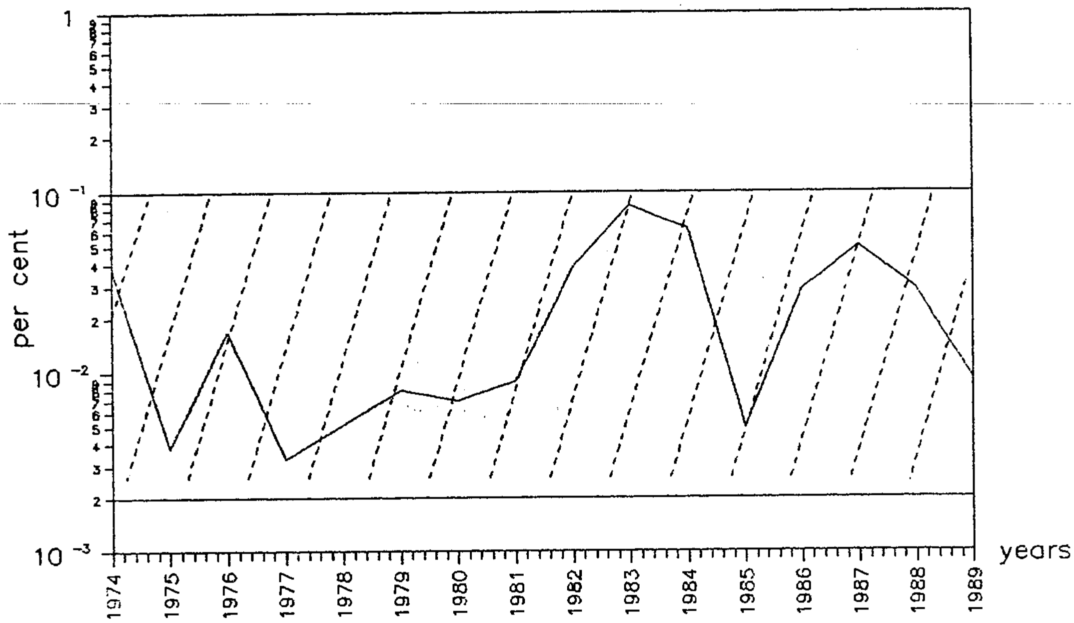


Fig.2 The dynamics of isolation of the failed SG heat-exchanging tubes (dashed lines) and the range of the calculation leak probabilities (shaded area).

——— calculation curve (solid)

- - - operation data (range frontiers) (dashed)

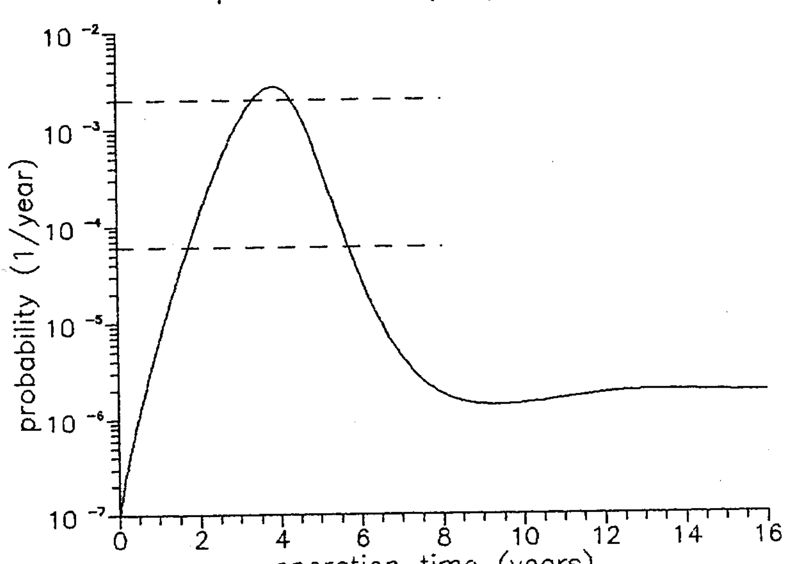


Fig.3 Dependence of the annual average probability of destruction of the zirconium parts of the technological channels on the operation time.

emergency situations, the calculation of the probability of destruction of the HBR-HYPO reactor vessels under conditions of overcooling accidents was performed. The initial data corresponding to the longitudinal weld N 2-273A of the HBR-HYPO apparatus were entered into the program. This permitted the MAVR-2.1 calculation results to be compared with the similar results obtained by the Oak Ridge National Laboratory code OCA-P intended for calculations of the vessel destruction probability in accidental situations. The calculations were carried out for several versions of transients, which were divided into two groups: versions with relatively small and relatively large temperature differences over the vessel wall cross sections. For the group the temperature difference was 70÷100 ^{o}C, for the group it was 130-170 ^{o}C.

Fig. 4 presents the ranges of conventional destruction probabilities calculated for various OCA-P and MAVR-2.1 versions for the single reference volume and single defectness in them. The comparision permits the agreement of the results obtained by two codes to be considered as resonable.

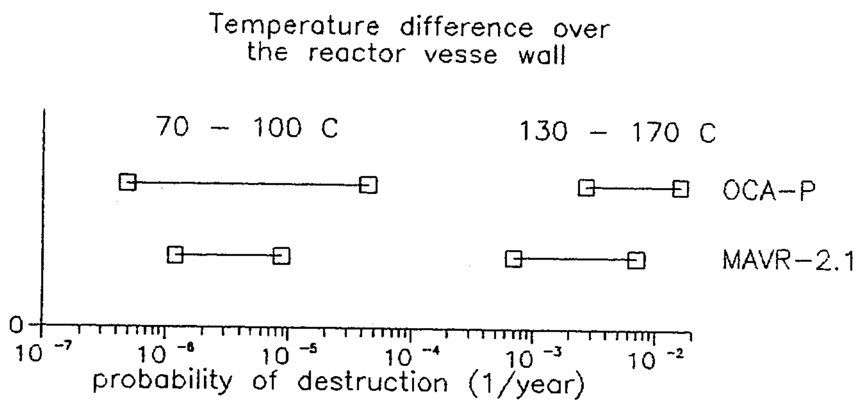


Fig.4 Comparison of the OCA–P and MAVR–2.1 calculations of the destruction probabilities of the HBR–HYPO reactor vessel

Thus, the verification studies of the MAVR-2.1 code under different operation conditions make it possible to cosider it as a reliable tool for solving the problems listed in the first section.

As exemple of the program application, Fig. 5 presents the results of calculation studies of the "leak-before-break" concept validity for various elements of the VVER- and RBMK-type reactors.

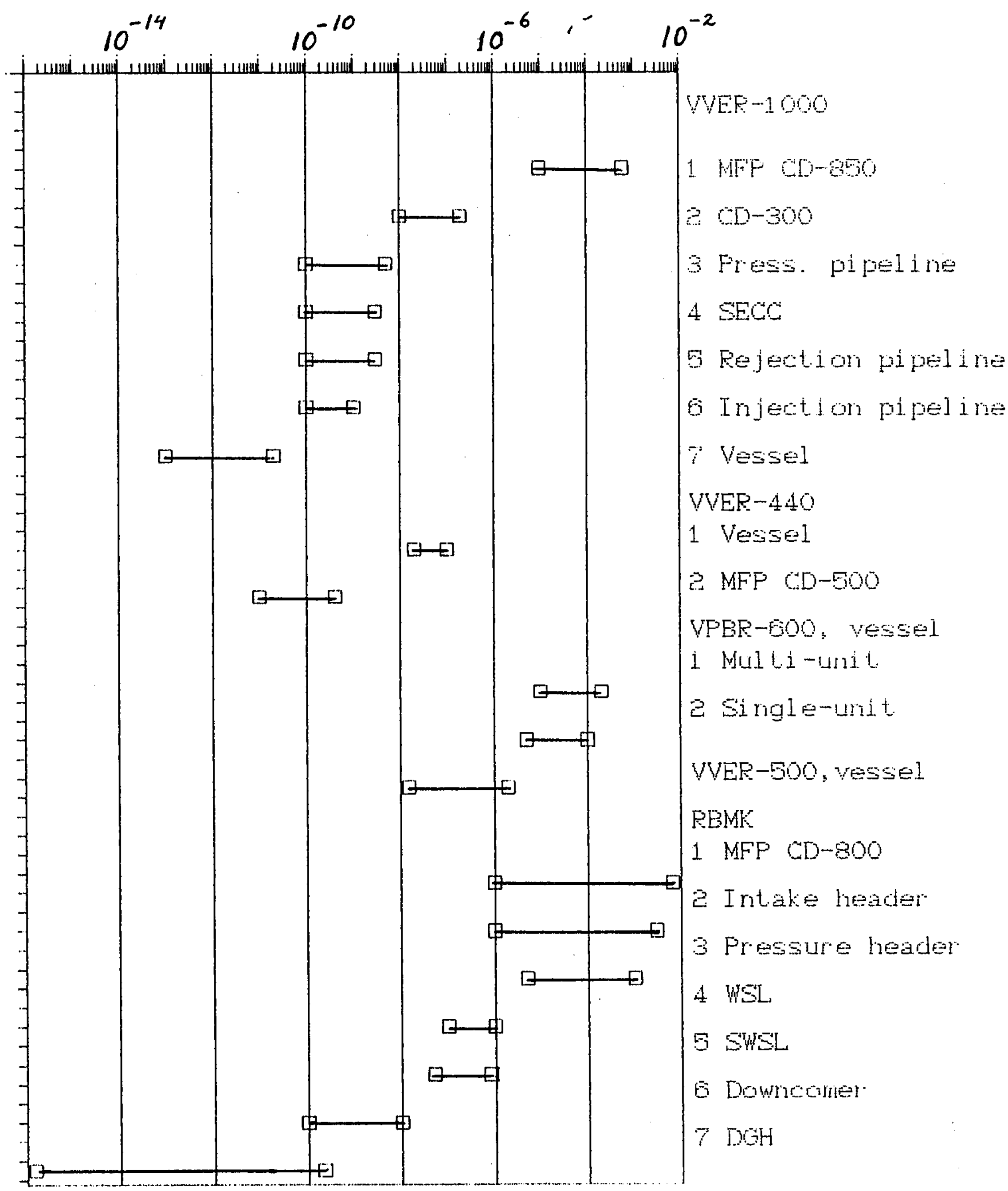


Fig.5.Break/leak probabilities ratio