Investigation of the protective airtight shell’s operational reliability at the construction stage

O A Gubeladze, A R Gubeladze and L F Kirilchik*

Don State Technical University, 1, Gagarin Square, Rostov-on-Don, 344010, Russia

E-mail: 9185578207@mail.ru

Abstract. The actual values of the sealed enclosure internal parameters differ from the design results, in addition, the existing calculation models do not take into account the complex distribution of prestressed reinforcement, as well as the ropes’ behavior of the prestressing system. The article discusses the issues of developing an instrumental survey program to eliminate uncertainty in assessing the technical condition of a power generating unit.

Potentially hazardous facilities (PHF) certainly include the atomic energy facilities in use (AEFU). The main goal of ensuring safety during the operation phase of the AEFU is to prevent severe emergency situations (ES), as well as to localize and eliminate the consequences if such was implemented. Safety criterion is the magnitude of the likelihood of the realization of the AEFU hazard. The criteria are established taking into account all types of impacts, which are determined by the results of ES modeling (the quantitative value of the criterion is determined by the determined design parameters of the object and the stochastic characteristics of external influences) [1].

The concept of defense in depth of nuclear power plants, which certainly belong to PHF, includes the installation of successive barriers: fuel matrix and fuel element cladding; coolant circuit; protective containment (PC). The most important function in case of adverse events is the localization and retention of radioactive substances within the accident localization zone [2]. The effectiveness of the implementation of the protective functions of the containment depends on how successful will be the counteraction of the PC to unregulated destructive factors (UDF), and more specifically, the destructive factors (DF) of these effects [3]. We use the concept of survivability, which implies the PC property to maintain its functions of retaining radioactive substances (preservation of tightness) under UDF conditions. The full survivability index (which is not essentially an object’s own characteristic) for a given ES, in the case of successive exposure to DF, can be represented as:

\[ P_s = p_s^{(1)} p_s^{(2)} \cdots p_s^{(n)} \]

where \( p_s^{(i)} \) - is the private survival rate for \( i \)-th destructive factor [4].

In a real ES, it is necessary to expect the simultaneous or combined (the first time UDF was the source of subsequent effects) effect of several DF. The solution to this problem is complicated by the presence of uncertainty, which is associated with the remoteness of the protection direct application stage, the uncertainty of the very moment of its use, the characteristics of the system at the time of the
emergency, and future application conditions. PC, in turn, is also exposed to UDF. This applies not only to impacts immediately at the time of the emergence, but also to the UDF in the previous period of the power unit’s existence (construction, installation, testing, operation) [3].

The construction will be able to fulfill its protective functions only if the requirements of the construction work project are strictly met during the construction at the construction site, installation of equipment, strict adherence to the prestressing mode of the containment and permissible crack opening.

Figure 1 shows the UDF scheme for S2 - the shell and S1 - for the elevating and transport systems of the reactor compartment (ETS RC), taking into account the mutual influence [3,5]. The following is presented here: group $v'_1$: $v'_1$ – is the deviations from the project during the circular crane installation (CCI); $v'_{1,2}$ – shows the errors of the construction of the PC; group $v'_2$: $v'_2$ – defines the loads associated with mass-inertial characteristics of the study object; $v'_{2,2}$ – shows the deviations from the dynamic and static tests program; $v'_{2,3}$ – is the impacts associated with violations during transport and technological operations; $v'_{2,4}$ – defines the loads excessively deforming crane tracks; group $v'_3$: $v'_3$ – defines sheath deformation during installation, testing of ETS RC; $v'_{3,2}$ – is the sheath deformation on the horizon of the crane track consoles during installation and commissioning of the containment prestressing system (CPS); $v'_{3,3}$ – shows the sheath deformation on the horizon of the crane track consoles during testing; group $v'_4$: $v'_4$ – defines the violations of preloading technology; group $v'_5$: $v'_5$ – shows the violations of the test program for the PC tightness and strength.

The purpose of assessing the PC reinforced concrete structure is to determine its current state under implemented operating modes and conditions, the devices parameters that ensure their safe operation and environmental protection [1,6]. The initial data for the stress-strain state (SSS) calculation of the containment are the results of instrumental control: the results of determining the spatial position of the containment; the PC geometric parameters geodetic measurements results; the results of determining the physical and mechanical properties of the building structure materials. In this case, the maintenance of the safe operation of nuclear power plants is facilitated by: preventing the commissioning of structures that violate the design requirements; timely detection of the significant deviations in order to take measures to prevent the emergency situations; accumulation of information for predicting the protective shells’ behavior, adjusting the design patterns and design techniques in project [7,8].

The analysis of the existing calculation models showed that they do not take into account the complex distribution of reinforcement in the shell’s body, as well as the CPS ropes’ behavior along the structure wall thickness in the so-called channel formers. Ultimately, we have a significant discrepancy between the design data (in terms of the stress-strain state) compared with the actual (obtained during the construction of the PC). The real values of the internal parameters of the shell (mainfold $H$) differ from the design results, and sometimes are generally out of tolerance, as a result of the destructive effects on the shell during its construction.
By the moment of physical start-up of a nuclear power unit, the internal parameters of its elements are the manifold \( \bar{f} \) [9]:
- the design parameters \( (r_{ext}, r_{int}) \) – external and internal PC radii;
- \( \delta_i \) – defines the thickness of the PC cylindrical wall at the control points;
- physical and mechanical characteristics of the construction materials;
- the mode parameters \( (\Delta p_{test}) \) - the value of the overpressure of the test medium when testing the containment for strength and tightness;
- \( \Delta p_{ES} \) – is the expected value of the medium overpressure during a design emergency that the PC is able to withstand;
- the parameters of the PC SSS at the control points;
- forces in the reinforcing ropes of the CPS;
- loads from ETS RC located inside the containment.

PC of the NP-1000 project perceive external climatic and technogenic influences, and also perform the localizing functions in the ES event. The errors in the calculation models led to a number of significant discrepancies in the project in terms of SSS compared to the real one [1,9]. During the routine inspections of various nuclear power plants’ PC, it was found that the ropes have a loss of effort significantly exceeding the normative. When pulling the ropes (where such an operation is provided), the wires break in them, which indicates the actual discrepancy of the SSS of the containment to the design.

The measurements at the construction stage of the NP-1000 project PC with CPS-M power units in the period from the containment prestressing end to the start of testing it made possible to conclude that the deformations’ manifestations lead to an increase in compressive stresses in the bar reinforcement and compressive deformations in concrete [7,10,11]. A certain influence is exerted by the channel formers’ manufacture quality. So, during the construction of one object, the walls of the
channel former were squeezed with concrete mix, because of which it was necessary to carry out the unscheduled repair and restoration work (Figure 2).

**Figure 2.** Technological hole for replacing a channel former in the structure wall

During welding operations of the PC structural elements, the plastic channel formers were ignited. The area of the fire according to the comments of the Ministry of Emergencies was 350 m² [12]. Without nuclear power plants, there was no radiation hazard, but serious damage to the containment design was caused, including a decrease in the strength of concrete in the fire zone (Figure 3).

**Figure 3.** Fire Zone
The decrease in effort on the heavy anchors of the reinforcing ropes of the cylinder and the dome of the containment of the power unit for the period under consideration is due to losses in the first few days after the pre-stressing procedure, as well as seasonal temperature fluctuations [10]. Since it is impossible to tighten the reinforcing elements (CPS-M), the question of the effort loss in them already in the tension process arises due to: friction against the walls of the channel formers; efforts’ reduction when transferring the load from the jack to the anchor device; efforts’ loss in the reinforcing elements from the shell deformation during compression; stress reduction caused by stress relaxation in the beam wires; efforts’ loss due to creep and shrinkage of concrete. The efforts’ loss in the reinforcing ropes due to the action of the friction forces between the rope and the channel former exceeds those declared by the CPS-M manufacturer [10]. The loss of force in the reinforcing elements from the deformation of the shell during prestressing of the structure, as well as the loss of force due to creep and shrinkage of concrete, need additional evaluation [13]. Despite the claims of the CPS-M developer about the possibility of replacing the reinforcing ropes, it is not possible to count on a favorable outcome since there is no experience of a long-term operation after replacing the reinforcing ropes in a polyethylene sheath at the already existing nuclear power plants. Removing the reinforcing rope with a possible interlacing along the length (especially in the bending ropes areas when bypassing the holes), volumetric compression taking into account the compression strains of the sheath, shrinkage and creep of reinforced concrete without damaging the polyethylene sheath of the rope is not possible [13].

To eliminate the uncertainty in assessing the technical condition of the power generating the unit’s PC, during the instrumental examination it is necessary to obtain as complete and reliable the information as possible about the parameters of the elements of the object under study, achieved during the implementation of the design decisions during the construction of the containment and the reactor compartment elevating and transport systems’ installation [3, 14.15]. This requires careful development of a program for instrumental examination of the protective tight shell in the power unit, indicating the nature and specific scope of the research.

In addition, the CPS state assessment by the existing diagnostic systems after UDF will in many respects be subjective. This is due to the fact that a number of elements are not subject to performance checks. It will be especially difficult to assess the condition of individual elements that do not have noticeable damage. To justify the composition of promising systems for diagnosing the technical condition (SDTC), it is necessary to apply the set of initial data and characteristics associated with the UDF parameters, as well as the effects realized during normal operation.

Summary
The external influencing factors’ characteristics values are determined from the facility operating experience analysis (for the regulated impacts), as well as an analysis of the past accidents and experimental and theoretical studies of the possible incidents (for UDF). The following incident analysis procedure is proposed:

1. Establishing a list and intensity of incidents with the facility.
2. Analysis of the UDF causes and conditions with the object.
3. Determination of the DF characteristics.
4. Analysis of the UDF consequences.
5. Linking the characteristics of the incidents to the construction (operation) stages.
6. The formation of the source data to set the requirements for SDTC.

Thus, the results obtained make it possible to formulate a list of basic requirements for the developing systems, and subsequently make the selection of the necessary and sufficient composition of SDTC and their characteristics.

References
[1] Denisov O V, Gubeladze O A, Meskhi B Ch, Bulygin Yu I 2016 Integrated safety of the population and territories in emergency situations. Problems and solutions; under the general (ed. Yu.I. Bulygina, Publishing Center DSTU, Rostov-on-Don).

[2] Gubeladze O A, Novik Yu S 2018 Features of the assessment of the designs of protective tight shells of nuclear power plants with a VVER-1000 reactor during the construction period [Text] / OA Gubeladze Engineering Bulletin of the Don 4. Information on ivdon.ru/ru/magazine/archive/n4y2018/5380.

[3] Gubeladze O A, Gubeladze A R, Burdakov S M 2017 Determination of the geometric and physico-mechanical characteristics of elements of a nuclear power unit and their use as source data for a probabilistic safety analysis Global Nuclear Safety 3 (24) 102-109.

[4] Gubeladze O A, Gubeladze A R, Burdakov S M 2017 Safety of promising spacecraft with a nuclear power plant [Text] / OA Gubeladze Global Nuclear Safety, 1 (22) 13-20.

[5] Pimshin Yu I, Klyushin Ye B, Gubeladze O A et al 2016 The influence of a circular crane on the technical condition of the protective shell of a nuclear power plant under construction Global Nuclear Safety 2 (19) 33-42.

[6] Pimshin Yu I, Klyushin E B, Medvedev V N, Gubeladze O A 2016 Diagnostics of the technical condition of protective tight shells of nuclear power plants University proceedings “Geodesy and aerial photography” 4 55-59.

[7] Gairabekov I G, Pimshin Yu I, Gubeladze O A, Medvedev V N The results of the work carried out in the framework of monitoring the protective tight shells of the building blocks of the Rostov ES 2014 Collection of articles on the basis of scientific and practical conferences. Appendix to the journal: Proceedings of the universities “Geodesy and aerial photography” 7(1) 29-30.

[8] Pimshin Yu I, Zabaznov Yu S, Kirilchik L F 2014 Analysis of the work of building elements of a sealed shell of a nuclear power plant during its prestressing and testing Engineering Bulletin of the Don 1. Information on ivdon.ru/ru/magazine/archive/n1y2014/2263.

[9] Korobov L A, Shernik A O 2014 Russia is in danger of radioactive contamination Our Contemporary 5 230-233.

[10] Medvedev V N, Kiselev I A, Krutko E S, Ulyanov A N, Strizhov V F, Potapov E A 2015 Field observations of the protective shell of power unit №3 of the Rostov ES after prestressing Global Nuclear Safety 3 (16) 57-76.

[11] Medvedev V N, Kiselev Alexander S, Kiselev Alexey S, Ulyanov A N, Strizhov V F, Potapov E A 2014 Field observations at the stage of construction of the protective shell of power unit №3 of the Rostov ES Global Nuclear Safety 3(12) 89–99.

[12] Meskhi B Ch, Denisov O V, Gubeladze O A 2014 Fire safety of nuclear and radiation hazardous facilities (Publishing house of DSTU, Rostov-on-Don).

[13] Medvedev V N, Ulyanov A N, Kiselev A S, Kiselev A S, Strizhov V F 2012 On the application of the modernized pre-stressing system CPS-M on the protective shells of nuclear power plants Global Nuclear Safety 4 2-3.

[14] Pimshin Yu I, Zabaznov Yu S, Gubeladze O A et al. 2015 A method for determining the deformation characteristics of a protective hermetic shell, Patent 2546990 of the Russian Federation, IPC G01 M 99/00, publ. 10.04.2015, bull. №10. Information on http://www.fips.ru.

[15] Pimshin Yu I, Klyushin Ye B, Zabaznov Yu S, Gubeladze O A, Pimshin P Yu 2016 A method for evaluating the operational reliability of a protective hermetic shell of a reactor compartment of a nuclear power plant, Patent 2577555 RF., IPC G01 M 99/00, publ. 03/20/2016, bull. №8. Information on http://www.fips.ru.