IAEA Workshop on "Erosion-Corrosion including Flow Accelerated Corrosion and Environmentally Assisted Cracking Issues in NPPs"

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Methodology of NPP elements' FAC problem solving taking into account experience gained in Russia and Overseas

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Scientific-certification training center «Center of Material Science and Lifetime Management»

Scientific-Certification training «Center of Materials Science and Lifetime Management» (SMSLM Ltd.) was organized at 2004 year for more effective use of 25-years experience by guaranteeing of safety exploitation (operation) of Nuclear Power Plants equipment.
At present development of such forms of organizations becomes very important in connection with course of our Government to support of small-scale business.

Center has all necessary licenses of Rostehnadzor, accreditation of Concern Energoatom in the field of guaranteeing of safety exploitation of NPPs and Lifetime management.

Into structure of CMSLM Ltd. there are enter 5 profile Laboratories:

- Laboratory of calculation experimental analysis of residual resource of equipment;
- Laboratory of non-destructive inspection (control);
- Laboratory of material science and mechanical investigations ;
- Laboratory of development of devices (means) for inspection (control) and diagnostic;
- Group of inspection (control) of buildings and structures.

34 specialists work in the Center.
There are 5 doctors of technical sciences and 4 candidates of technical science.
It is extremely important that all our specialists have high scientific and practical qualification, because it gives the possibility to raise not only quality of the works but also responsibility for results. These aspects also are very important when we speak about small-scale business organizations.

The main directions of activity of scientific – certification training Center

The main directions of CMSLM Ltd. activity are the following:

- ❑ Estimation of materials condition of the main equipment, pipelines and buildings and structures;
- ❑ Conduction of the works by substantiation of prolongation of the design period of NPP operation (exploitation);
- ❑ Development and improvement of the methods, methodics and means (devices) for full-scale inspection of the equipment condition;
- ❑ Teaching and training of personnel and publication of text-books in the field of diagnostic of nuclear power engineering objects.

Estimation of materials condition

Estimation of materials condition works in this direction are conduction on the base of Laboratory of materials science and mechanical investigations. This laboratory is equipped by modern devices:

Samples preparation

Mechanical testing

Analysis of structure

Here are conducted investigations of ageing mechanisms of degradations of mechanical properties and structure, development of data base of equipment materials after different periods of operation (exploitation).

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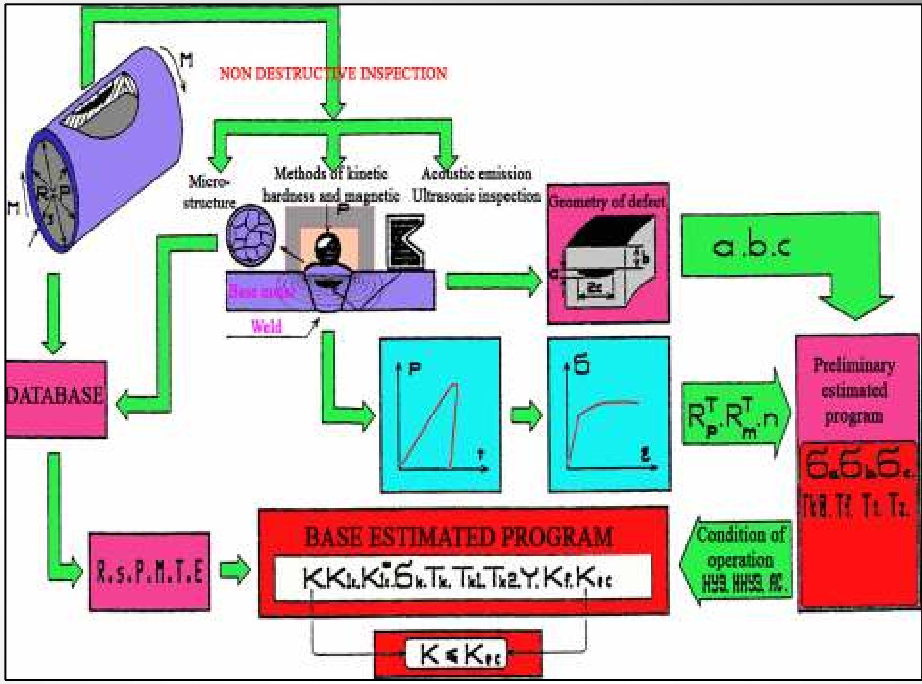
Residual resource

Conduction of the work by substantiation of design period of operation (exploitation) on the base of Laboratory of calculation – experimental analysis of residual resource
Directions of this activity are the following:

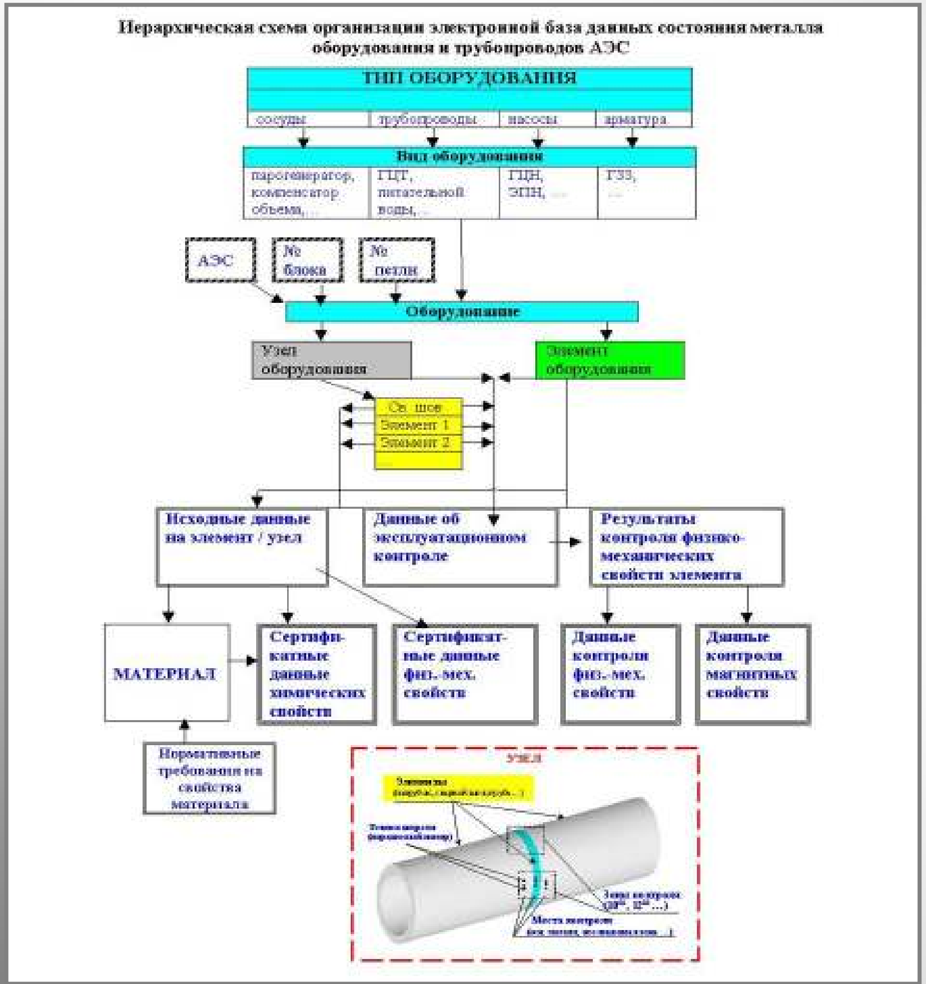
- collection and analysis of design documentation;
- analysis of the history of exploitation (operation);
- check-up (verification) by use calculation estimation of durability and selection of the places (zones) with maximum operational damage;
- organization and conduction of expert full-scale inspection of equipment condition;
- elaboration of technical substantiations of prolongation of operational period (period of exploitation).

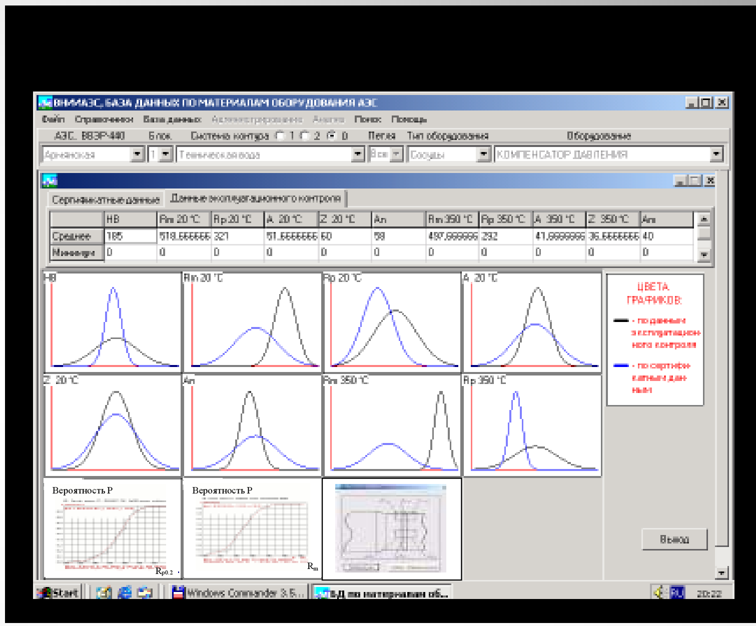


Estimation and of the level of ageing after extra-design period of operation (exploitation).

The multi data base of in-service inspections

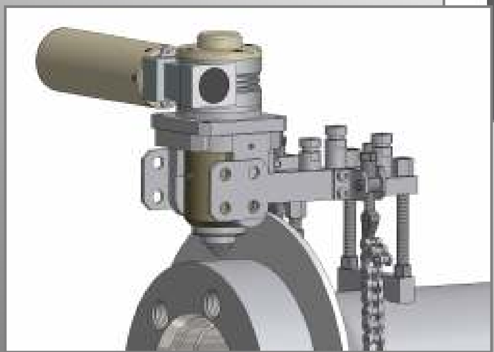
Selection of components → Program management routines and expert control → Data base system of long period

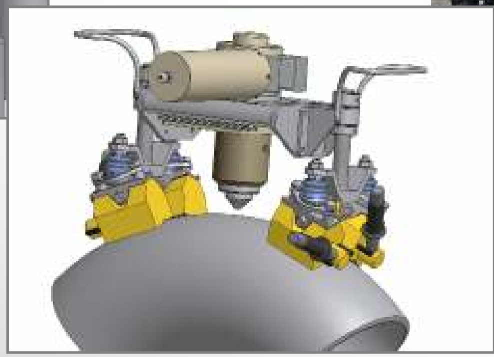




The work by development and improvement of modern methods, methodics and means (devices) of full-scale inspection of the equipment condition are conducted on the base of Laboratory of non-destructive inspection (control) and of Laboratory of elaboration of means of inspection (control) and diagnostic.

Development of specimen-free non-destructive method of the control (inspection) of mechanical properties on the base of kinetic Hardness Method (ABIT).





Introduction to FAC

At present in the atomic industry in Russia there is the problem of improvement of the monitoring of NPPs' equipment and pipelines which are manufactured from carbon steels and are subjected to the flow accelerated corrosion (FAC) wear.

The FAC nature consists in **mutual influence of three physical processes**:

- *corrosion* (chemical and electrochemical);
- *erosion* (mechanical destruction of the surface layer);
- *dilution* (for example of the oxide film).

The objective: to make controllable the type of metal operational damage (degradation) caused by the FAC mechanism and to avoid cases of NPP equipment failures due to the following measures:

- improvement of the operational inspection of metal wall thickness;
- development and application of effective calculative codes for FAC rates assessment;
- execution of opportune repairs (replacements) of the damaged elements;
- reduction of metal wear rates (changing of materials, changing of geometry, reduction of the corrosive activity of a working medium).

History of the FAC problem

For the last 20 years extensive experimental researches of FAC mechanisms had been executed in the world, as a result of this the main factors which are responsible for wear rates are established, and appropriate trends of FAC rates dependence from influencing factors are determined. A push for broad investigations have been done after the accident at the «Surry» NPP, Unit 2 (USA) happened 02.12.1986.

The result of the accident was a guillotine rupture of a section of the feed water piping (Ø 457 mm) from the inlet side of the main feed pump.

Thinning of the pipe was observed at the big area; metal wall reduction was generally from 12,7 to 6,3 mm, and up to 1,5 mm in local zones.

Development of the FAC calculative codes (software)

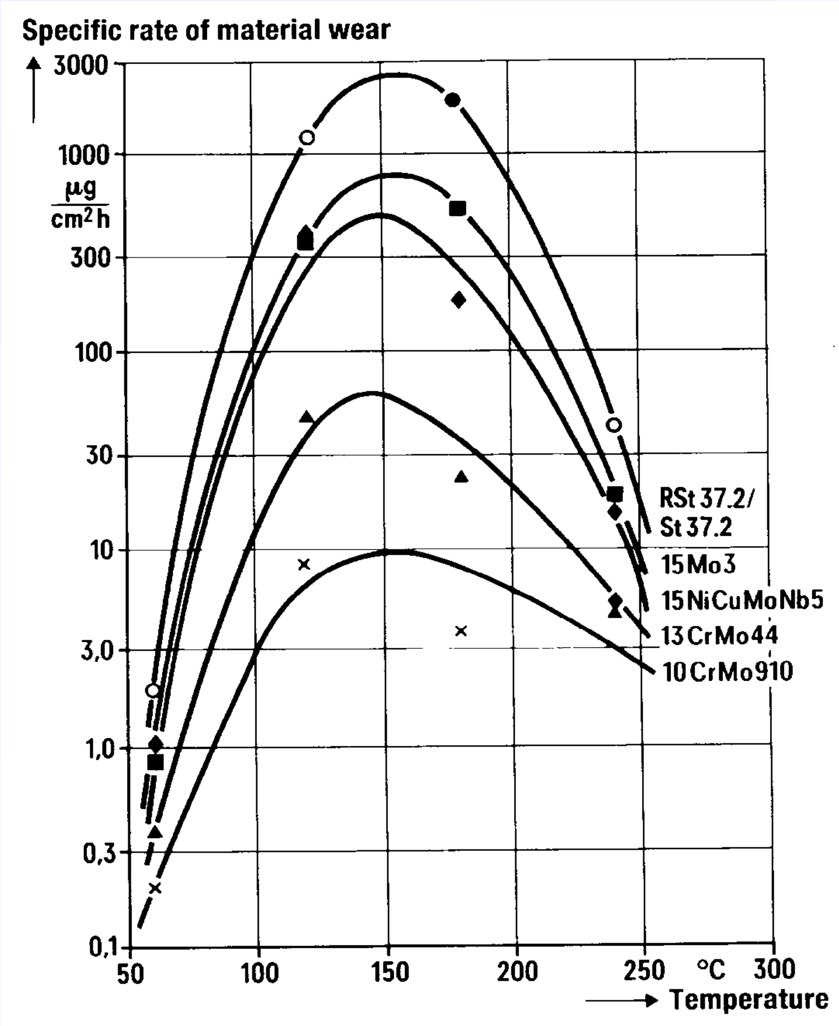
The result of the work on the analysis of reasons of accelerated (more than ten times) compared to the designed thinning of the equipment metal (a design margin set on metal wall thickness to foresee corrosion process is 1,2 mm on 30 years of operation – it is 0,04 mm per year) led to development of the FAC calculative codes (software) for NPP equipments' metal: CICERO in France (1994), CHECKWORKS (CHECMATE) in USA (1995), COMSY in Germany (1998).

The rate of the erosion-corrosion wear (W_{FAC}) in the presented calculative codes is determined as a combination (function) of the following parameters: temperature (T), metal chemical composition (Cr, Cu, Mo), steam content (α), component's geometry (G), mass transfer (MT), pH, oxygen content (O_2).

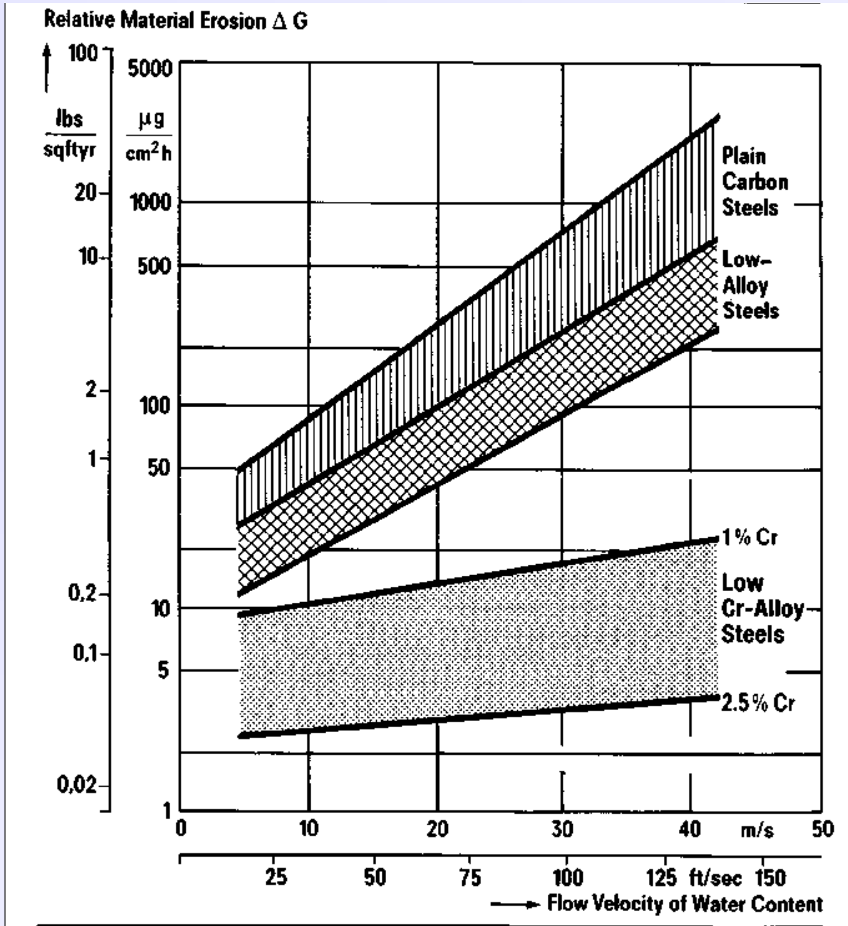
$$W_{FAC} = f_1(T)\cdot f_2(Cr, Cu, Mo)\cdot f_3(\alpha)\cdot f_4(G)\cdot f_5(MT)\cdot f_6(pH)\cdot f_7(O_2)$$

Main trends of FAC rates dependence from influencing factors

Temperature influence



Flow speed influence

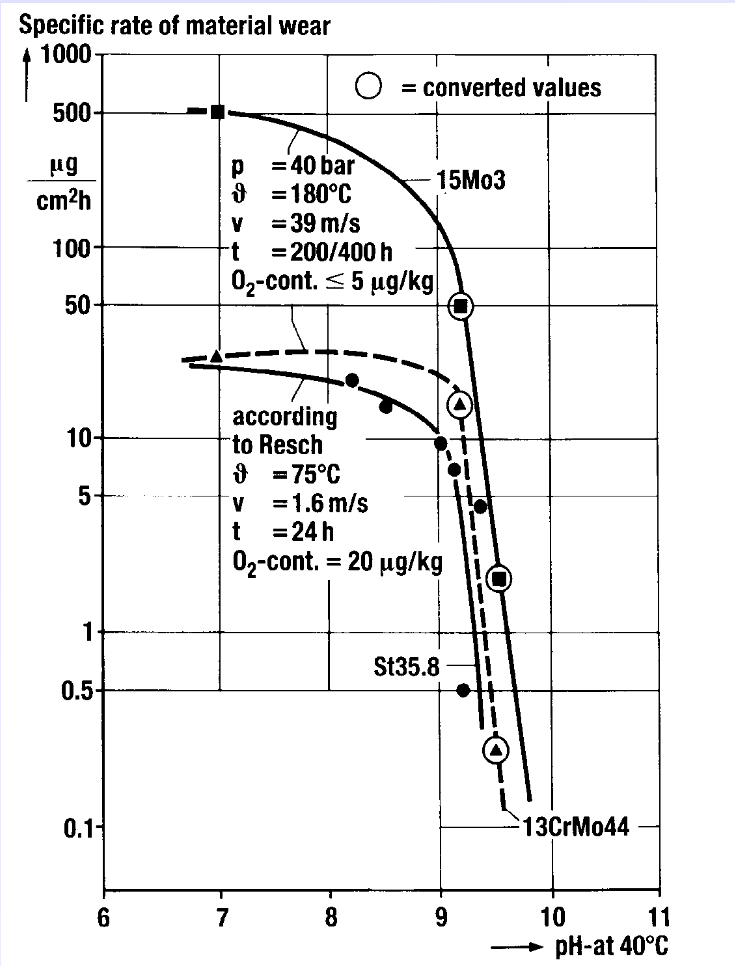


Erosion–Corrosion of Steels
(pH 7, temp. 356°F/180°C, press. 580 psi/40 bar)

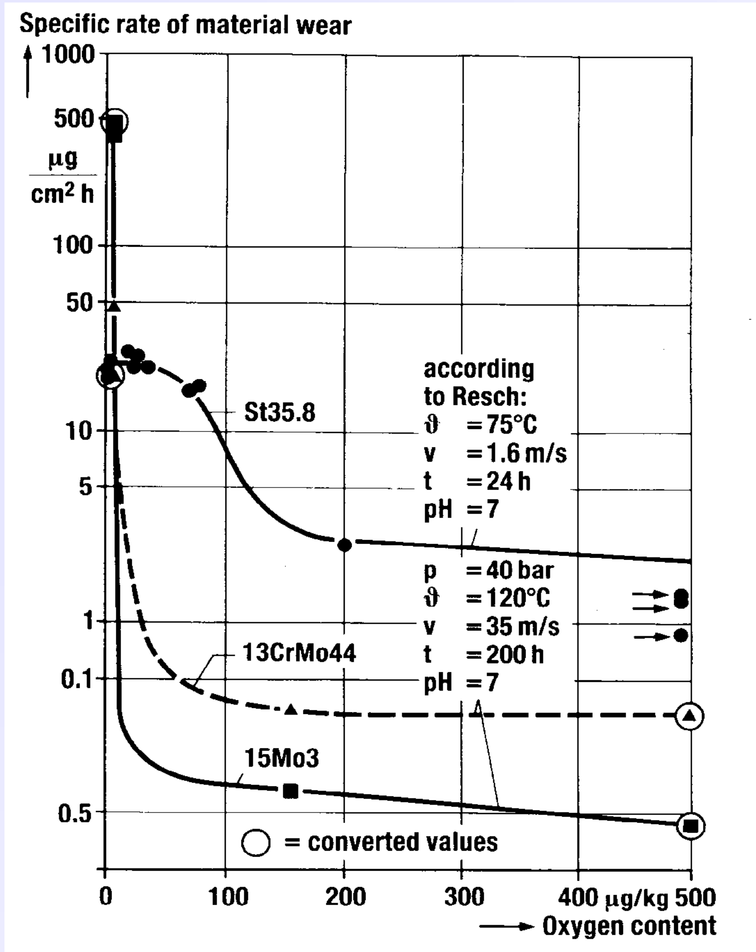
E 85 1712Ce a

Main trends of FAC rates dependence from influencing factors

PH level influence



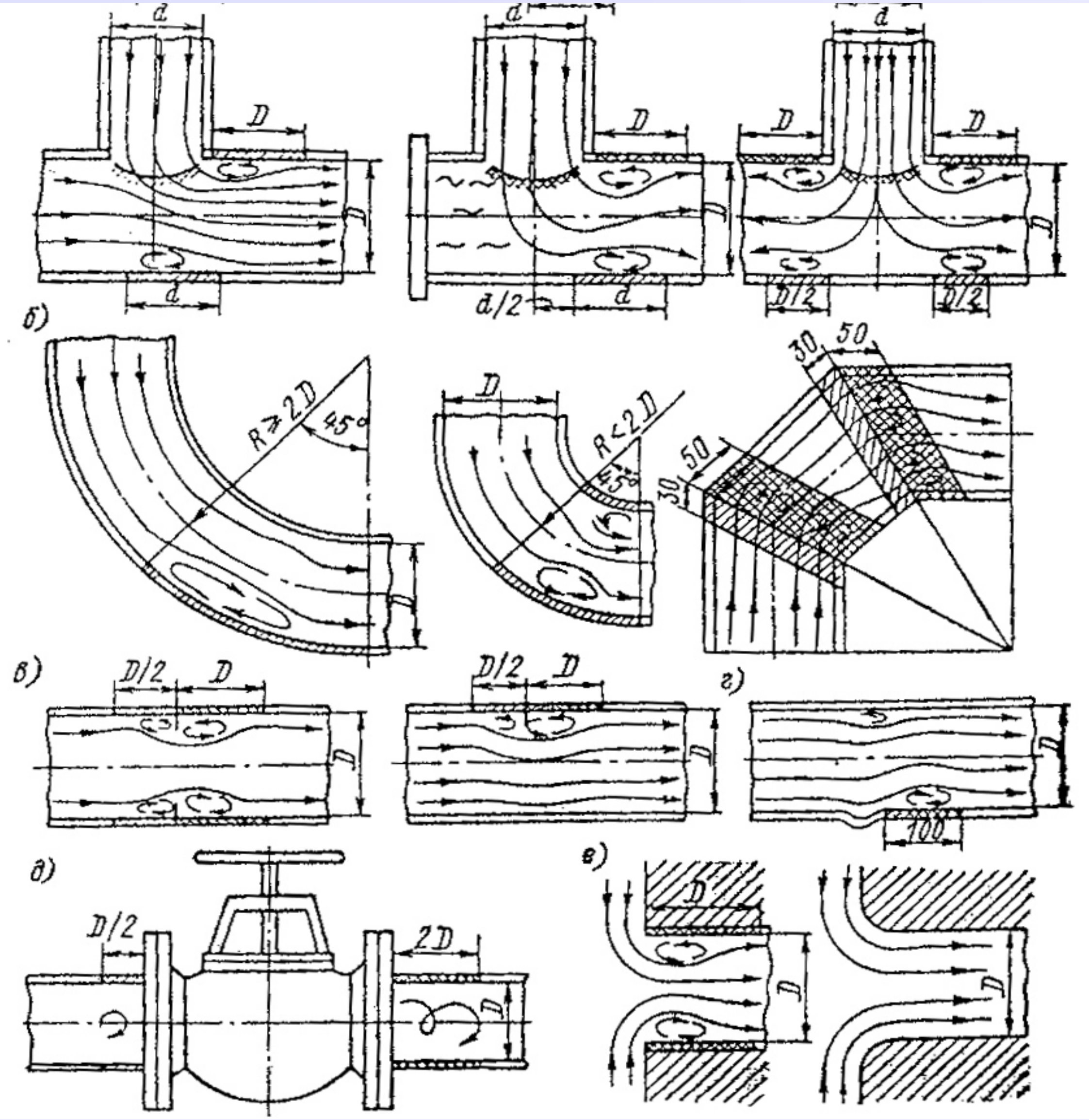
Oxygen concentration influence



Metal chemical composition influence (Dyreks' formula):

$$W_{FAC}=W_{FAC}^{max}/83Cr^{0,89}Cu^{0,25}Mo^{0,2}$$

Influence of elements' geometry on FAC

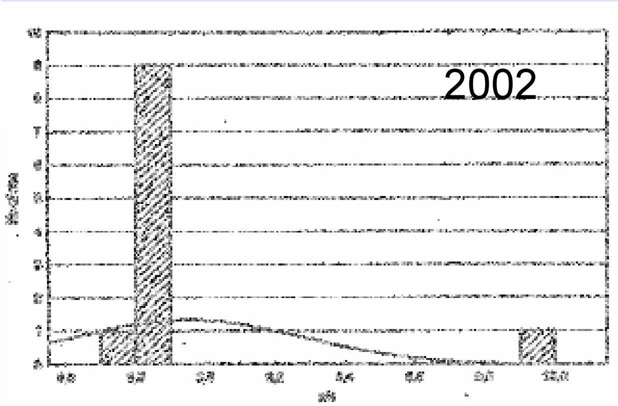


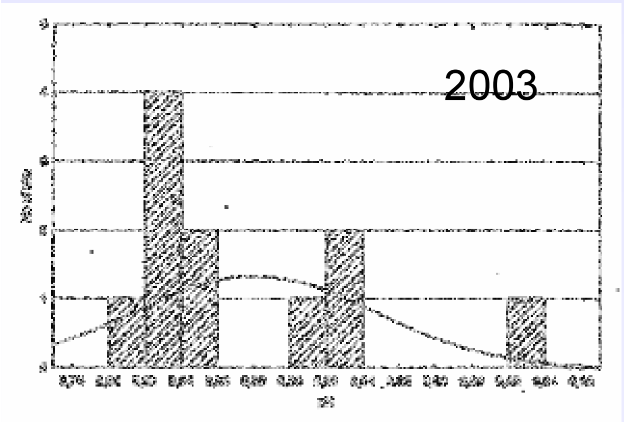
- T-joints
- Bends, elbows
- Orifice, dents
- After fittings and input zones

Instability of the technological parameters

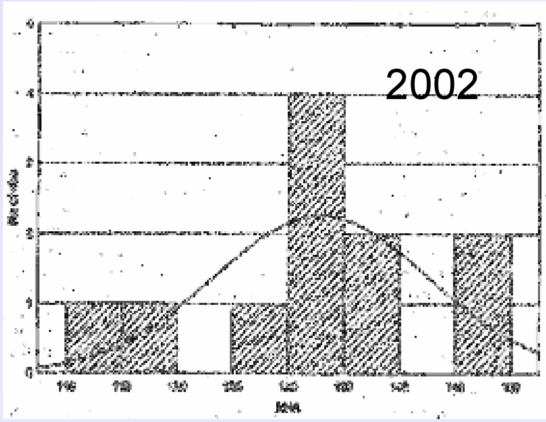
NPP equipments operate in changeable conditions from the point of view of instability of parameters which are responsible for FAC.

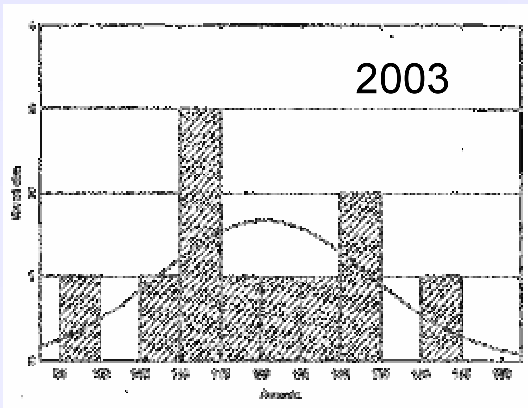
Distribution of pH



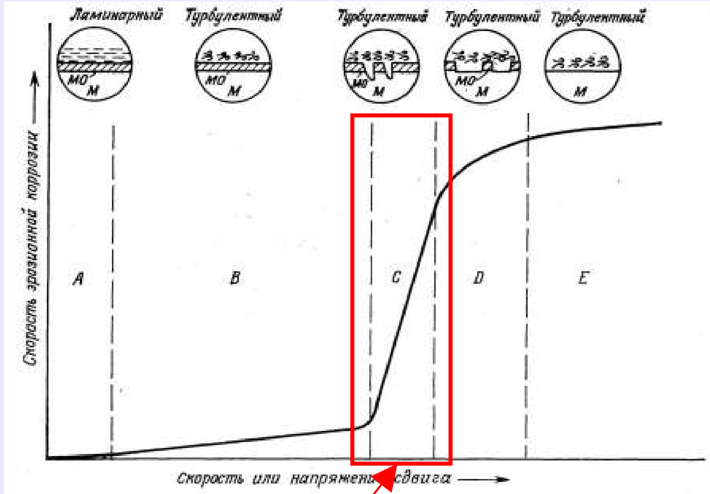


Distribution of ammonia concentrations





Changing of FAC wear rates resulted by the flow velocity



Considerable changing of FAC rates is observed at small changing of the flow hydro-dynamic parameters in the region "C"

Development of FAC calculative codes in Russia

Russia also implements works on development and certification of FAC calculative codes with integration of the world and domestic experience of the activities on the FAC challenge:

- It was executed the development and certification of the software EKI-02 and EKI-03 for calculation of FAC and metal wall thinning of the pipelines working in a one-phase and two-phase medium at WWER-440 NPPs in normal operating conditions. Developer – VNIIAES. The date of certification 17.03.2003 and 23.06.2005. Reg. № 165 from 19.09.2003 and № 534 from 17.03.2003.

- It was executed the development of the software EKI-01 and EKI-04 for calculation of FAC and metal wall thinning of the pipelines working in a one-phase and two-phase medium at WWER-1000 NPPs in normal operating conditions. The work on certification is in progress. Developer – VNIIAES.

- It was executed the development of the calculative model of erosion-corrosion (RAMEK) of metals in a one-phase and two-phase flows. Developer – Geoterm-M.

Problems accompanying the codes application

The base of the successful application of the FAC calculative codes consists in a qualitative collection of **all input data**.

Now at Russian NPPs **the task of the collection** of the reliable and well stored input data for the FAC calculation **is the main task** which is the most labour-intensive and, in some cases, is too hard to be implemented.

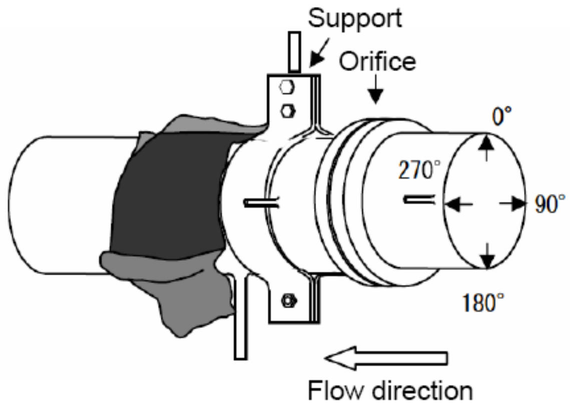
The CMSLM experience gained in works on the collection and analysis of the FAC data at Russian NPPs shows the following main problems to be solved:

- a unified electronic data base which includes the results of a periodical operational inspection of metal wall thinning is not available;
- certificate data on the metal chemical composition for the majority of NPP piping systems are absent, and it leads to necessity of execution of the in-situ metal chemical composition inspection;
- in some cases the actual layouts of piping and elements locations differ from the design and mounting layouts, and this requires the layouts correction in situ;
- problems of determination of actual pH(t) values (at the working temperature) for each specific elements around the circuit.

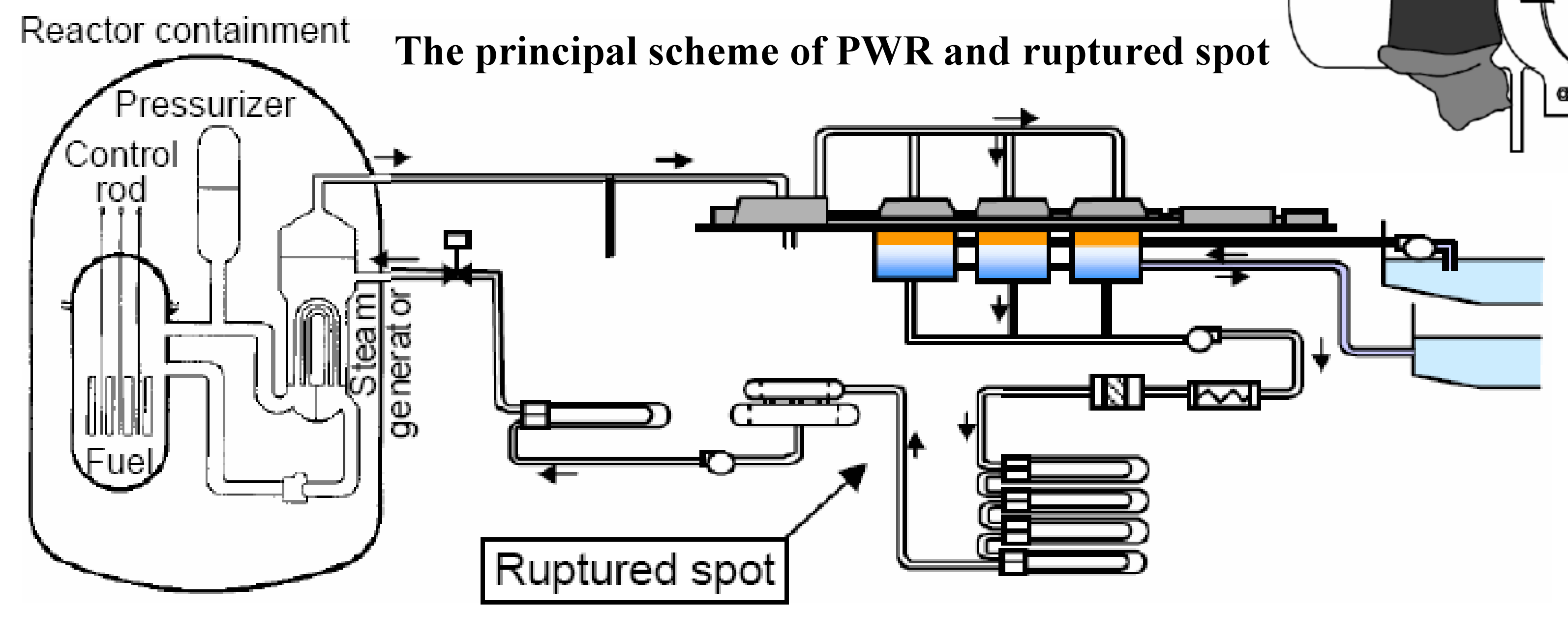
Uncertainties in setting of the input data raise the inaccuracy in calculative assessments of metal wall thinning and it reaches 100 % and more.

History of the FAC problem (continuation)

The second push to the improvement of approaches for calculative-experimental assessment of FAC was made after the accident at «Mihama» NPP, Unit 3 (Japan), happened 09.04.2004. The accident was resulted by the rupture of the condensate pipeline Ø 559 mm of loop «A» at the section downstream of orifice, metal wall thinning was from 10 up to 1,8 mm.



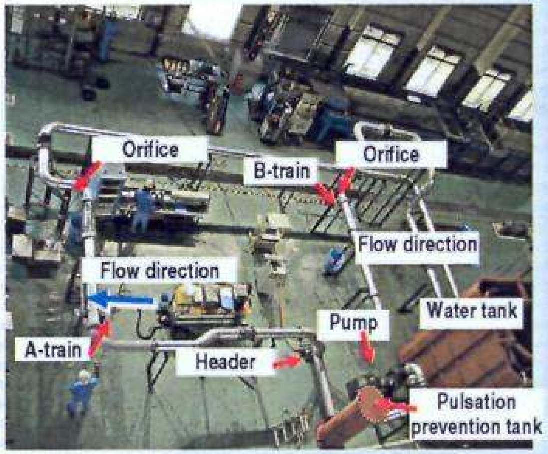
The principal scheme of PWR and ruptured spot



Investigations being made by the Japanese specialists (WANO materials are used)

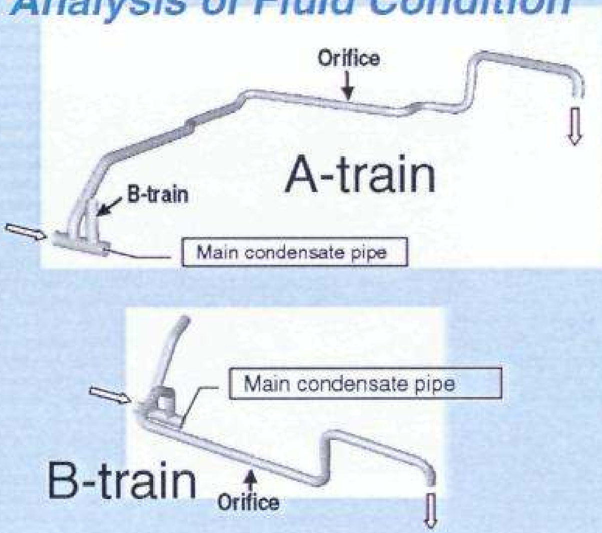
Visualization System and Fluid Analysis Model

Visualization Test



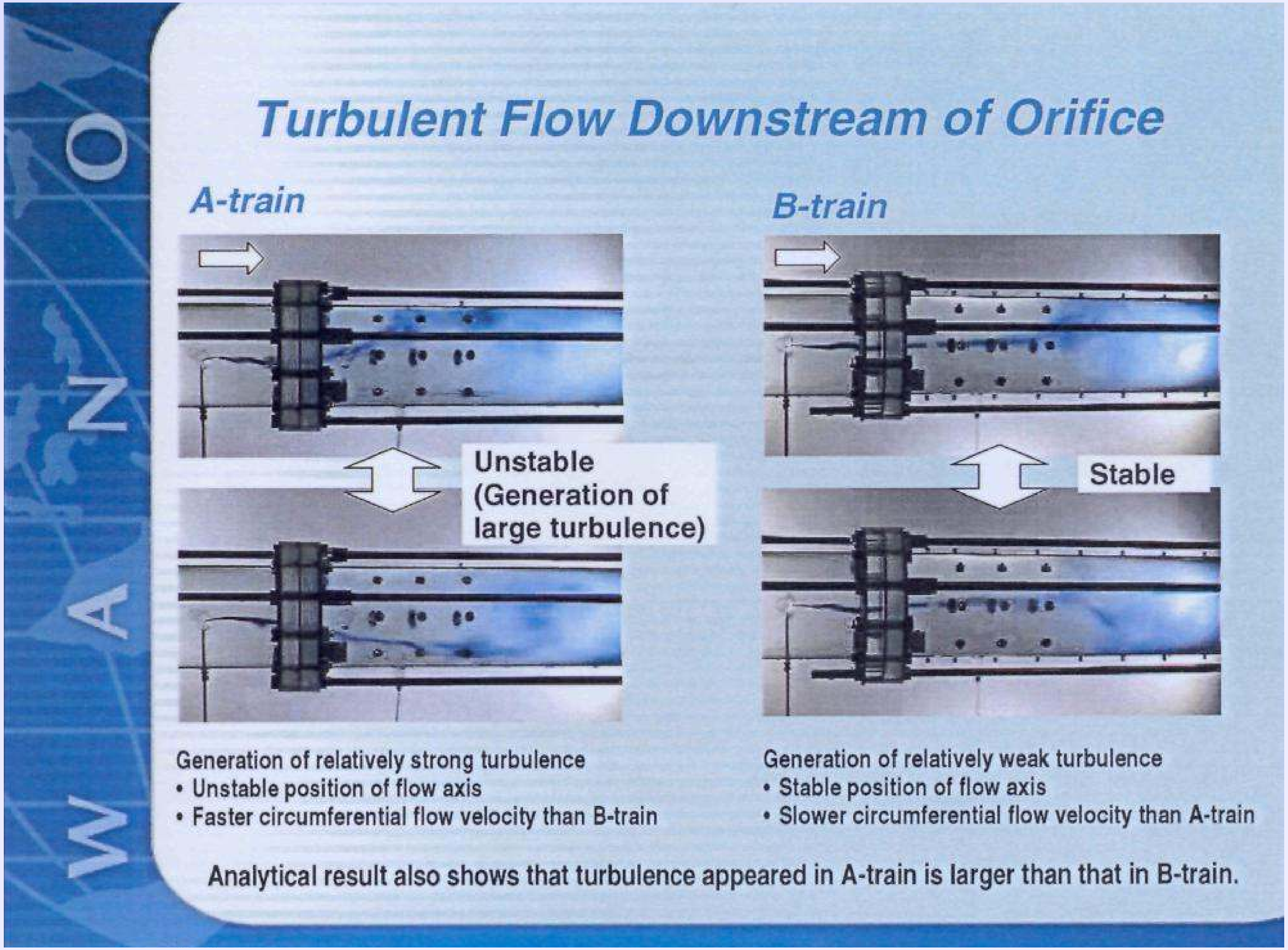
The test system reproduces A and B-train piping from the main condensate pipe header to the section downstream of orifice in a 1/2.6 scale

Analysis of Fluid Condition



The analytical model reproduces A and B-train piping from the main condensate pipe header to the section downstream of orifice

Investigations being made by the Japanese specialists (WANO materials are used)

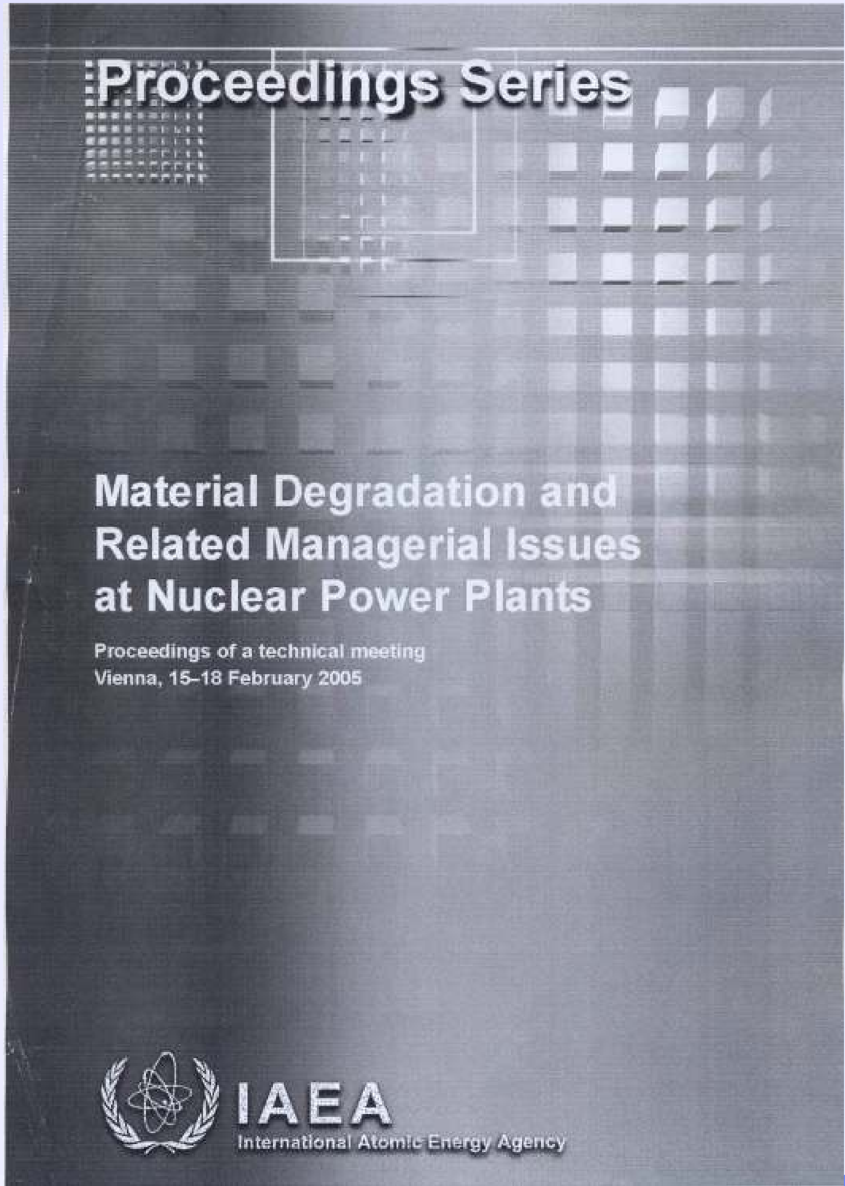


Actions of the concern "Rosenergoatom"

As a result of the described incidents the concern "Rosenergoatom" in order to avoid occurrence of the similar accidents had issued "The corrective actions for Russian NPPs" which were based on a big scope of additional inspections of metal thickness of steam and condensate-feed circuits' piping elements having hydraulic resistance.

In 2006 В 2006 г. the concern "Rosenergoatom" had developed "The comprehensive program of actions on fractures avoidance and increase of operational erosion-corrosion resistance of NPP piping and equipment".

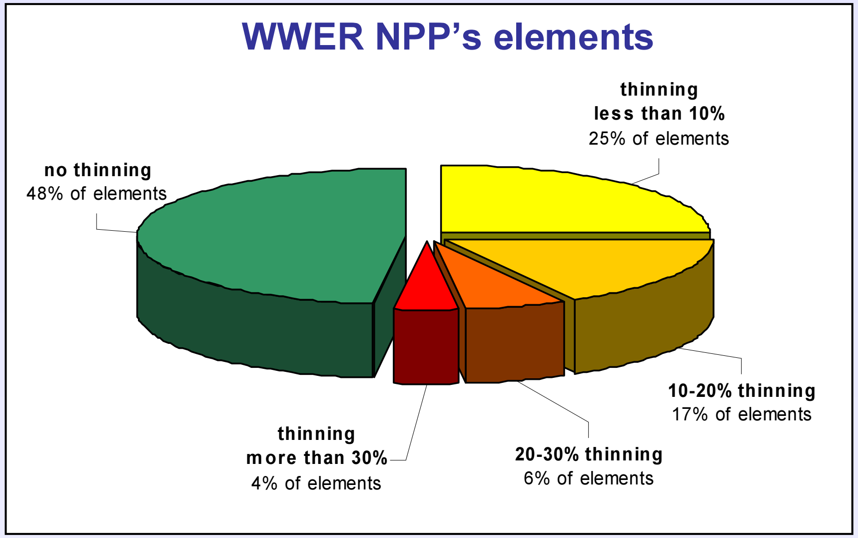
IAEA actions

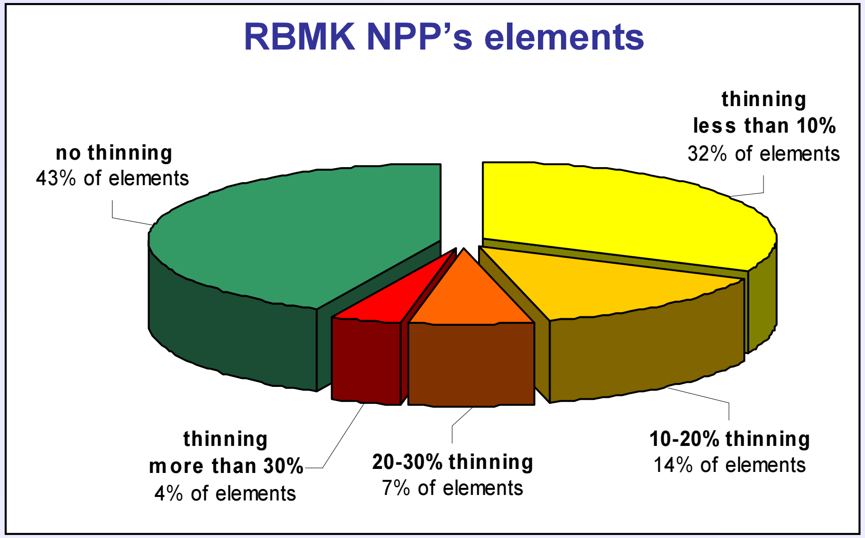


Statistic analysis of the operational wall thinning inspection

Now at Russian NPPs a considerable scope of the data concerning results of the periodical operational inspection of the metal wall thinning is accumulated. These data require their systematization and detailed analysis.

The analysis of the results of the metal wall thinning inspection of typical elements (T-joints, bends, transitions, after fitting) shows that **only 10 % of the total number of elements are subjected to a considerable wall thinning** (more than 20 % of wall nominal thickness) and are potentially dangerous to reach the critical unacceptable wall thinning.





The total number of the type elements subjected to FAC at one WWER-1000 unit is more than 1000 pieces.

Proposals for implementation of the calculative-experiment approach for the FAC control at Russian NPPs

Step 1 Selection of the pilot NPP units (we propose to select the WWER-1000 Units № 1÷4 of the Balakovo NPP – the units are analogous to each other, are of modern type, were commissioned step-by-step during 8 years, have analogous operating conditions; all the facts above allow to collect the relevant data taking into account the real FAC dynamics).

Step 2 Ranking of all NPP elements on groups taking into account the actual wear rates caused by the FAC mechanism.

Step 3 For one-type elements having high and middle FAC wears carrying out the specification of elements' geometry and collection of the input data from all four units.

Step 4 Execution of the metal wall thickness inspection for the chosen elements by use of modern methods (procedures) for wall thickness control, assessment of the wear dynamics through the inspection of one-type elements at the units 1, 2, 3, 4.

Step 5 Execution of checking stress calculations of minimum acceptable thicknesses taking into account the obtained data.

Proposals for implementation of the calculative-experiment approach for the FAC control at Russian NPPs

Step 6 Execution of independent assessment of the effectiveness of various calculative codes with the help of the initial data base containing FAC parameters.

Step 7 Carrying out of the contrastive analysis of the data being obtained through the calculation (step 6) and operational inspection; selection of the most effective software on the base of the performed analysis.

Step 8 Implementation of works on improvement of the software code by using the data on FAC operational inspection.

Step 9 Execution of the calculative validation of zones and FAC rates for the WWER-1000 NPP.

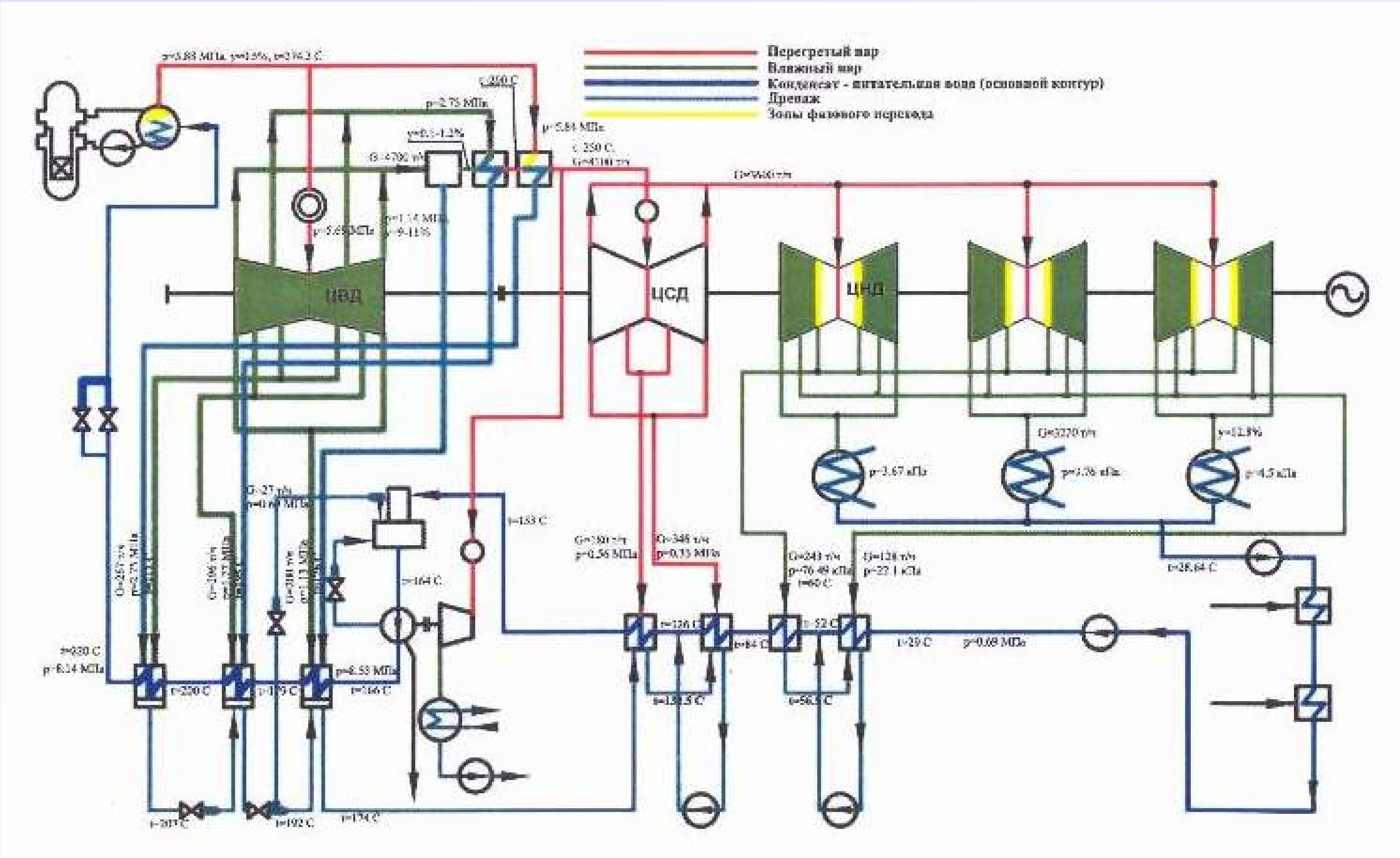
Step 10 Elaboration of the improved "Typical program of operational inspection of equipment and piping base metal and weld joints…" ATPE-9-03.

Step 11 Application of the experience gained on FAC works to the NPPs having another type of the reactor assembly.

Recommendations for the FAC program realization taking into account the CMSLM experience of FAC works gained at Unit 3 of the Balakovo NPP

STEP 2

About **1500 elements** of the secondary circuit were analyzed and **30 most critical elements** after the throttling, regulating and transition elements were selected for the detailed analysis and inspection.



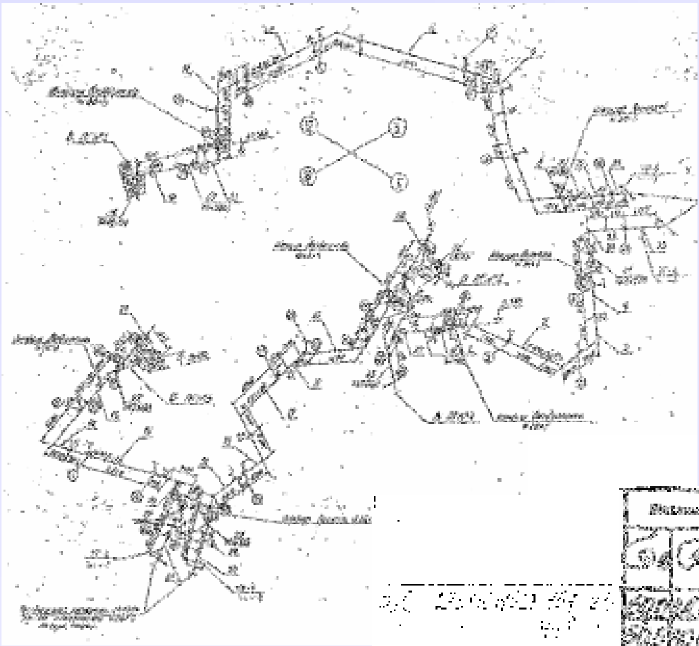
WHAT?

WHERE?

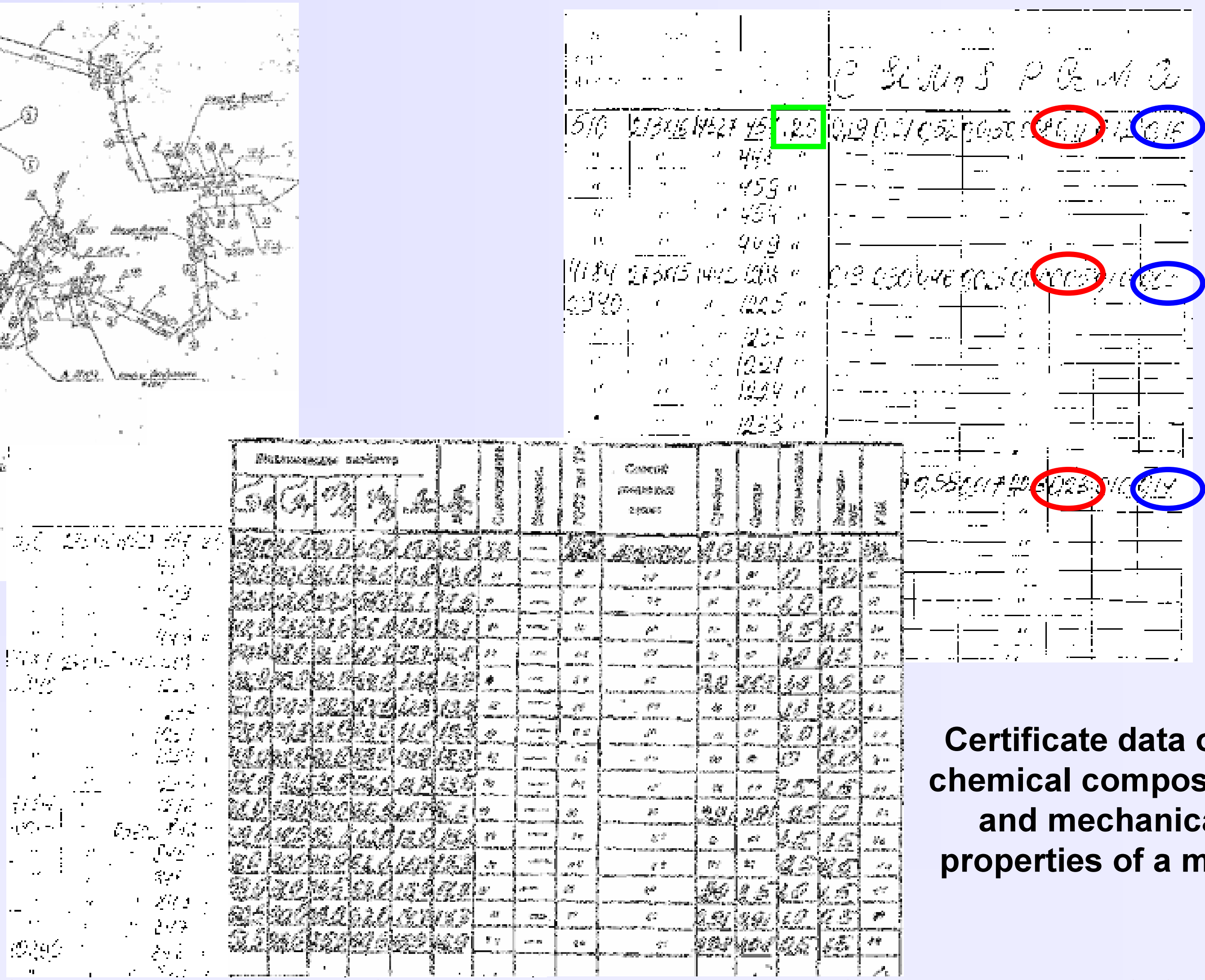
HOW?

To inspect

STEP 3 Collection and analysis of the input data



Example of a piping layout

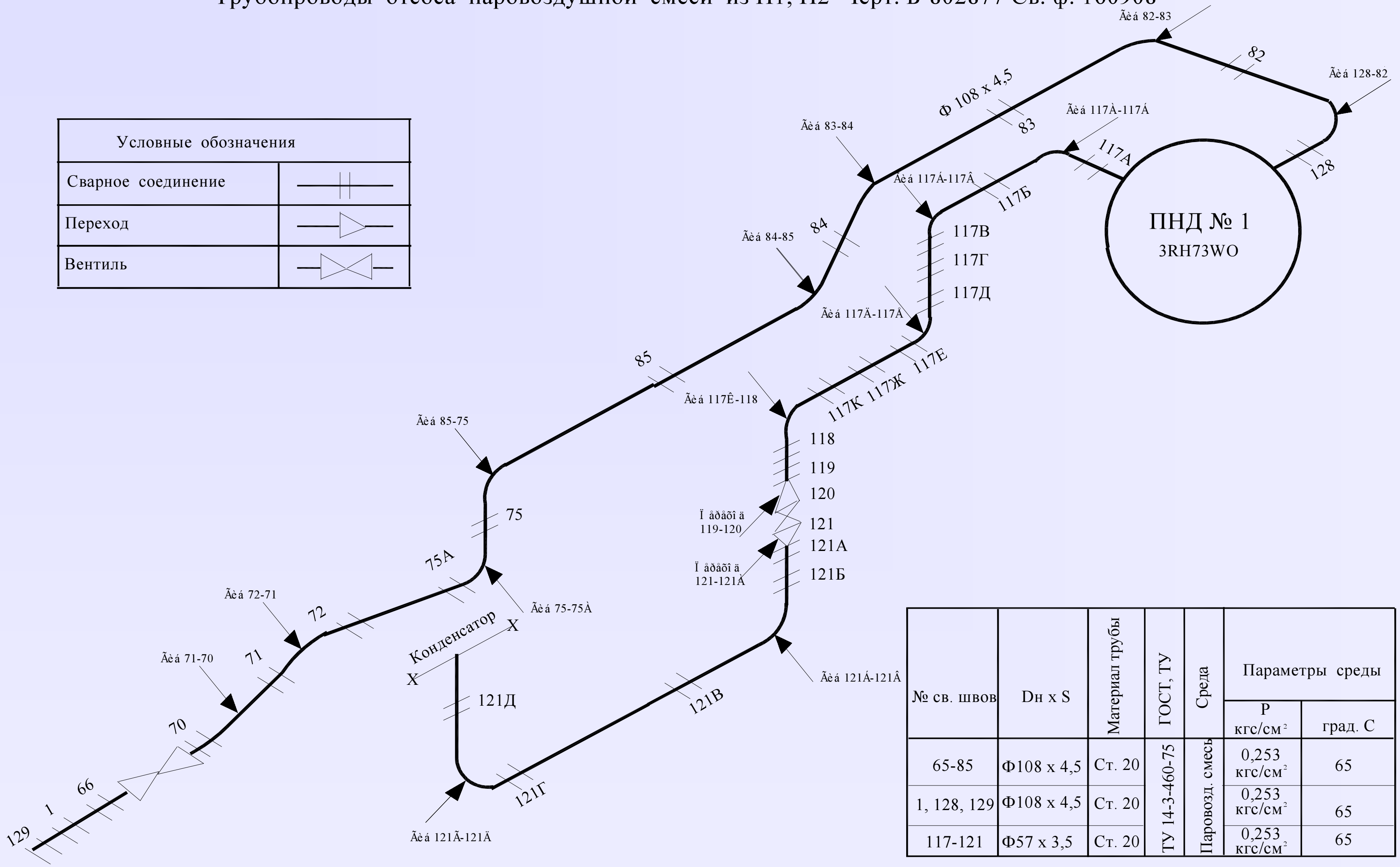


Certificate data on a chemical composition and mechanical properties of a metal

Conclusion: it is necessary to inspect metal chemical composition

STEP 3 Database of pipelines layouts

Трубопроводы отсоса паровоздушной смеси из П1, П2 Черт. Б-802877 Св. ф. 160908



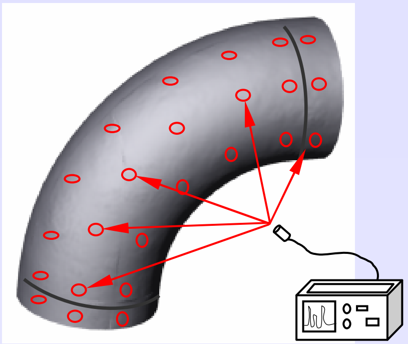
Условные обозначения	
Сварное соединение	
Переход	
Вентиль	

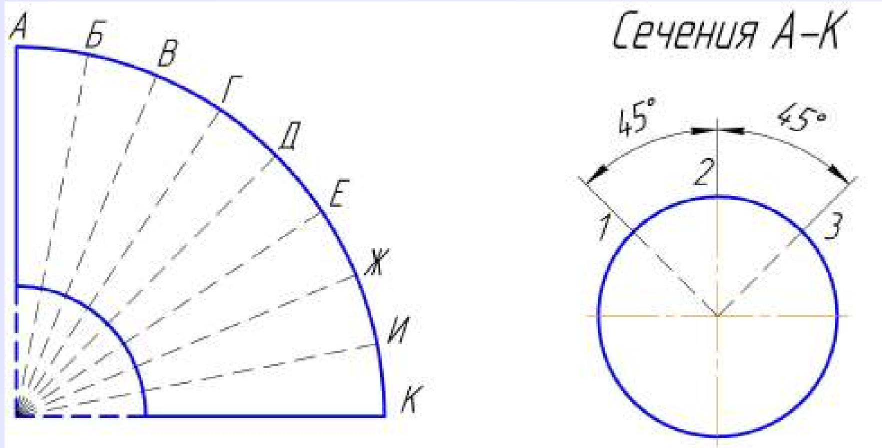
№ св. швов	Dн x S	Материал трубы	ГОСТ, ТУ	Среда	Параметры среды: P кгс/см²	Параметры среды: град. С
65-85	Ф108 x 4,5	Ст. 20	ТУ 14-3-460-75	Паровозд. смесь	0,253 кгс/см²	65
1, 128, 129	Ф108 x 4,5	Ст. 20			0,253 кгс/см²	65
117-121	Ф57 x 3,5	Ст. 20			0,253 кгс/см²	65

Conclusion: it is necessary to specify the geometry

STEP 4 In-situ inspection of metal thickness

Traditional inspection of metal wall thickness

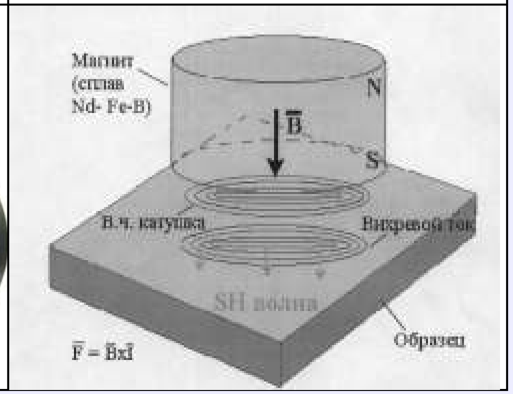




More informative continuous wall thickness inspection

Main objectives

- Continuous scanning of metal surfaces
- Reconstruction of FAC wear 3D-shapes
- Revealing of a local wall thinning
- PC-recording of the inspection data
- No surface preparing for the inspection

EMA-tester	Physical principle
	

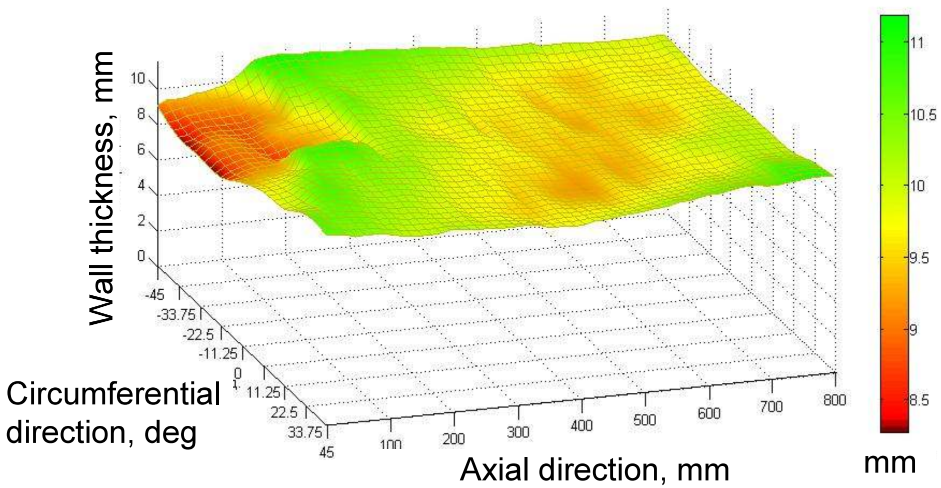
STEP 4 In-situ inspection of metal thickness

Traditional form of the inspection results

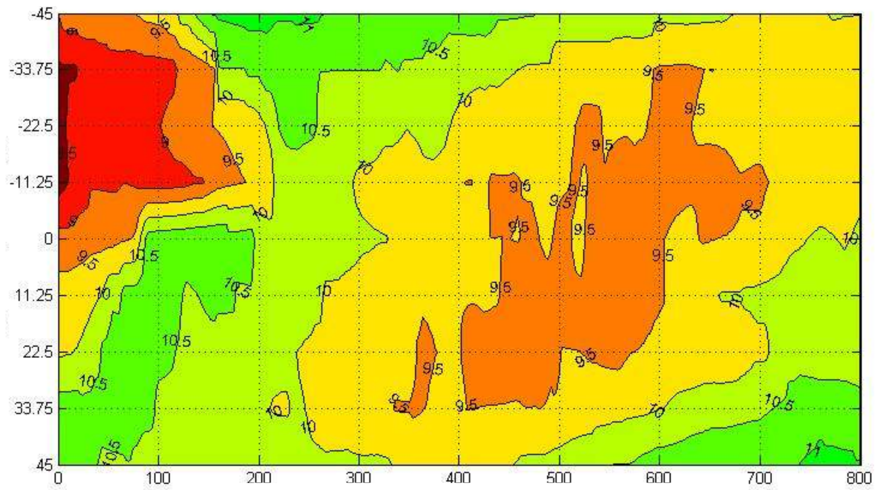
Зона контроля, град.	Места контроля толщин по участкам, мм								
	0 (А)	100 (Б)	200 (В)	300 (Г)	400 (Д)	500 (Е)	600 (Ж)	700 (И)	800 (К)
-45°	9.01	9.67	11.17	10.99	10.70	10.29	10.10	9.97	10.00
-33,75°	8.33	8.80	10.60	10.50	10.15	9.71	9.45	9.69	9.87
-22,5°	8.36	8.94	9.83	10.21	9.90	9.71	9.45	9.73	9.70
-11,25°	8.32	8.77	9.54	9.93	9.90	9.57	9.45	9.38	9.84
0°	9.15	10.78	10.36	10.07	9.81	9.36	9.48	9.63	10.10
11,25°	9.76	10.68	10.36	9.87	9.53	9.34	9.46	10.08	10.05
22.5°	9.92	10.63	10.29	9.77	9.55	9.43	9.57	9.90	10.15
33,75°	10.73	10.37	10.03	9.72	9.65	9.60	9.98	10.41	10.69
45°	10.66	10.34	10.27	10.05	9.79	10.17	10.72	10.85	11.02

Improved (modified) form of the inspection results

3D-shape of FAC wear surface



Flat topogram of FAC wear surface



STEP 5 Assessment of internal FAC features

It is important to understand the main failure mechanisms caused by corrosion. The two mechanisms are:

• **Leakage.** This results in relatively small loss of product.

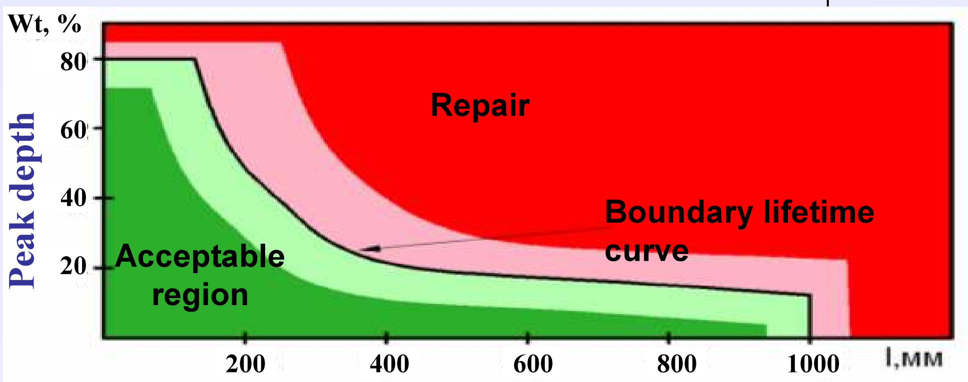
• **Rupture.** Larger defects fail with a sudden release of pressure that can cause propagation or “running” fractures in isolated cases.

Commonly used FAC assessment methods

Approach 1
Effective area methods:
• ASME B31J
• RSTRENC

Defect assessment strategy

Approach 2
UTS based methods:
• DNV level 1
• Ritchie & last
•Battelle



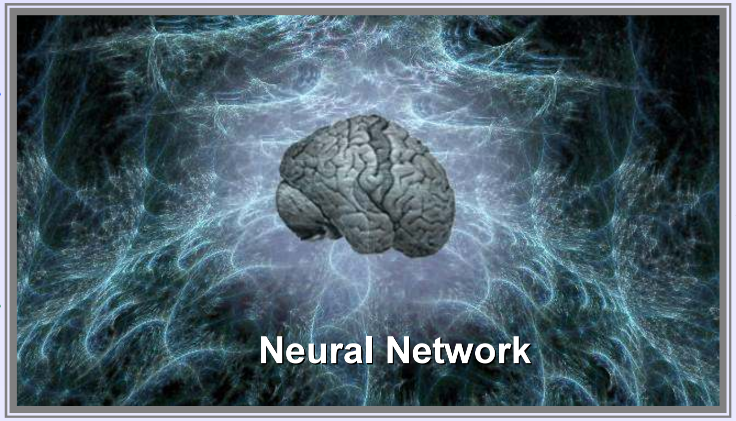
Axial length

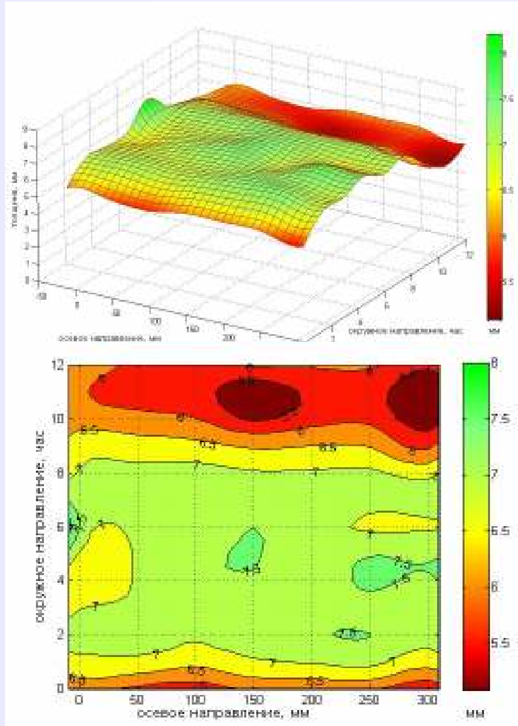
STEP 6

Application of neural networks

Element's work parameters:
- -pH
- -temperature
- -chemical composition
- -oxygen
- -time of operation

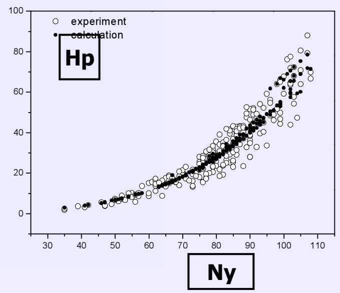
Checking stress calculation





Model of kinetics of damages

PREDICTION of appearance and growth of defects



STEP 7 The modeling and prediction of the erosion-corrosion damage on the Chech WWER NPPs – application of the CHECKWORKS code

Beginning from 1993 CHECKWORKS software is successfully used in Chech republic for WWER-440 and WWER-1000 NPPs.

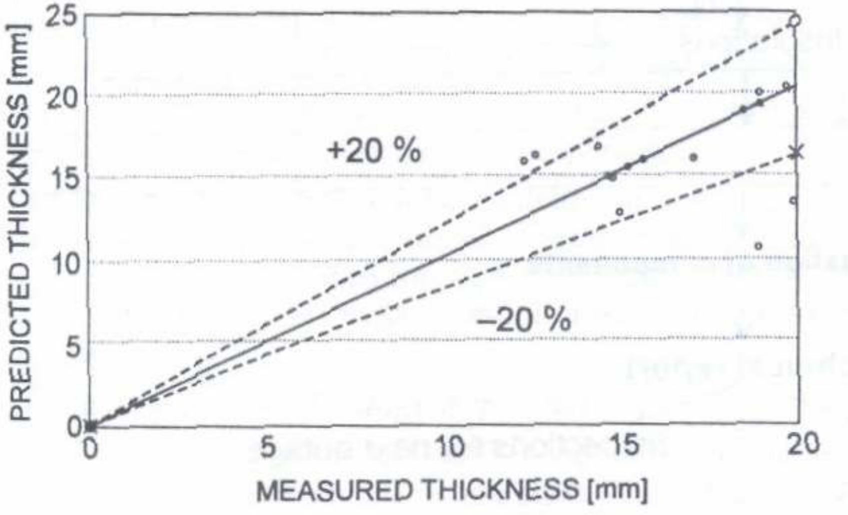


Fig. 3 The correlation between predicted and measured wear in FW piping. Outage 12/1993.

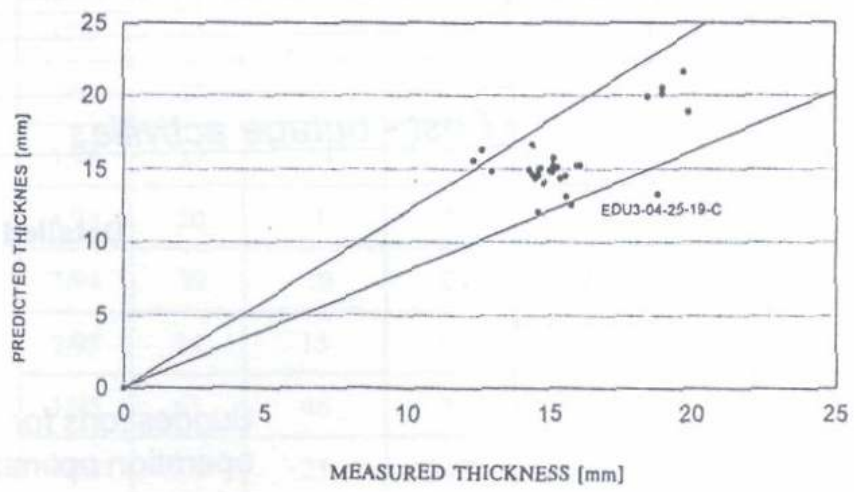


Fig. 4 The correlation between predicted and measured wear in FW piping. Outage 1/1995.

Thank you for attention