Possible Solutions for Improving Operational Safety of NPP

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Following the accident in Fukushima Daiichi NPP stability of NPP against external conditions was verified by applying stress-tests and achievement of high-level operational safety satisfying "international requirements" was declared all over the world.

Nevertheless, given the experience of at least two accidents – Armenian NPP in 1982 and Chernobyl in 1986 (the author had been involved in elimination of consequences of the latter) – we shouldn't have made this declaration with such confidence. Internal latent factors remained out of sight – appearing to become possible sources of accidents or of their progressing. These factors did not make themselves known before the specific situation and therefore don't appear in any document type of "Probabilistic Safety Analysis" or "Safety Analysis Report" and can't be discovered using stress-tests.

Some of the hidden factors and possible ways of overcoming them have been investigated in the present paper.

One is In-core Monitoring Systems (IMS) based on the ideology of the neutron monitoring and neutron detectors acting as primary transducers. A hidden defect, not taken into account in the safety analysis could be caused on one hand by the absence of a reliable metrological maintenance of neutron detectors and on the other hand by the influence of the processes of burning out detector fuel and materials (processes burnout) on the reliability of the measurements and the resulting information. Accounting for these factors is associated with the large volume of related assumptions, additional data and auxiliary computing operations [1, 2]. This leads to the presence of software of huge complexity in today's ICMS, which may result in failure of standard systems in an emergency situation to give the information necessary for adequate decision-making.

The defect can be eliminated if we include in neutron IMS a system based on monitoring thickness of the gamma radiation flux, which is accurately connected to quantify the fission rate.

A project of this kind had been done by us in case of the 2nd unit of the Armenian NPP in 1985 [3]. As primary transducers we used specially developed calorimetric gamma detectors (CGD) [4] (Figs 1, 2, 3). The main advantages of such a system are:

- reliability of metrological provision of primary transducers;
- presence of the calibration element within the detector;
- avoiding the effects of burnout and simplicity of the algorithm for transition from the reading by transducers to the energy release in cassette.

In numerous commissioning experiments and long-term endurance tests on the unit, the information content and reliability of gamma transducers and measuring channels - calorimetric probes as well as the accuracy and reliability of the control algorithms have been verified (Figs. 4, 5). The system withstood without loss of function even the common-cause accident at the NPP (1982) and the emergency situation in time of the earthquake in Spitak in 1988 (in the area of NPP magnitude 7 was measured).

The combined system IMS - on the basis of two independent monitoring channels - can be implemented at the level of power unit as a diagnosing system with functions of early prediction and detection of abnormal situations in the technology process (Figs. 6), and we implemented post-accident monitoring of reactor facility. This combination will significantly increase the level of operational nuclear safety of NPP.

The second is control of radiation exposure to the material of the reactor vessel and an assessment of its effects. The hidden defect, which was not taken into account in the safety analysis, was related to inadequate definition of the value of the neutron exposure and to a limited assessment of its effects by using the "method of sample-witnesses." Probability of display of a defect is especially high when assessing satisfactory resources in connection with the general trend of extending the operation period of the reactor.

Today's regulation of these estimates (PB-007-99, Russia, Ukraine ...) requires to define neutron exposure based on flounce of neutrons with $\mathbf{E_n}$ >0.5 MeV, measured by neutron activation detector ^{237}Np. But, first, work with fissile detector is complicated by a number of serious limitations and in practice not carried out. Second, the effective threshold $\mathbf{E_{eff}}$ in the PWR spectre in the area of reactor vessel according to our estimates is about 1÷1,5 MeV and contribution of unrecorded neutron groups in the so-called "damaging flow" is 35 - 40%. According to our information, for example, in the Ukraine, the organisation engaged in research on the programme "sample – witnesses" neutron exposure is generally decided to use experimentally adapted calculation of the spectre.

In fact, experiments, which we carried out between 1979 and 1981 in collaboration with the Central Scientific Research Institute "Prometheus" (Sankt-Petersburg), proved that accounting of radiation exposure would be more adequate and physically justified if it could be determined based on the amount of energy transmitted by neutrons in the process of scattering (elastic and inelastic) in the irradiated material. That is by the amount of the absorbed neutron dose in a given material [5, 6]. According to this approach, the neutron exposure is set for the value of the radiation effect normalised for intensity (neutron dose in the i-th material $\mathbf{D_i}^{\mathbf{n}}$), as a function of the spectral parameter of neutron radiation in the area to be controlled. Method for determination of on-line neutron dose in any material and spectral parameter $P_{f\text{-}H}$, which determines the impact of the shape

of the spectre on the function of damage, was developed and published by us [7, 8]. As for measurement, the above mentioned calorimetric detector is equally used.

The third hidden factor is the lack of an international system of collective nuclear security and expert support of operational personnel of NPP in emergency situations.

In order to implement an international system of expert support of NPP Diagnostic Centre for Higher Level 4 at the IAEA should be organised, and the current regional crisis management centres of all countries operating NPP should be connected to it. At the same time the IAEA should become from an advisory body into a decision-making and enforcing organisation - Collective Nuclear Safety Council – such as the Security Council of the UN. But this requires, of course, taking a decision at the level of Heads of Government of all countries operating nuclear power plants.

The Regional Centre for Crisis Management is technically the top-level diagnostic centre in a 3-tier system to prevent nuclear accidents in each of the IAEA member states. It provides operational support to the operators of emergency unit with their own top-level experts, at the same time concentrating this high level of expertise of their NPP. It is assumed that the initial and primary level of expert support for the safe operation shall be provided by the crisis centre of the NPP and diagnostic system of the unit.

The concept of such a regional system for the Ukraine has been developed by us and published in 1995. [9] To date, the Ukraine implemented all the components of such a system [10] with the exception of just the lower level - the system diagnostics. Therefore, the creation of IMS on the unit with a combined gamma-neutron ideology and two independent channels of primary transducers - to make it a diagnostic system with the function of early prediction of abnormal situations is a priority within the task of significant improvement of operational safety of the reactor facility.

It should be noted that today’s level of security of units provided by gauging means, the overall level of development of information technologies and means of communication - can solve above mentioned problems very quickly and without any problems.

The possibility and efficiency of remote monitoring of highly dangerous technical system was confirmed by organising the remote support for the operators’ diagnostic system “SHATIOR” (“TENT”), created by us on the devastated 4th unit of the Chernobyl NPP. The computing complex of the system has been connected with two pairs of non-switched telephone wires to the analogue complex in Kiev (150 km), which is controlled by physicists having been taking part in liquidation of to the consequences of the accident directly on the unit. Their knowledge of the object itself and experience of dealing with radiation hazardous works provided substantial assistance to the new operational staff of the unit in the event of situations with serious deviations of parameters from the safe level [11].

Literature:

[1] **V. Mitin**, O.Mitina “Metrological characteristics of IMS type M “Atomic Energy” v.103, №2, 2007 (in Russian)

[2] **A.Kurchenkov**, A.Kalinushkin, V.Mitin “Way of definition of energy release in the reactor core according to indications of neutron detectors in use VVER reactors” Patent RF 2451348 from 10.08.2012, Moscow

[3] **Y. Tsoglin** “About possibility of In-core Monitoring System for Reactors VVER-type based on the alternative physical ideology of energy-release monitoring” Magazine of Work of Science from Sevastopol University of Nuclear Energy and Industry, in 1(37) p.73, 2011, Sevastopol, Ukraine (in Russian)

[4] M. Korotenko, **C. Ogorodnik**… and Y. Tsoglin „Radiation-thermal divergentor of integrated energy flux” Patent of the Soviet Union № 230914 Publishers “Inform. Bulletin” №35, Moscow 1968 (in Russian)

[5] E. Kramer-Ageew…and **Y. Tsoglin** “Of neutron exposure in the study of radiation damage of materials in nuclear reactors” Atomic Energy v.34, №4, Moscow 1973 (in Russian)

[6] **A. Parshin** et al. “Material science. Technique of structural materials. Radiation material science” Publishers of Technical University, St.-Petersburg, p. 331, 2003 (in Russian)

[7] **Y. Tsoglin,** S. Ogorodnik “The definition of absorbed dose from neutron scattering in materials irradiated in nuclear reactors” Bull. “Problems of atomic science, the nuclear constants series” №13б, p.123, M.1974

[8] **Y. Tsoglin**, S. Ogorodnik „The spectral parameter of reactor gamma radiation” Atomic Energy v.38, №2, 1975(Russ.)

[9] **Y. Tsoglin** et al. “Ukraine early warning: on-line diagnostics and computer networks for monitoring, accident prevention and response”, Nuclear Engineering, Vol. 40, Nr.490, pp. 31-33, May 1995

[10] **I. Klimenko, L.Taranenko** ivl@ivl.ua, Mag. “Mir Avtomatizacii“№1, Kiev, March 2010 (in Russian)

[11] **Y. Tsoglin** “Standard diagnostics system in the collapsed reactor of the Chernobyl NPP”, Report of Annual Meeting on Nuclear Technology ‘94, Publishers of “INFORUM GmbH” Bonn, Germany, 1994

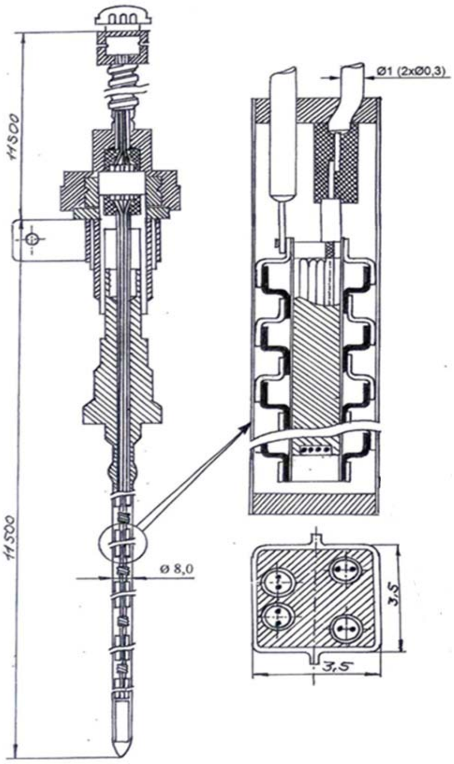

Figure 1: Calorimetric gamma-probe and gamma-calorimeter for energy release monitoring Channel of reactor VVER-440 of the Armenian NPP

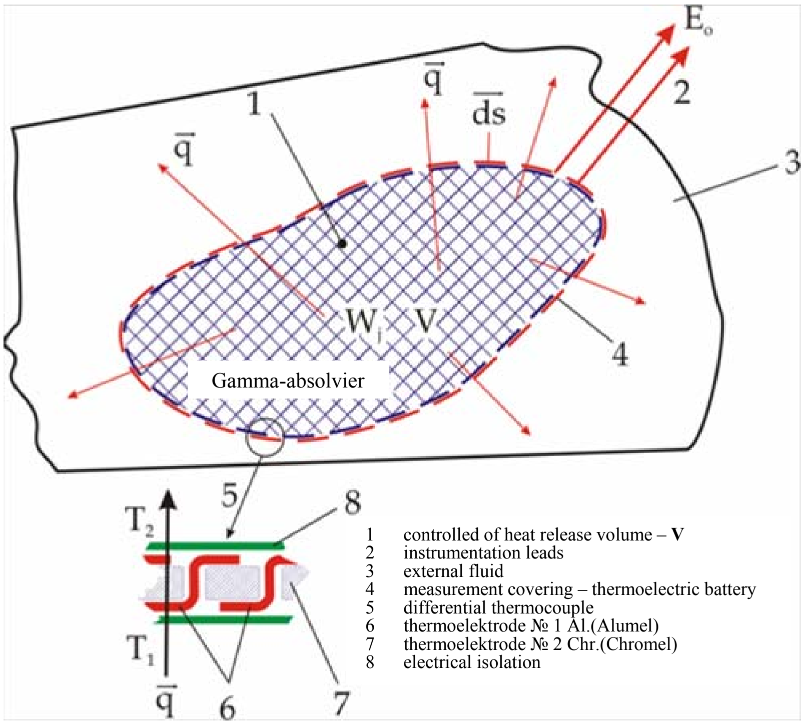

Figure 2:
Principle of operation of the gamma-calorimeter, based on the Ostrogradsky-Gauss integral theorem:
Basic equation

$$Wv = \sum_{j=1}^{\infty} w_j = \int_V div\vec{q}\,dV = \oint_S \vec{q}\; d\vec{s} = \sum_{i=1}^{N} q_i \Delta S_i = \sum_{i=1}^{N} \left(\frac{\lambda}{\delta}\right)_{эфф} \Delta t_i \Delta S_{эл} = \left(-\frac{\lambda}{\delta}\right)_{эфф} \frac{\Delta S_{эл}}{\alpha} \sum_{i=1}^{N} \Delta E_i = kE_0$$

W_V	- power energy release in the controlled volume	$(\lambda/\delta)_{eff}$	- heat-transmission resistanz of measurement covering
W_j	- local power of energy release in the elementary volume a *j*-point source	α	- differential thermoelectric power
$\vec{q}$	- heat flax vector	k	- calibration coefficient
$\vec{ds}$	- differential of area	E_0	- electric signal of the calorimeter

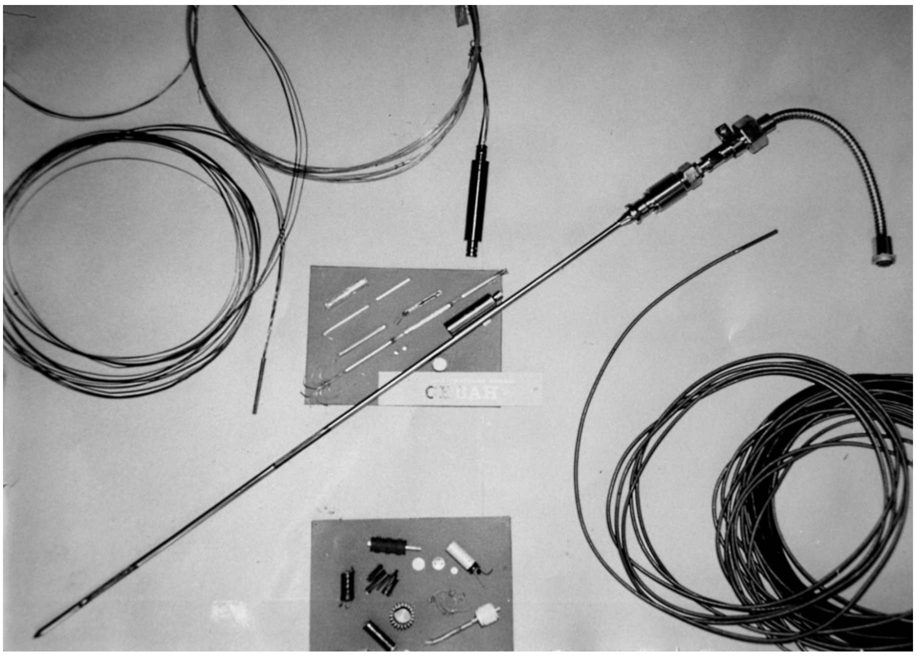

Figure 3: The Samples of calorimetric detectors [4] and Probe

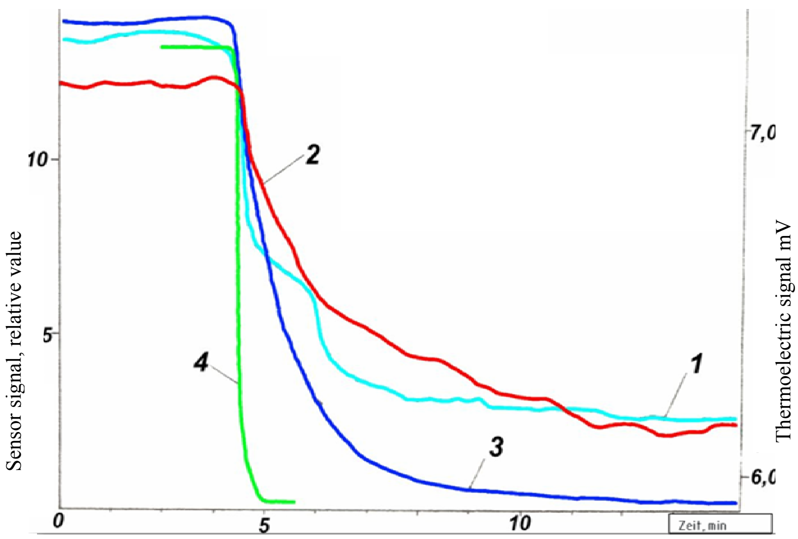

Figure 4:
Characteristic of the calorimeter dynamic

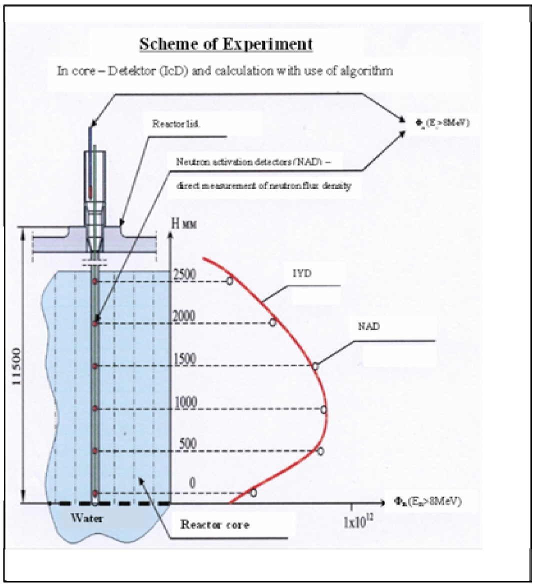

Figure 5:
Scheme of test experiment on check of correctness of algorithm of gamma control of energy release

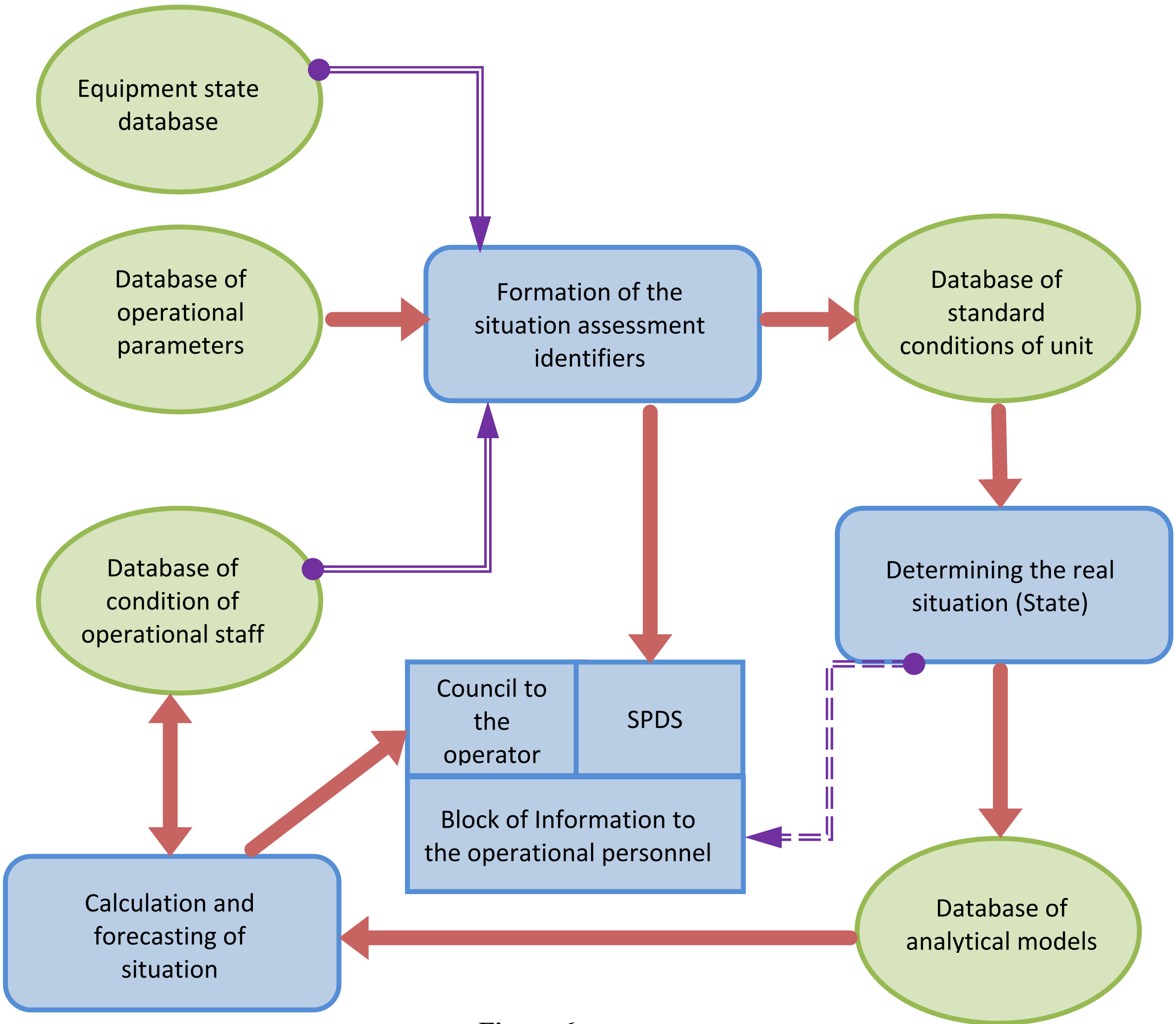

Figure 6:
Structure of the organization of information support of reactor operators on the basis of the diagnostic system of the NPP power unit