The Chernobyl Disaster in Ukraine. Experience in Overcoming the Consequences of Accident and “Shelter” Object Transformation to Safe System



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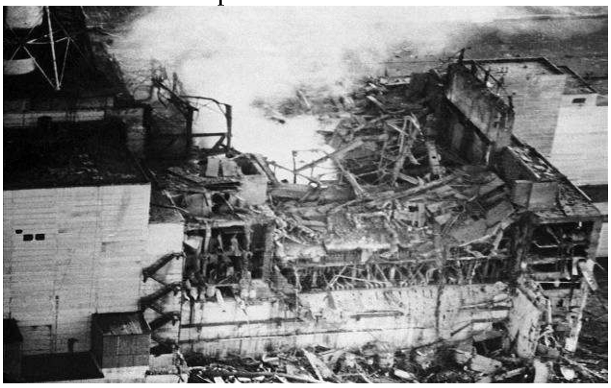
ABSTRACT: The report focuses on building aspects of state assessment of the Chernobyl NPP forth power unit building structures, damaged in the accident on the 26th of April, 1986, as well as newly constructed “Shelter” Object (SO) structures. In the report there are characteristics of damage of the Chernobyl NPP forth power unit, description of the structural scheme of “Shelter” Object and its current state. The measures on strengthening (stabilization) of the unstable structures, realized on “Shelter” Object, are considered and the basic provisions for Strategy of formation “Shelter” Object as an ecologically safe system are given. Attention is paid to stages of new safe confinement (NSC) concept selection and characteristics of the NSC and its basic objects are given. It took 25 years after the accident. During this time a lot of works on decontamination of the local zone territory, ensuring personnel and population radiation safety and strengthening of some unstable structures were realized. But the problem of the object safety is actual at present. The consequences of the nuclear accident on the ChNPP forth power unit have long-term danger for personnel, population and environment. In the report there is analysis and comparison of ChNPP and “Fukusima-1” Japanese NPP accident consequences; attention is paid to consequences of the unfavorable catastrophic natural phenomena influence.

1 INTRODUCTON

Preliminary assessment of dangers and levels of territory radiation contamination after explosion [1] showed that inside the SO there is more than 95% of highly active fuel [6]. On the object site under the gravel, concrete and sand layer there is minimum 0,75 t of fuel. The total area of the West Europe country territories with level of contamination of 137Cs made up about 280 thousand km^2, because of the Chernobyl accident of more than 20 kBq/m^2 (it is almost 10 times higher than global background). At present the total radioactivity of materials in SO premises exceeds 20 MCi [2].

Most of the reactor block building structures were destroyed or damaged (Fig.1).

The central hall tent structures above the elevation of + 53.00 are completely destroyed, floor structures and walls of drum separator premises, also covering above the main circulating pumps from the north and south sides are destroyed. The upper slab of biological shielding (scheme “Elena”) weighting 2000 tons with remains of fuel channels was planted, and it took position at an angle of 15° to the vertical. The metal structures of the reactor base (scheme “RB”) were lowed by 4,0 m from the initial position



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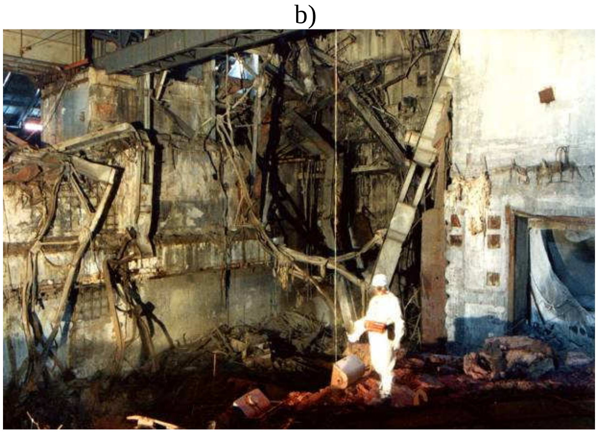

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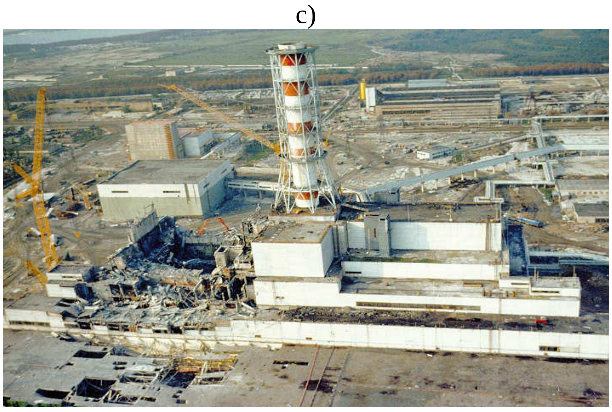

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Fig. 1 General view of the destroyed ChNPP forth power unit structures:
a – the first days after the accident; b – destroyed frame of the deaeration stack; c – ventilation shaft of the reactor; d - the beginning of construction.

The upper storeys of the deaeration stack (above the elevation of +24,3 m) in axes of 42 – 52 were seriously damaged (destroy of the bearing structure reinforcement) and deviated by 0,7 – 1,5 m in the southern direction from the vertical position. The reinforced concrete wall of the western frame along the axis 50 is deviated by 64 – 85 cm in the west direction. The northern and southern reinforced concrete ventilation shafts were significantly weakened in bore cross section.
The degree of structure destroying is not classified according to the requirements of the modern norms. Some structures were and are in postcritical state. Their bearing capacity is exhausted. Consequences of the ChNPP forth power unit accident remain in the sphere of public attention and make people of Ukraine, Russia, Byelorussia and other countries to worry. Over the years a lot of researches, construction and installation works were realized to improve the SO safety.

2 CONSTRUCTION OF THE “SARCOPHAGUS”. STRUCTURAL SURVEYS OF THE “SHELTER” OBJECT (THE FIRST PHASE, 1986 – 1991).

The structural surveys of the ChNPP forth power unit were realized immediately after the accident of 1986 by specialists of different Russian, Ukrainian and Belorussian organizations: the I.V.Kurchatov institute of atomic energy, complex expedition of the Kurchatov institute, the A.Khlopin radium institute, VNIPIET, NIKIET, Institute for problems of electrodynamics of Academy of sciences of Ukraine, Institute of nuclear energy of Academy of sciences of Belorussia and many other organizations.
On November, 1986 the protective structure – “SARCOPHAGUS” was built around the destroyed structures. Construction was realized in short time under conditions of extremely unfavourable radiation environment at use of the remote sensing methods of erection, using unitized units (Fig.2). At construction of “SARCOPHAGUS” 250 000 m^3 of concrete is laid and 7000 tons of metal structures are mounted. From April, 27 to May, 10 in the period of active accident phase at destroying of the forth power unit 15000 tons of different materials: lead shot – 1500 t, lead ingots – 5220 t, marble chips – 3532 t, dolomite – 1167 t, boron carbide – 42 t, rubber – 489 t, zeolite – 1890 t, polymerizable liquid – 140 t, trisodium phosphate – 1536 t were ejected from the helicopters.


a)

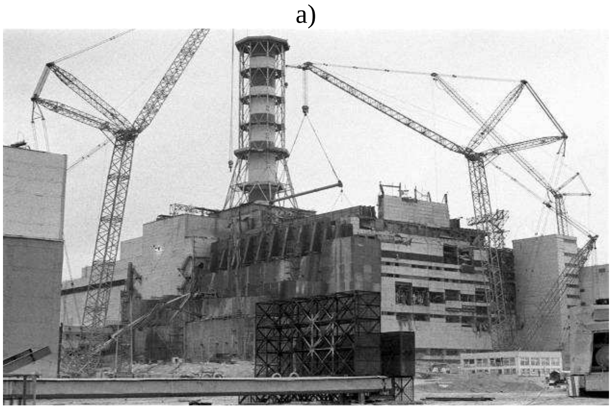

b)

Fig. 2 Liquidation of the accident consequences, 1986:
a – territory decontamination from the helicopters;
b – construction of the western buttress wall, using the metal blocks, filled by concrete.

The north cascade wall of “SARCOPHAGUS” was made of concrete with ledges up to 12 m. Internal volume of the cascade wall ledges was filled by spatial structures, including containers with highly radioactive wastes.

The western side of the destroyed unit was closed by metal buttress wall, height of which is about 50 m. Barriers and walls, which separate the forth and the third power units, are erected. In the control room the monolithic wall, thickness of which is 2,3 m, was erected to a height up to the elevation of +19,0. General view of new structure is given in Fig.3. Along the perimeter of the structure there are “pioneer” protection walls of reinforced concrete, height of which is 6 – 8 m. The destroyed structures of the forth power unit were used as supports for newly erected SO structures.

In 1989 the USSR state committee for construction, architectural and housing policy decided to have NIISK as leading organization on preparing of the Building program to assess state and monitoring of the SO building structures. In 1991 – 1995 the works on studying of the SO state were realized by Ukrainian organizations under the leadership of “Shelter” ISTC (at present ISP NPP) of the National academy of sciences of Ukraine and NIISK of the State committee for construction, architectural and housing policy of Ukraine.

The general SO structural system is (see Fig. 4):

- a system of the reinforced concrete and metal forth power unit structures, destroyed by explosion;
- a system of SO roof structures, including new metal structures, erected in 1986;
- a support contour, which supports the roof system;
- a foundation – basement part (monolithic reinforced concrete foundation slabs and a system of longitudinal and transverse walls up to the elevation of +12,0 m).

The results of the preliminary field surveys showed that according to the requirements of the normative documents the SO building structures are destroyed and in transcendental stage of deformation. It is impossible to assess their residual life on the basis of SNiP recommendations.


a)


b)

Fig. 3 “Shelter” Object view: a - in 1986; b - in 2011.

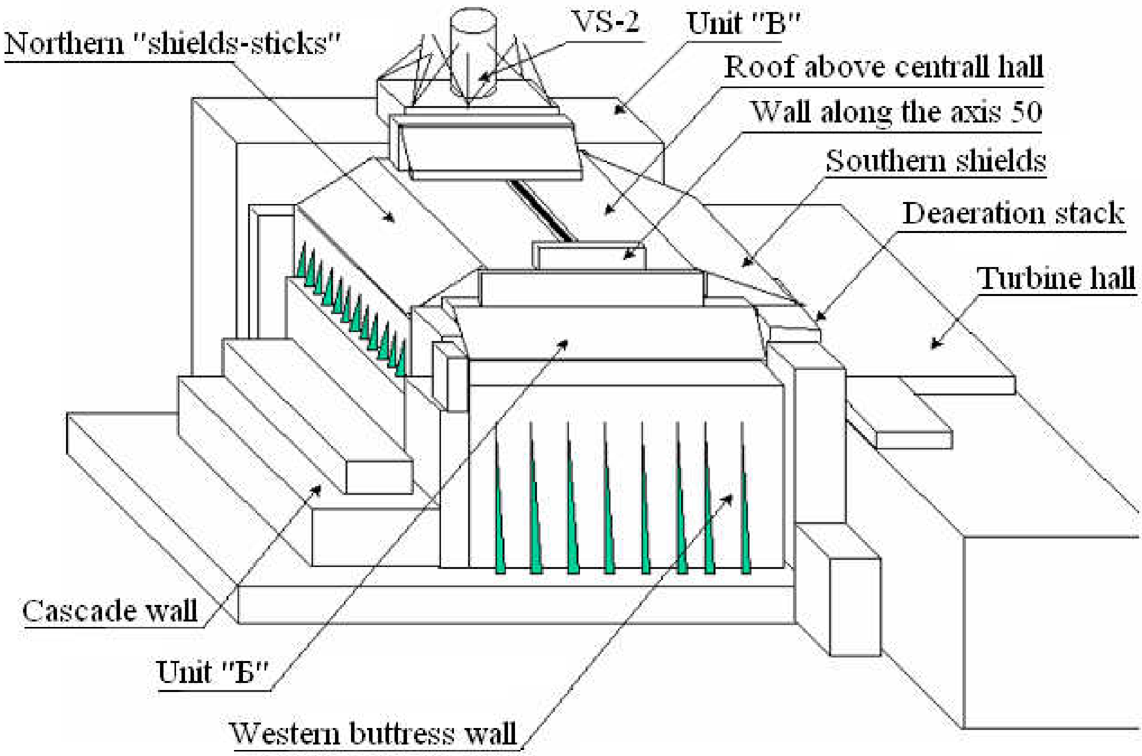


Fig. 4 “Shelter” Object protection structure location

3 “SHELTER” OBJECT STATE

Following results of surveys and studying of the object, it is clear that its current state is characterized by risks, caused by combined influences of some factors [6,7], among which are: influence of the natural initial events, building structure state, behaviour of fuel-containing materials (FCM) in object, fire danger.

The natural initial events are: climatic conditions on the site (distribution of air temperatures, influence of snow and wind, atmospheric circulation), formation of ice and hoarfrost, snowstorms and thunderstorms, tornados, tectonic features of the area (design and maximal calculated earthquakes) and hydrological factors [3, 4, 5].

The current state of SO building structures during operation is determined by behaviour of critical zones in external SO shell, which were found on the basis of field surveys and generalization of their results. Criteria for critical zones are loads from the impacts of design earthquakes, tornados, snowfall and other natural events, at which structure stability can be damaged. Such zones are:

- stack on the block “B” (ventilation pipe);
- Б1 and Б2 beam supports in row “Ж”;
- frame of the SO western zone;
- southern shields – “sticks”;
- frame of the deaeration stack and other structures.

The analysis of deaeration stack frame geodetic survey results shows a constant tendency of frame deviation in the southern direction. The process of structure degradation continues. According to NIISK data, the corrosion of metal structures can be up to 40 – 50 micrometers per year of operation. The general service life of metal structures is 80 years. Concrete is exposed to moisture, freezing and thaw, what causes destroying and reduction of concrete structural strength.

FCM behaviour is related to the change of their properties in time. The silicate matrix of lava-like fuel-containing masses is destroyed in time. Radionuclides, containing in it, transfer to movable radioactive formations, which can go outside the SO and have danger for personnel, population and environment. Destroying of unstable structures increases the risk of such event.

Fire danger for the SO is the least studied factor. It is related to availability of about 2000 tons of combustible materials in the object. At fire the risks of radioactive aerosol distribution beyond the industrial site are increased.

4 MEASURES ON UNSTABLE STRUCTURE STRENGTHENING (STABILIZATION)

4.1 *The strategy of stabilization*

Erection of the SO on destroyed forth power unit structures and in extremely hard radiation conditions could not meet design regulations and norms for nuclear facilities, objects for radioactive waste handling and also for ordinary industrial facilities.

The purpose of SO building structure stabilization is to decrease the danger of building structure destroying, causing to great radioactive material release into environment.

Considering problems to insure SO safety and performing field surveys of unstable building structures, the NIISK specialists concluded that SO structure safety can be insured by strengthening of the most dangerous (according to radiation consequences of destroying) (unstable) object structures. Here we consider several stages (versions) of the object.

The first stage considers a short-time (at least 10 year) operation of the SO before building of a new “Shelter-2” Object above it. At this stage the short-time stabilization of the existing “Shelter- 1” is necessary.

The second stage considers more durable (about 50 year) working life of “Shelter-1”. In this case radiation and nuclear safety is insured under the strengthened “Shelter-1”. Such scheme of formation needs structure strengthening for longer period.

At works on problem of SO structure stabilization the most important task was to determine a list of structures, which should be strengthened. Long observations for building structure state and surveys of SO zones and structures were realized to determine a minimal number of measures, not decreasing a necessary level of reliability.

The first list of stabilization measures, developed in SIP project (1997) as the first stage of SO formation as an ecologically safe system, had 29 measures. Classification of stabilization measures was realized according to the object zones (the northern, eastern, southern and western).

The assessment of 29 measures was performed, taking into account the requirements of the normative documents of Ukraine, results of realized surveys and repetition of normative load interval during 15 – 40 years.

Within SIP project on package A, performed by International consortium “Chernobyl” - ICC (MK) JV in 1999 – 2000, the strengthened structure operation life reduction up to 10 – 15 years (for time, necessary for construction of the new safe confinement (NSC) and dismantling of the unstable structures) was analyzed and grounded. It helped to perform detailed calculations of the unstable structures, review a list of stabilization measures, reducing their number up to 20 and then up to 15.

However, realization of even reduced list of measures (“List 15”) results in significant personnel radiation doses. Especially significant collective effective doses were necessary to realize works on fixing of covering structures, which were unstable at influence of tornado, when significant disclosure of the external covering and radiation release were possible. That is why, in the process of further work on project, design tornado characteristics at different criteria were assessed and possibility to reduce “List 15” up to 9 necessary urgent measures, given below, was determined.

The realized stabilization measures meet design criteria, approved by the State committee of nuclear regulation and insure a necessary SO safety level on the basis of fifteen year period of stable structure operation, taking into account the completion of new safe confinement construction within the given period. The time intervals of stabilization are determined, taking into account the general strategy of SO formation as ecologically safe system [8], assuming that new safe confinement (“Shelter – 2”) will be erected within the given period of time.

4.2 *Assessments of stabilization measure reliability*

On the basis of “weak zones” analysis the stabilization measures are determined and reliability of the given measures, which are given in table 1, is assessed.

Table 1. Probabilities of SO structure failure before and after stabilization

Structures or zones	Probability of failure, γ_0	
	Before stabilization	After stabilization
Zones of Б1, Б2 beam supporting along the axis 50		
on vertical load	$1 \cdot 10^{-4}$	$1 \cdot 10^{-4}$
on horizontal load	$2{,}0 \cdot 10^{-3}$	$1 \cdot 10^{-4}$
Walls along the axis 50 ambient frame	$1{,}3 \cdot 10^{-1}$	$2 \cdot 10^{-3}$
Deaeration stack	$1{,}3 \cdot 10^{-1}$	$1 \cdot 10^{-3}$
Supporting zones of “Mammoth” beam		
on vertical load	$1{,}0 \cdot 10^{-4}$	$1 \cdot 10^{-4}$
on horizontal load	$1{,}3 \cdot 10^{-1}$	$1 \cdot 10^{-3}$
Northern shields - sticks	$1{,}4 \cdot 10^{-2}$	$1 \cdot 10^{-4}$
Southern shields	$1{,}0 \cdot 10^{-4}$	$4 \cdot 10^{-4}$
Southern shields - sticks	$1{,}4 \cdot 10^{-2}$	$4 \cdot 10^{-4}$
Western buttress wall	$1 \cdot 10^{-4}$	$1 \cdot 10^{-4}$
Coating between the western buttress wall and the wall along the axis 50	$1 \cdot 10^{-4}$	$1 \cdot 10^{-4}$
Western sticks	$1{,}4 \cdot 10^{-2}$	$1 \cdot 10^{-4}$

Determination of structure reliability is reduced to a comparison of load figures (internal forces) (Q) and structure strength (N), which are characterized by differential functions of distribution (f_Q and f_N) and failure parameters γ_0:

$$\gamma_0 = \int_0^{\infty} f_Q(Q) \int_0^{Q_N} f_N(N) \cdot dN \cdot dQ = \int_0^{\infty} f_Q(Q) \cdot F_N \cdot (N) \cdot dQ \qquad (1)$$

The probabilistic and deterministic methods for analysis and assessment of structure destroying (failure) risks, caused by natural and industrial initial events, are used.

Calculations show that probability of the structure failure is reduced by two-three after strengthening. The list of necessary urgent measures to increase the structure bearing capacity is determined.

4.3 *Assessment of stabilization terms in the time interval*

The analysis of interdependence of stabilization measures and new confinement construction showed that:

- Stabilization is expedient. Urgent construction of the new safe confinement (NSC) results in great collective personnel radiation doses;
- The pause between stabilization and NSC construction is possible, but not more than 10 – 15 years. At pause of more than 20 years the collective doses for stabilization or liquidation of possible SO building structure accident consequences are increased.

4.4 *Short-term stabilization measures*

9 short-term stabilization measures for SO zones, given above, were determined within SIP (see Table 2 and Fig. 5). The design documentation on stabilization measures was developed by the Ukrainian consortium “KCK” (KIEP, NIISK, ISP NPP). The calculations are performed, using software complex “Lira-Windows” (NIIASS of the State committee for construction, architectural and housing policy).

The requirements on reliability of stabilization measures were developed in accordance with conditions of facility structure failures after realization of stabilization measures with probability of not more than 10^{-3} - 10^{-4}. When stabilization measures were realized, probabilities of building structure failures were specified (Table 3).

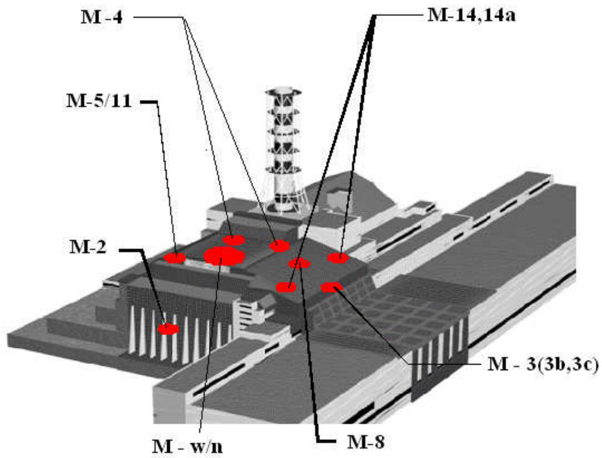


Fig. 5 The “Shelter” Object stabilization zones, realized by the consortium “Stabilization” in 2004 - 2008

Table 2. The list of urgent stabilization measures

# of measure	Name of measure
Western zone	
2	“Shelter” Object western fragment strengthening
Southern zone	
3	Stabilization of the deaeration stack frame
Eastern and northern zones	
4	Local ventilation shaft strengthening
5	Concreting of the upper part of the northern buttress wall
Covering	
8	Connection of the southern “shields-sticks” with the southern shields
11	Connection of the northern “shields-sticks” with the buttress wall, using anchor - locks
14	“Mammoth” beam western support strengthening
14a	“Mammoth” beam eastern support strengthening
w/n	Repair of the light roof

Table 3. Probabilities of structure failures after stabilization

Zones of stabilization	After stabilization
Western zone	$1{,}0\cdot10^{-4} \div 3{,}0\cdot10^{-5}$
Southern zone	$1{,}0\cdot10^{-2} \div 2{,}0\cdot10^{-3}$
Northern zone	$1{,}0\cdot10^{-2} \div 2{,}0\cdot10^{-3}$

The Fig. 3,b shows the SO western fragment strengthening – the most complex and intensive stabilization measure #2, which was completed in 2008. Below in Fig. 6 – 10 there is description of other urgent measures, realized within SIP in 2004 – 2008 [9, 10].

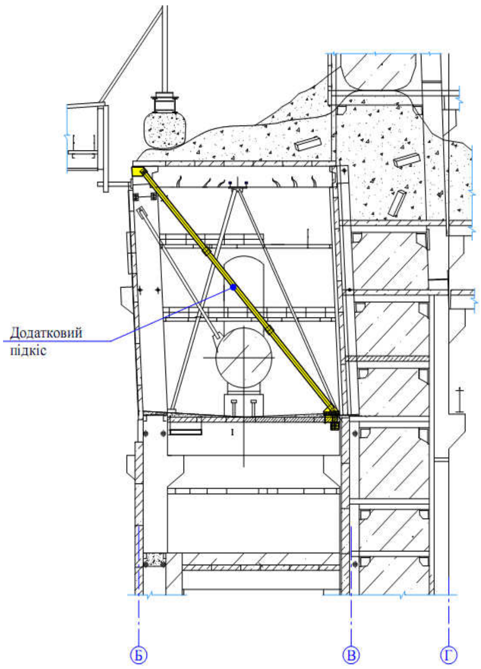


Fig. 6. Stabilization of the deaeration stack frame (measure #3)

Stabilization of the destroyed deaeration stack frame elements considered the installation of the additional metal deviated elements (struts), which connect the upper part of columns and have significant deviation from vertical to the side of the control room with floor structures, which are placed lower and have not significant damages.

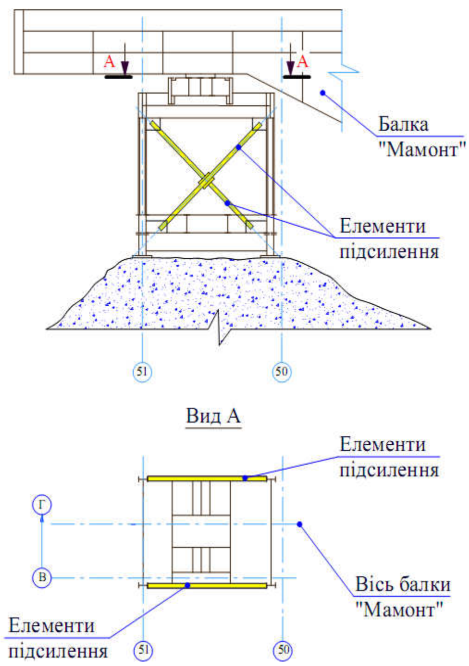


Fig. 7. Stabilization of the "Mammoth" beam western support (measure #.14)

Stabilization considered the vertical cruciform tie strengthening by increasing of their section, using welding of the additional elements.

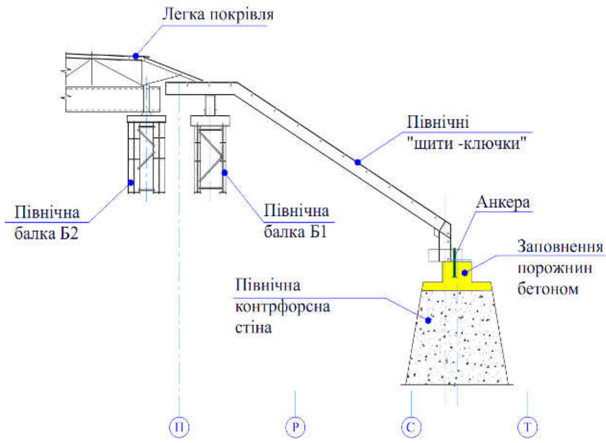


Fig. 8. Stabilization of "Shelter" Object northern part (measure #.5 and #11)

Realization of stabilization measures considered combination of two tasks:

- combination of the "shield-stick" northern elements and buttress wall to one structural system (measure #11);
- buttress wall strengthening by its upper part concreting (measure #5).Combination of "shield-sticks" and buttress wall was realized by installation and strengthening of anchor – locks in "shield-stick" support parts, their placement in wall internal space, which is not filled by concrete, but is going to be concreted in future.

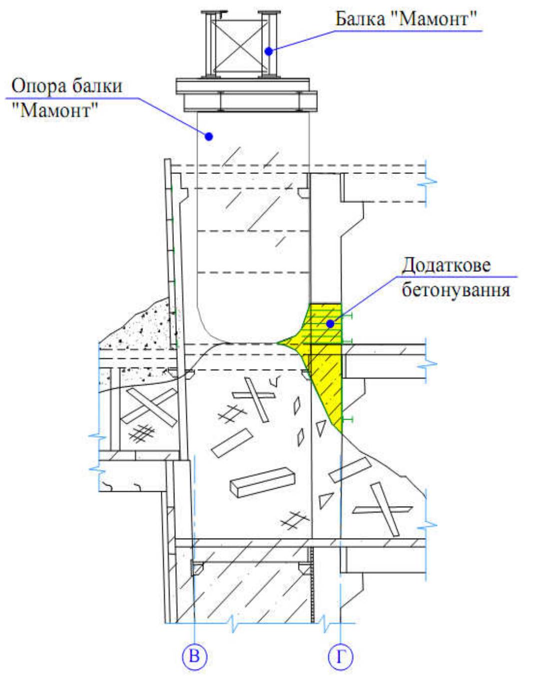


Fig. 9. Stabilization of the "Mammoth" beam eastern support (measure #14a)

Stabilization was realized by concrete filling of the spaces, observed in support base.

Fig. 10. Repair of the light roof (measure w/n)

The repair of the light roof considered:

- installation of the new covering of shaped decking on 40% of the roof area;
- replacement of battens between roof blocks;
- installation of covers and hatches for modernized dust suppression system.

5 THE STRATEGY OF “SHELTER” OBJECT FORMATION

Works on formation of SO as a safe system were realized on SO within Shelter implementation plan (SIP), which considered several strategically important stages of formation.

5.1 *SIP purposes and tasks*

The main purposes are determined in team report “The Chernobyl power unit #4. Shelter implementation plan”, prepared by members from Ukraine, Ministry of energy of the USA and European Union in May, 31, 1997. SIP is prepared on the basis of five purposes, which should be reached at its systematic realization, and includes 22 tasks, classified according to the purposes:

- Purpose 1 – Decrease of probability of building structure destroying/strengthening – includes necessary surveys, assessment and monitoring of seismicity, stabilization measures;
- Purpose 2 – Decrease of accidental collapse consequences – solution of tasks on dust handling and preparing for accident;
- Purpose 3 – Increasing of nuclear safety – includes tasks on SO water handling, characteristics of the fuel-containing materials (FCM), criticism and nuclear safety;
- Purpose 4 – Increasing of personnel and environment safety – solution of tasks on technical safe, physical and fire protection, integrity monitoring system, data bases, radiological protection;
- Purpose 5 – Long-term strategy and survey for formation of SO as ecologically safe system – development of the strategy, TEO, technology of FCM extraction, radioactive waste handling, creation of the new safe confinement for the further dismantling and FCM extraction.

Ten stages of program, which determined scope of works and terms to take important solutions, were included to SIP. Three of them are key program solutions:

- approvement of solutions on stabilization (П1);
- solution for strategy of optimal localizing shell (П10);
- solution on FCM extraction strategy, which determines optimal method and time of FCM extraction with grounded analysis of expenses and possibility for realization (П8).

The main SIP purpose is to decrease risks for personnel, population and environment, to prepare the site and to realize SO formation as ecologically safe system for the next 100 years. The NSC creation is the basic mean to reach the given purpose. The NSC ensures the SO protection against current processes of structure degradation and fuel-containing materials, radioactive dust release to environment, including dust, which is expected to arise in result of accidental SO structure destroying. The NSC ensures safe conditions to realize early dismantling of the SO roof and other unstable structures and to realize works on long-term handling with fuel-containing materials (FCM) and other radioactive wastes. Below there is information on current realization of SIP tasks and purposes.

5.2 *Purpose 1 – Decrease of destroying probability – building structure strengthening*

The building structure strengthening decreased significantly the probability of their destroying. Realized in 2008 measures on stabilization of the forth power unit unstable structures were a result of significant decreasing of SO collapse probability during NSC construction and insurance of structure stability for the next 10 – 15 years, for which the New safe confinement (NSC) should be erected.

5.3 *Purpose 2 – Decreasing of the accidental destroying consequences*

The consequences of the SO destroying are decreased. This was realized by modernization of dust suppression system, using more areas to put dust suppression mixtures and use compositions with a high content of dry remains, and by development of effective measures of accidental planning for ChNPP, including SO. Realization of the given works was a result of strong protective shield covering creation on surfaces in internal space under SO roof and decreasing of radioactive dust rise.

5.4 *Purpose 3 – Increasing of the nuclear safety*

Three tasks were determined as necessary to reach the purpose. The understanding of FCM criticism risk was reached. The other determined tasks on FCM characterization were realized partially. It was decided that the complete FCM characterization should be related to long-term safe measures after SIP realization. It is also necessary to realize task on handling with water, placed inside of SO.

5.5 *Purpose 4 – Increasing of personnel and environment safety.*

The task to insure the personnel safety is improved. Tasks 15 and 18 are realized. The rest tasks are in stage of realization. The works on project of physical protection modernization and SO access control are close to be completed, what insures the necessary level of nuclear material and radioactive wastes (RAW) protection at construction of the NSC and its further operation.
The works on increasing of SO fire protection are realized, what applies to decrease the risk of fires and their influence on personnel, population and environment.
The works on design and installation of the integrity automotive monitoring system (IAMS) are close to be completed. IAMS operation helps to keep the object in safe state in the process of new safe confinement construction and for the next years up to fuel-containing material extraction. IAMS includes subsystems of control for nuclear, radiation safety, state of the most responsible building structures and seismic monitoring in zone of SO.
The works on creation of integrity SO data base (ISDB) – a great information resource, which allows to manage the electronic archive, interact with integrity automotive control system, keep planning and safe work implementation, are completed.

5.6 *Purpose 5 – The long-term strategy and survey for formation of SO as an ecologically safe system.*

The tasks to achieve Purposes 5 are realized or in the stage of realization or nor realized, and strategy of SO formation as an ecology safe system should be specified. The preliminary strategy of FCM handling, determined by solution of П7, considers the realization of constant monitoring for FCM state and to use extraction, when the reservoir would be created, i.e. for some decades. Considering this time, it is inexpedient to develop early considered prototype of FCM extraction technology (task 20) to develop strategy of FCM extraction, taking into account cost and graph of its realization, because this work needs significant finances and dose expenses. Taking into account this information, international consult group does not recommend continuing works in this direction. It is necessary to take into account that necessary data on price, man-hour and dose expenses can be obtained in the process of realization of early SO unstable structure dismantling to develop strategy of FCM extraction.
Work on Task 21 to develop the strategy of the safe confinement is completed. The results of works on creation of “Conceptual NSC project” were agreed by Regulating bodies and Project was approved by the Cabinet of Ministry of Ukraine in 2004.
Works on NSC design and construction, early dismantling of the SO unstable structures (task 22) are uncompleted. At present parallel to NSC construction there are also works on cleaning of the construction site territory against technological materials and radioactive wastes, construction works on erection of erection zone foundations, working platform and foundations of elevator towers for Arch assembly.

6 NEW SAFE CONFINEMENT (NSC) DESIGNING AND CONSTRUCTION

The key stage of the “Shelter-2” feasibility study was completed in July, 1995. Taking into account the comments elaborated by the Ukrainian side, the international «Alliance» developed the final solutions and submitted them to the Chernobyl NPP in as a multivolume set. The feasibility study second stage presentation was held in Kiev on July 11-12, 1995. The main solutions and strategy of the Shelter-2 construction are described in the «Operational abstract».

6.1 *New «SARCOPHAGUS» - ARCH- Proposal of the «Alliance» consortium (France)*

The design solutions developers state, that the Arch shape of the Confinement will ensure the most balanced distribution of materials consumption, subsequent dismantling of the SO, and the improvement of the Shelter-1 safety. The “Shelter-2” structures are erected as an Arch on the erection site westward from the existing SO. As the

Object becomes ready, its sliding in the eastern directions is being carried out.
According to the «Alliance» assessment, the total costs of the SO transformation will be from 1.2 to 1.5 $ billion. These costs do not satisfy in full the Technical Specification, as they do not include two important elements of the SO transformation, namely RAW management and Shelter-1 structures dismantling after the Shelter-2 erection.

6.2 *New Safe Confinement*

6.2.1 Preliminary input information

Within the SIP framework the first priority packages were singled out. Presently, they have been implemented. The objective of these packages was to perform the preliminary investigations to ensure the basis for the future specific projects on the following issues: the assessment of unstable structures and of the consequent actions and development tendencies regarding the new confinement, as well as conceptual approaches to the RAW and FCM removal etc.
To select a safe confinement conception the available reports and proposals on the confinement designs were analyzed.
All existing conceptions were classified into groups based on the features similarity, in particular:

- Conceptions, which do not envisage the creation of a new localizing envelope in order to use the part/parts of the existing SO by means of the stabilization or repair of the existing building structures;
- Conceptions envisaging the creation of a new localizing envelope in order to ensure conditions for unstable structures dismantling and early FCM extraction and RAW management (commencement during 15 years and accomplishment not later than in 100 years);
- Conceptions envisaging the delayed (for more than 100 years) FCM extraction and RAW management.

For verification and assessment of each conception conformity with functional objectives the requirements and criteria matrix was developed. Each safe confinement (SC) conception was assessed using these criteria. Based on the performed analysis, the three conceptions of the safe confinement, which to the best advantage comply with the specified criteria, were selected among 12 available conceptions.
These three alternative conceptions include the following:

- Small-sized confinement («FRAME»);
- «ARCH» («VAULT»);
- Dock-Cofferdam ("CANTILEVER").

The validity of taken solutions was confirmed by the analysis of these three versions of the SC. Further the three SC conceptions were analyzed and assessed using additional qualitative criteria. The independent Ukrainian experts have discussed the SC strategy in their paper, which was generally approved by the Scientific Council of the Construction Academy of Ukraine. The International Advisory Group (IAG) of experts also considered the SC various versions and drew a conclusion that up to now the available information is not sufficient to choose a single version of the SC for the subsequent elaboration during the next designing stage. In the IAG opinion, all the three SC versions are exercisable, with the conception of the ARCH type confinement being the most satisfactory regarding the key functional requirements.
In Fig.11 there are the overall views of the Safe Confinement three versions mentioned above and developed by the ICC (MK) JV Consortium.
The structure of «FRAME» type confinement (Fig. 11,a) is a spatial lattice with dimensions of 210x99 m and 89,5-m height. The load-bearing structures of the shelter are composed of two main beams, arranged in the «north - south» direction. The roof trusses are arranged in the «east - west» direction and rest on the beams.
The SC «CANTILEVER» (Fig. 11,b) is composed of two facilities of a different purpose – the engineering unit and the crane unit. The confinement overall dimensions (along the axes of load-bearing structures) are as follows: 114x246x97 m.
The arch type confinement allows covering the existing SO and the part of the Turbine Hall. The confinement is composed of the separate components: the arch structure proper, end walls and foundations. The arch structure is formed of four segments each 36 m long and having the axis spans of 257 m and height of 108 m (Fig. 11, c).
The concept design (CD) for the safe confinement was elaborated on the ChNPP order by the united team of two consortia: 1) American-French consortium «BISI» including Bechtel (leader company), Battel (USA) and EDF (France) and 2) Ukrainian consortium «KSK» including KiEP (leader organization), NIISK (a leader at the first stage) and International Scientific and Technical Centre (ISTC) «Shelter».
Resolution of the Cabinet of Ministers of Ukraine of 31.03.2003 №421 [12] has established a procedure for the Shelter Implementation Plan execution. In compliance with this Resolution, the procedures of New Safe Confinement designing, in which the requirements of the Ukrainian Building Code DBN A.2.2-3-2004 were taken into account, were defined as follows:

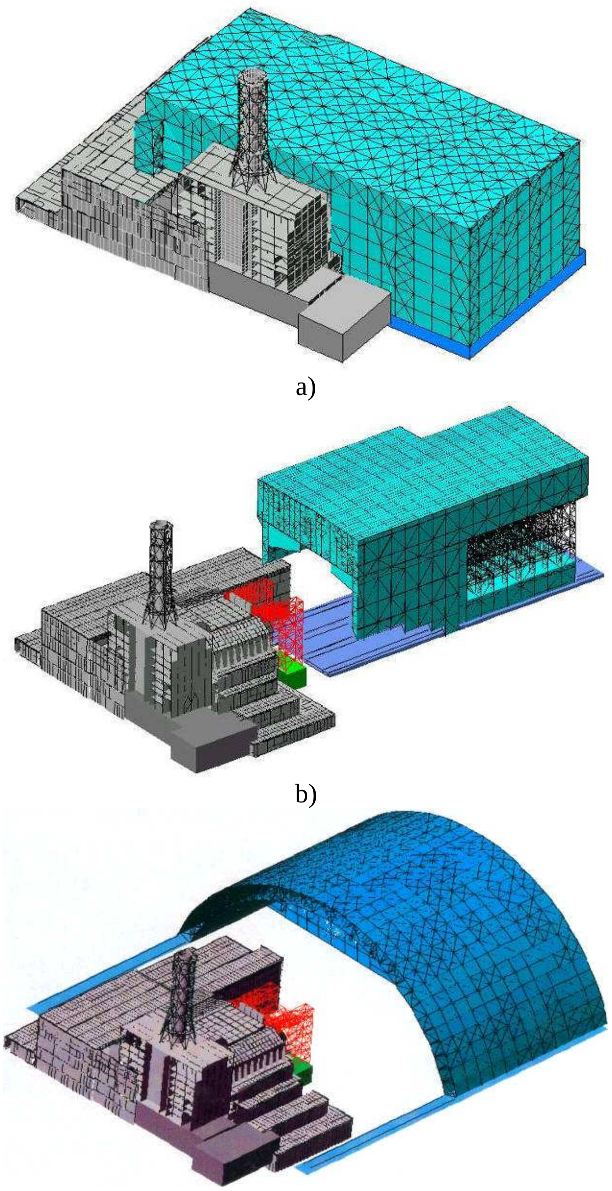


Fig 11. The main design systems for the new Safe Confinement (SC):
a) – «FRAME»; b) – «CANTILEVER»; c) – «ARCH».

- NSC designing shall consist of three stages (CD, design, and work documentation) according to the DBN of Ukraine terminology and of two stages (conceptual design and detailed design) according to the Western terminology. Here the detailed design includes the implementation of two stages (designing and working documentation). The national and western approaches should be necessarily combined due to the conditions of all activities implementation at the expense of the EBRD;
- The NSC feasibility study (conceptual design) and design (the first stage of the detailed design) should be subject to the public composite examination. Taking into consideration the above, the estimate documents shall be excluded from the NSC design documentation subject to the public composite examination and from the corresponding approval. The results of the entire previous activities and decisions made on the state level show that there is no need to additionally substantiate in the framework of the feasibility study the expedience and economic efficiency of the NSC construction.

Moreover, the decisions made earlier definitely specify the NSC structure as an Arch, which shall be assembled at a distance from the NSC and then "slid" into the design position.

6.2.2 NSC general characteristic

In compliance with the goals of creation and functionality set forth in the conceptual design (the feasibility studies) the NSC shall contain the following main objects: the main building with the Arch structure; foundations; west and east end walls; auxiliary systems including systems ensuring the unstable structures dismantling/strengthening; technological building; auxiliary buildings and facilities (sewage pumping station, facility for fire-extinguishing means etc.). The NSC general view is given in Fig. 12.

In the NSC CD the eight modifications of Arch roof configuration of round and paraboloidal shape were considered. The arch-shaped roof is east-westward directed and consists of 13 arch structures arranged at a distance of 12.5 m from each other. The arch-shaped roof is 150 m long. The configuration was chosen due to the SIP package «A» recommendations and taking into account the requirement to ensure the sufficient height for the 80-m crane beams arrangement and the crane working zone necessary for the SO unstable structures dismantling.

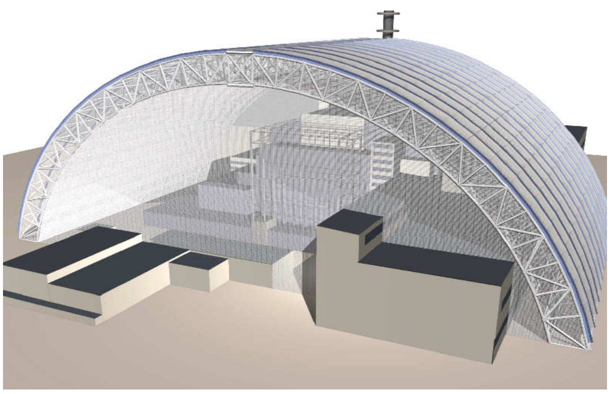


Fig. 12. NSC general view

6.2.3 Arch structure

Arch structure is a metallic spatial structure with the span of 257 m, width of 150 m and height of 108 m consisting of 12 sections of 12.5 m width and the east and west end walls (the distance between the chords of arch trusses is 12 m). The arch structure shall be equipped with all necessary processing tools.

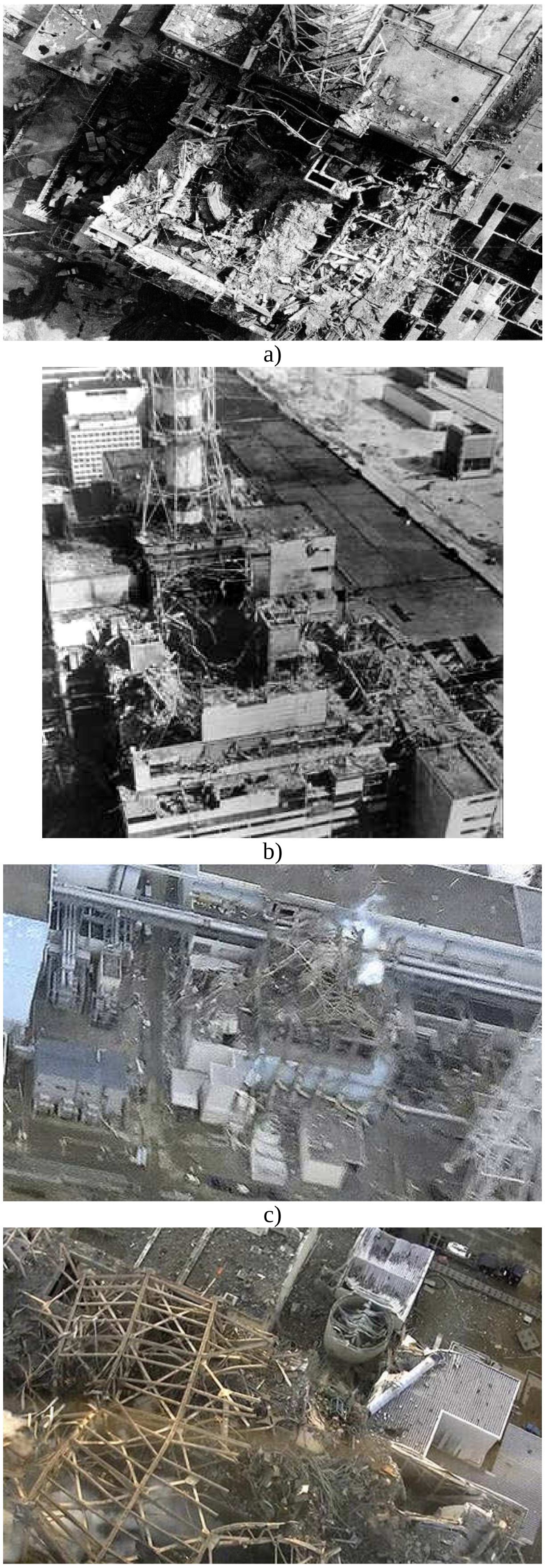
The subsequent stage of the SO transformation relates to the development of the Detailed (Working) Design of the NSC construction and is now being carried out by the International Consortium "NOVARKA" with the participation of the Ukrainian design, research-and-development and production enterprises. The NIISK and ISP NPP perform the functions of the ChNPP Client Engineer in this project. The main goal of their activities is to provide the engineering support in the consideration and analysis of the SIP design documents. This includes verification of design and construction solutions compliance with the normative documents of Ukraine, as well as an assistance in issues of nuclear and radiation safety, participation in integrated assessment of the conducted activities impact on the environment and execution of necessary engineering surveys and investigations at the ChNPP site.

7 THE EARTHQUAKE IN JAPAN ON MARCH 11, 2011

On March 11, 2011, Friday, at 05:46:23 of Coordinated Universal Time (UTC) seismic stations of Japan and United States Geological Survey (USGS) recorded an earthquake of 9.0 magnitude. The earthquake characteristics were given by the National Research Institute for Earth Science and Disaster Prevention [14].

The earthquake occurred in the Pacific Ocean at a depth of 24.4 km at a 130-km distance to the city of Sendai and in 178 km to the city of Fukushima in the North-Eastern region Tohoku of Honshu Island, the largest island of the Japanese Archipelago. The distance from the earthquake epicenter to Tokyo was 373 km [15].

The consequences of such accidents should be given the comprehensive investigation and the norms of designing and safe operation of the nuclear and other dangerous objects should be improved (Fig. 13). In 25 years nature has reminded us about this demand once more. The comfort safe conditions without any earthquakes and technogenous accidents, fires and explosions require increasing the safety culture and improving the prevention measures against dangerous accidents.



a) b) c) d)

Fig. 13. The overall views of the destroyed power units in Ukraine, 1986 (a, b) and in Japan, 2011 (c, d)

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