CURRENT STATUS AND PROSPECTS FOR CHERNOBYL UKRINITIE

Bernard JAMPSIN, European Commission, Directorate General IA
Jean Louis Le MAO, Alliance

1. Introduction

In 1986, there were six reactor blocks at the Chernobyl site. Four were operational, and two units, 5 and 6, were under construction. On the 26 of April 1986, an explosion and fire severely damaged reactor 4 at Chernobyl Nuclear Power Plant, whole site and surrounding areas were contaminated by a mixture of radioactive materials. This accident has been already described in great details in many reports and no purpose would be served on repeating them.

The debris of the reactor and its enclosing structure were encased into a shelter, otherwise known as "the Sarcophagus", erected in great haste and under extremely arduous conditions. It was completed in October 1986. It is this building together with the destroyed unit 4 which is known as "Ukrinitie". It is now known that this structure is unstable, has over 1000 m2 of voids, and can no more be considered as safe. Subsequent monitoring and analysis has shown that the initial expectation of a 30 years lifetime was unlikely to be achieved.

The three other reactors, units 1, 2 and 3, were closed after the accident, and restarted after the clean up operations. Unit 2 was closed again in 1992 after a fire on the electrical generating system and has not been restarted so far.

In the summer of 1992, the National Academy of Sciences of the Ukraine decided to launch a competition with the intention of soliciting ideas that could be developed into an acceptable solution to transform the existing encasement of Chernobyl unit 4 into an ecologically safe system. This competition attracted some 394 entries and, because no entry was deemed by the judges to meet all of their criteria, no first prize was awarded although the French consortium "Resolution" was declared the best entry. Five other entries from France, Germany, Great Britain, Russia and Ukraine were jointly awarded third place.

On the 12th of August 1993, acknowledging the results of the competition, the Cabinet of Ministers of Ukraine issued a decree (N 604) instructing various organizations to prepare an international tender to carry out a feasibility study to define a concept for an environmentally safe system.

The European Commission accepted to finance this study and allocated for that purpose 3 million ECU under its programme of Technical Assistance to the Commonwealth of Independent States (TACIS).

The Terms of Reference for the tender were endorsed by the Ukrainian Minister for the Protection of the Population from the Consequences of the Chernobyl Accident.
(MINCHERNOBYL) as well as by the President of the National Academy of Sciences. They were substantially based on the rules adopted for the competition. These terms required, inter alia, that any solution for the transformation of Ukritiye into an environmentally safe object be effective for one hundred years and be compatible with the continued operation of the three remaining reactors at Chernobyl NPP. It was inevitable that these conditions, which reflected genuine concerns in the scientific community in Ukraine, would have a major impact on the type of solution and its final cost.

On September 1994, a contract was awarded to "ALLIANCE", a consortium formed by Campenon Bernard, Bouygues and SGN from France, AEA Technology and Taywood Engineering of the United Kingdom, and Walter Bau of Germany, for the carrying out of a feasibility study for the project entitled "The stabilization of the existing shelter and the containment of both the exiting shelter and the damaged remains of Reactor 4 at the Chernobyl Nuclear Power Plant".

The study was carried out in two phases. The first phase was an analysis of the problem and the definition of final technical orientations. The second phase was to take the design option (or options) recommended in the first phase, forward to an outline design, a budget cost and to produce an implementation schedule.

At the end of each phase, the results were presented to a panel of Ukrainian and international experts for comments and proposals.

2. Background

2.1 The accident

The accident which occurred at Chernobyl Unit 4 on 26th of April 1986 arose from an enormous power surge which caused local fuel melting and disintegration. Fragments of the fuel were ejected into the surrounding water causing steam explosions. These explosions ruptured fuel channels and led to major structural damage to the reactor structure. The reactor hall was substantially destroyed: the walls, roof and floor of reactor hall, the steam separator room, the north main circulating pump (MCP) room, part of the south MCP, the upper floors of de-aeration stack and the Emergency Core Cooling System (BPO). The west wall of the reactor building was also damaged. (Figure 1, view of damaged reactor block).

The reactor core was completely destroyed and the 2000 tons upper biological shield was displaced and rotated 105° so that it now stands some 15° from the vertical and the reactor base was displaced some 4m downwards.

During the fire fighting efforts, more than 12,000 tones of material were dropped from helicopters and some of this material now stands 15m high on the hall of the reactor hall. The turbine hall suffered damage to the roof and there was lateral movement of the trusses and framework.
2.2 The sarcophagus

In the months following the accident, the Russian and Ukrainian authorities constructed a containment building on and over the debris of the damaged Unit 4. Vertical walls were constructed in front of the west and north sides of the reactor block. A wall was constructed in the turbine hall between the power units. Beams were laid on top of the damaged reactor building to support the roof structure of the new building. It is this building together with the destroyed Unit 4 which is now known as the Ukritije.

(Figure 2, the Ukritije)

2.3 The radioactive inventory

The Ukritije contains some 205 tons of irradiated fuel from the reactor and the short-term cooling pond. This fuel contains about 700 kg of transuranium elements (plutonium, americium, curium), 2 tons of enriched uranium and about 3 tons of fission products. This material is distributed about the Ukritije. It occurs as the following:

- Lava-like fuel containing masses which contain various quantities of fuel and construction materials. These amount to 50-120 tons. Observations of this material show that it is forming a fine-dust.
- Fragments of the reactor core. The total amount of these parts is estimated as 10-36 tons of uranium. A further amount of fuel from the core was thrown from the central hall and is situated now under the debris from the accident. There are also present, in the short-term cooling pond in the reactor hall, (according to different estimates) between 132 and 169 fuel assemblies.
- There are liquid radioactive wastes also present which arose from precipitation that penetrated roof openings and other sources, such as decontamination liquids, dust suppressing, boring and other solutions. The total volume is estimated as 3000 - 3500 m³.

Measurements carried out by the organization ISTC Shelter show that by April 1994 there were nearly $10^{17}$ Bq of radio nuclides in the Ukritije including $6 \times 10^7$ Bq of alpha-active nuclides. These materials give rise to widely varying dose levels inside the Ukritije. On the roof the dose levels reach over 30 R/h and, in places within the Unit 4, 15-300 mR/h.

3. The study

The first phase was an analysis of the problem and the possible solutions. It was necessary to determine the present condition of Ukritije and the essential structures. The study was not required to design any of the facilities that might be contained within any new structure, but it was necessary to examine the functions that the new structure had to accomplish in sufficient detail that the solution offered by the study did not preclude any reasonable future operation to dismantle and remove the destroyed reactor. These functions included an examination of any reasonable methods that might be adopted for the dismantling of the destroyed reactor and a provision for full and proper treatment of the vast quantities of radioactive waste that would be generated throughout the site preparation, construction and operational periods of the project.
3.1 The design basis criteria

One of the more important elements of the first phase was to determine the safety objectives and the design criteria that were to be used. The Ukrainian National Regulatory Authority (NRA) at the time of the study, had not prepared any analysis of the safety requirements. The regulations that existed were contained in sets of special legal Acts, norms and regulations described generally as:

- Laws and resolutions of the Verkhovna Rada, Presidential Decrees, Resolutions of the Cabinet of Ministers of Ukraine and Regulations of the supervising organizations.
- Instructions and procedural documents of the Regulatory body, the Administration of the Exclusion Zone and the operating organization concerning the Chernobyl accident, the Ukrniiye and the Chernobyl NPP.
- Specified norms, regulations, recommendations and standards of the IAEA and other international bodies.

These standards could be modified from time to time, under advice from the Nuclear Regulatory Administration of the Ministry of Environmental Protection and Nuclear Safety, to take account of the particular conditions of the Chernobyl exclusion zone.

It was thus necessary for the study team to produce a draft set of safety and design criteria, for this particular task, which would then be approved by the NRA before the outline design work was started.

3.1.1 Criteria derived from risk considerations

Design criteria were developed so that the following events would not give rise damage or the uncontrolled release of radioactive material from Shelter 2.

- Structural failure of the existing buildings: the design of Shelter 2 had to be such that collapse of Ukrniiye (in part or whole) would not compromise the structure or its function. The stability of the block “D” and ventilation stack, the mechanism of possible collapse (i.e. away from or towards Shelter 2) and the probable frequency of collapse (or events which may lead to collapse), gave rise to concern and had to be taken into account in the design. This included assessment of the ability of the ground to support the building during seismic events.

- The criteria for resistance to seismic and atmospheric events (wind, tornado, snow, flood, temperature extremes, drought and lightning): the design criteria required Shelter 2 to be resistant to events which had a 10,000 year return interval. Fire protection would be achieved by the use of appropriate materials and preventative measures.

- Further events such as accidental explosion, aircraft impact, dropped load etc. were considered of resolution by administrative and operational controls. For the case of a criticality event, it was assumed that the magnitude of the energy emission would be unlikely to compromise the integrity of the Shelter containment.

3.1.2 Criteria derived from civil engineering considerations

The design criteria that derive from the civil engineering aspect of the new structure need to consider the following elements:

- Dimensions of the new building: the building had to be of such a size that its support is independent of the existing structures, the Ukrniiye of Block “D”, since the stability of these has been shown to be inadequate.

- Position of the eastern wall of Shelter 2: the nearest possible location of the east wall to the Ukrniiye is in Block “D”. Block “D” could only form part of the containment if
the stability of the Block could be proved under the design basis earthquake or extreme environmental loading, and if the ventilation stack and other plant in Block "D" could be relocated. If these conditions could not be met, then the east wall had to be located beyond Unit 3 and the Shelter will not be a stable radiological containment until the fuel removal route from Unit 3 is no longer required: that is until Unit 3 is closed and the de-fuelled.

- Minimum clearance from existing structures: the dimensions of the Shelter 2 structure had to be such that it is at a horizontal distance from any Ukriyie structure greater than or equal to the height of that structure or at a shorter distance if it could be proved that the Ukriyie structure would fall within that shorter distance. Furthermore, clearance had to be allowed between the Shelter 2 foundation and existing foundations to reduce any influence to an acceptable level.

- Dismantling requirements: an estimated 20m headroom above the Ukriyie structures had to be allowed for the dismantling cranes and 8m of side access plus a further crane end approach of 9 m and 4m for side approach. Working areas for dismantling totaling 2340m² had to be also provided within the building, further dismantling facilities could be placed outside of the main building in an annex of the containment.

- The positioning of the foundations for the initial design purposes could assume that contaminated debris, minor constructions and fill would need to be removed.

- The building envelope had to include a waterproof membrane requiring minimal maintenance for 100 years.

- Working conditions: for radiological safety risks nuclear design criteria would apply. Where there are no radiological safety risks non nuclear code requirements could be applied. It was necessary to demonstrate that the construction activity over the Ukriyie would not provide an unacceptable hazard resulting in a release of radioactivity to the environment.

3.1.3 Criteria derived from radiological and nuclear safety considerations

All works associated with the new Shelter had to be conducted so that the magnitude of individual doses, the collective (group total) dose and the likelihood of incurring exposures, where these are not certain to be received, from direct radiation and form airborne discharges had to be kept within the accepted norms and, moreover, as low as reasonably achievable, economic and social factors being taken into account.

Radiation dose rates should be reduced by incorporating additional shielding into the Shelter 2 structure rather than by adding shielding to existing Ukriyie. The Shelter 2 design had to incorporate either walls with sufficient shielding or a restricted access area, which enclosed all areas with the potential for radiation levels above an acceptable value for long-term occupancy. The roof had to provide sufficient shielding to provide protection for workers engaged in inspection, maintenance and repair.

If the external radiation levels proved to be above the acceptable value for long-term occupancy outside the shelter walls, then continuous radiation monitoring instrumentation had to be installed to provide warning of significant changes in radiation levels within such areas. The Shelter 2 design should not preclude the installation of systems for the monitoring of levels of airborne radioactive at key locations inside the main containment structure. The ventilation system had to incorporate equipment for the quantitative assessment and continuous monitoring of airborne discharges into the environment.

The foundations of Shelter 2 should be sited, so far as is reasonably practicable, in areas which do not contain significant quantities of buried fuel or waste considered likely to contain bulk quantities of fuel.
The design of Shelter 2 had to provide a containment for radioactive materials taking into account the 100 years specified life span of Shelter 2. All potential containment failure locations shall be provided with a double containment and the operating volume of Shelter 2 should be maintained at pressure below prevailing atmospheric conditions. The internal faces of Shelter 2 and its surface finish had to be designed in order to facilitate the removal of potential contamination.

3.2 The analysis of the present state

3.2.1 Identified risks
The study evaluated a number of hazards (event giving rise to risk), together with the consequences of the event to produce a schedule of risks associated with Ukritiye for use within the design of the new building and improvements of the safety of the existing.
Sixteen key risks have been identified and these have been classified according to the severity of the consequences of the hazard and frequency of occurrence and assigned a resulting risk ranking into one of five risk levels according to the following:
Unacceptable: cannot be tolerated (not an acceptable solution)
Severe: only acceptable in the most extreme case (where no other solution is possible)
High: just acceptable (require careful consideration)
Medium: acceptable (subject to consideration and compliance with ALARP)
Low: acceptable
Of these sixteen key risks identified, four are in the category of severe risks, these are:
- Seismic event
- Egress of contaminated water
- Collapse of Ukritiye
- Block "D" collapse
Fire is classified as a high risk. There are further seven medium category risks and four low category risks.
A quantitative analysis of the structure of the Ukritiye and of block "D" shows that a seismic event giving rise to a ground acceleration of 0.09g would be sufficient to produce a collapse of the structure. The existing seismic data for the Chernobyl region show that the return frequency of a larger event, 0.18g, is 25 years.
The Ukritiye is, in effect, an unconfined source of a massive amount of radioactive material. On the time scale of the half life of the material there will be an egress of contaminated water even should there be no structural failure of the Ukritiye. The geological conditions beneath Chernobyl are water saturated gravel beds which will offer little resistance to the migration of radio nuclides from the Ukritiye to the Pripyat river and beyond. This risk will be of short term concern in the event of a structural failure.
The spontaneous collapse of the Ukritiye is likely to arise from the accelerated corrosion of the exposed steel structural component in the currently high humidity environment of the Ukritiye. A number of the reinforced concrete columns that were damaged in the accident are supported only by the (now exposed) reinforcing bars. It is the corrosion of these elements which could produce structural failure. These effects are resistant to quantitative analysis.
Priority needs to be given to these severe risks and all sixteen identified risks give rise to basic criteria which have to be used in future design. There are a number of different possible scenarios of work involving stabilization of the Ukriyte and construction of a new containment building. Each of these scenarios will have different level of associated risk.

3.2.2 Analysis of risks
The study carried out a quantitative analysis to rank the options for improving the safety of the Ukriyte according to the reduction in risk achieved. This work took into account the environmental risks arising from a collapse of the Ukriyte and the consequent release of radioactive dust.

The study compared the relative risks associated with nine different scenarios covering the main work packages and sequences of operations for Ukriyte stabilization and the construction of Shelter 2. The nine scenarios were considered to be representative of the range of options considered during the first phase of the study. The results of these risk assessments can be used to assist in evaluating the various options and can form an input to the final selection of an optimum solution.

For the purpose of the assessment a simplified model of the Ukriyte containment structure was adopted. This model consisted of four main elements which were considered most likely to collapse and thereby to generate a significant cloud of radioactive dust which may be released to the environment. The four elements were as follows:

a) The block “D” on the east side of Ukriyte between Units 3 and 4
b) The west wall which was damaged during the 1986 accident but which currently serves as a major structural support for the Ukriyte roof

c) The ventilation shafts within the former Unit 4 structure which support the eastern side of the Ukriyte roof
d) The Ukriyte roof structure itself which consists of beams, tubes and steel plates resting on the east and west supports

The postulated release mechanism was that one or more of the four elements collapses and falls (or causes the roof to fall) onto underlying structures within Ukriyte. This generates a cloud of radioactive dust which escapes into the environment through the hole made by the collapsed element.

Each of the four main structural elements was assigned a nominal annual probability of collapse based on a simple qualitative engineering assessment of available information relating to its stability. Seismic activity is a major external factor which may affect structural stability and there is currently significant uncertainty concerning the ability of the Ukriyte structure to withstand earthquakes exceeding a magnitude of 5 on the MSK-64 scale.

The principal protective measures under consideration were the stabilization of the Ukriyte structure and the construction of an additional containment structure around the Ukriyte.

It was assumed that both block “D” and the west wall could be stabilized sufficiently to ensure that there would be no significant risk of their subsequent collapse. This stabilization was assumed to incorporate an acceptable degree of seismic resistance/stability. It was assumed that stabilization of each of these structures would take two years to complete and that block “D” stabilization would only be practicable after either the closure of Unit 3 or after the removal/replacement of essential facilities and services used by Unit 3 and currently located within the block “D”.
It was considered likely that there could be an enhanced risk of structural collapse during the course of any stabilization work. For example possible accidents such as the dropping of heavy loads may increase the effective risk of collapse. Alternatively, stabilization work may include some actions which temporarily weaken the Ukritiye structure. It was therefore assumed that the risk of collapse associated with the block "D" or the west wall was doubled during their stabilization until the work is completed. It was assumed that with Shelter 2 in position around Ukritiye there could still be a release of activity if either the block "D" collapses or if the west wall collapses and knocks a hole in the Shelter 2 west wall. The magnitude of any environmental release in the event of block "D" or west wall collapse was assumed to be halved with Shelter 2 in position, i.e. Shelter 2 was assumed to provide a decontamination factor of 2. The mitigation of the consequence of collapse effectively halved the associated risk value when considered on the basis that "risk" is an arithmetic product of "probability" and "consequence".

The nine main scenarios considered in this assessment were as follows:

- **A)** Take no action (no stabilization, no Shelter 2)
- **B)** Stabilize the west wall, then the block "D", do not build Shelter 2
- **C)** Stabilize the west wall, then the block "D", then build shelter 2
- **D)** Stabilize the west wall, then build Shelter 2, then after 20 years stabilize the block "D"
- **E)** Build Shelter 2, no stabilization
- **F)** Build Shelter 2, then stabilize the west wall, then after 20 years stabilize the block "D"
- **G)** Build Shelter 2, then stabilize the west wall, then (immediately) stabilize the block "D"
- **H)** Build Shelter 2 sufficiently large so that the west wall cannot collapse onto it, then after 20 years stabilize the block "D"
- **I)** Build Shelter 2 sufficiently large so that neither the west wall nor the block "D" have any effect on the Shelter or its integrity

The options studies can be subdivided into four main categories according to the calculated risk of Ukritiye collapse and associated activity release:

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<thead>
<tr>
<th>100 YEAR INTEGRATED RISK VALUE</th>
<th>OPTION</th>
<th>DESCRIPTION</th>
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<tbody>
<tr>
<td>7.64</td>
<td>A</td>
<td>Do nothing (no stabilization, no Shelter 2)</td>
</tr>
<tr>
<td>4.25</td>
<td>B</td>
<td>Stabilize west wall and block &quot;D&quot; (no shelter 2)</td>
</tr>
<tr>
<td>2.27</td>
<td>E</td>
<td>Build Shelter 2 (no stabilization)</td>
</tr>
<tr>
<td>0.38 - 0.58</td>
<td>All others</td>
<td>Build Shelter 2, and stabilize structures which may jeopardize its containment</td>
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The "do nothing" scenario equated to an annual risk of collapse of approximately 1 in 15. Although uncertainties associated with this estimate are potentially large, it is clear that it is not an acceptable long term situation. Structural stabilization alone results in only a small reduction in the risk of environmental release because not all of the internal structures at risk of collapse can safely be stabilized. Construction of Shelter 2 without stabilization work was assessed as having a lower risk than stabilization alone.
The "do nothing" scenario gives an annual risk of collapse (of the Ukritiye and block "D") of approximately 1 in 13, and it is the events consequent on that collapse which need to be considered. The risks, probabilities and consequences of such events were beyond the scope of the feasibility study. Nevertheless, it is clear that any release of activity from Unit 3 would be much more severe and wide ranging than from the Ukritiye, because of the enormous heat source which is present in the operating reactor and its graphite and because of the greater inventory of short-lived radio nuclides. Measures must therefore be taken in the operations of Unit 3 to ensure that the reactor can be safely shut down in the event of a structural failure of the Ukritiye and block "D". It was thus clear that to do nothing was not an option that should be considered.

It thus appeared that the optimum solution was that Shelter 2 should be constructed to form a sealed containment around Ukritiye, and that structures which could jeopardize this containment should be stabilized at the earliest practicable opportunity. Ideally, Shelter 2 should be sufficiently large that collapse of neither the west wall nor block "D" would affect the integrity of its containment.

3.3 Phase one: options analysis

3.3.1 The design of the new shelter

3.3.1.1 Foundations

Since placing foundations inside the perimeter of Ukritiye is not viable, the structure support options are very limited, and consequently, the loads transmitted to the foundations will be locally high. Interpretation of the terrain data currently available shows that the expected settling is high, and suggests that the ground is probably unable to liquefaction under seismic loading. All of this information points, in the first instance, to a requirement for deep foundations rather than surface foundations. This matter was given further consideration in the second phase of the study.

3.3.1.2 Preparation of the site

After the accident, the surrounding of the damaged Unit 4 was filled in. Installation of the foundations means that the earth fill from around the foundations will have to be removed. The earth fill which is located within the bounds of the site installations must be cleaned.

The estimate of the volume of fill material was made by comparing two sets of survey maps, before the accident and after the accident. Depending on the options chosen and the accuracy of the maps, the total volume of fill material to be treated may vary between 135,000 m$^3$ and 270,000 m$^3$. This fill material is not homogeneous. The material containing the maximum waste is located to the south and the west of the machine hall, for a quantity of approximately 95,000 m$^3$ including 1145 one cubic meter containers containing highly radioactive waste (645 to the south and 500 to the west). To this must be added the transformers and the structures housing them, which were buried in the fill material closed off by the pioneer wall. To the south of the machine hall, within the foundations, there are 16 steel pipes of 2 meter in diameter buried 3 meters under the original site. To avoid excavation immediately to the south of the machine hall, the shelter must be extended southwards by 45 meters.

3.3.1.3 Construction methods

The choice of construction methods is directly influenced by the radiation level to which the personnel will be subjected during construction. Of all of the options presented for the new shelter, priority is given to off site pre-fabrication of a maximum number of ele-
ments to enhance the safety of the personnel. It is consequently more expensive, due to the cost of moving the structure and the building of additional foundations along the installation route. In situ assembly bears an additional potential risk: the consequences of dropping a part of the structure under construction onto the Ukriîys roof.

3.3.1.4 Regularity of the structure
The structure of the new shelter is greatly influenced by its earthquake resistance. Under these circumstances and due to the size of the structure, the configuration must be as monolithic as possible with a minimum number of irregularities. The need for regularity of the structure is also determined by the dimensions of the structure. To be sure of a correct structural behaviour, a large-scale structure, such as this, requires much simpler shapes than a small-scale structure.

3.3.1.5 Composition of the structure walls
The shapes of structures are made consistent with the size of the loads they have to absorb. For large spans, research has inexorably resulted in high inertia structures. This inertia is obtained by increasing the height of the cross-section by distributing the material as far to the outsides as possible: this is hollow structure technology. As the new shelter falls into the category of large-scale structures, it is natural to use the hollow structure concept for building the walls and the roof. The concept allows the installation of a maximum amount of instrumentation and equipment inside the hollow structure. Movement inside this hollow space would be protected from atmospheric agents and the hostile environment of the Ukriîys, thus facilitating the maintenance which needs to be carried out over the 100 year life-span required of the construction. The two external skins of the structure, which are in contact with the atmosphere and the potential contamination of unit 4 respectively, need to be as smooth as possible with a minimum of irregularities and corners.

3.3.1.6 The structure material
The choice of material to be used for the structure must meet numerous criteria. The two principal candidate construction materials are steel and concrete. These were compared on the basis of the lifetime, shielding, weight and cost. Careful analysis showed that in almost all of the cases studied, a composite structure of pre-stressed concrete supported by a steel structure is the most economical. In a composite structure, the cost of steel bracing has a major effect on the total cost and consequently optimization will be necessary.

3.3.1.7 Isolation joints
The exceptional dimensions of the structure demand provision against the thermal effects: the bigger the structure, the higher the distortion resulting from thermal variations. In the structure, stresses develop at the points where this distortion is prevented. This is particularly the case where a building joins its foundation; because the foundation temperature is much more stable than that of the building, it will distort less than that of the building superstructure, thus major stresses will develop at the point at which the building is embedded in its foundation. Expansion joints are sources of leakage and also weak points in the containment. Each of the options presented for the new shelter solves this problem to a certain degree and the way it is handled will be one of the assessment criteria for these options.

3.3.2 The review of the design options
Alliance together with the Ukrainian group ISTC "Shelter" reviewed the designs for the containment of the Ukriîys proposed in the entries to the Kiev '92 competition. An ex-
pert review (brain-storming session) led to six design options for the new Shelter: three structures based on a rectangular box and three structures based on an arch.

The six design options were subjected to an exhaustive objective analysis by reviewing their performance against a number of criteria which were grouped according to ability to provide the necessary facilities during the 100 years life-span, the possible construction difficulties and the capabilities of the structure. The criteria were as follows:

- **Life-span**
- **Radiation shielding**
- **Containment**
- **Lifting equipment**
- **Cleaning**
- **Available space**

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<thead>
<tr>
<th>Criteria</th>
<th>Construction difficulties</th>
<th>Structural capabilities</th>
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<tr>
<td>Life-span</td>
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The criteria were as follows:
- Life-span
- Construction difficulties
- Structural capabilities
- Radiation shielding
- Containment
- Lifting equipment
- Cleaning
- Available space

The analysis was achieved by awarding each option a score for each aspect of the performance and each aspect of the performance was weighted according to its importance in meeting the objective of the projects. This analysis concluded that the two highest scoring options, one box and one arch should be taken forward for further examination in the second phase of the study.

### 3.4. Phase two; conversion to a safe ecological condition

The first phase of the Feasibility Study was presented and discussed with the Ukrainian authorities. These discussions highlighted points that needed to be taken into account during Phase two. These included minimizing the removal of earth, minimizing the dimensions of the Shelter and analyzing several options for foundations. Discussions with Ukrainian earthquake experts, mainly with the assistance of the "Kiev State Institute on Engineering Survey and Research ENERGOPROJECT", confirmed the assumptions made during the design. New calculations of the radiation dose rates around the Ukritiy, made with the help of ISTC "Shelter", have concluded that the thickness of the skin of the shelter could be slightly reduced.

At the end of the first phase of the feasibility study, Alliance's proposals led to consideration of two options. Because of the limited time available, it was decided to take only one study forward for detail study in Phase two. The arch option was the solution chosen, for the following reasons:

1. the arch envelops a lesser volume than the box, and consequently meets better the economical requirements of aiming to minimize the dimensions of the shelter;
2. the box requires erection of the north and south walls in situ, close to the radiation sources of Ukritiy, whereas, for the arch, these walls are built under cover of the west wall;
3. the quantity of expansion joints is greater in the box option, which will lead to increased maintenance requirements;
4. the structure of the arch is more capable of supporting traveling crane loading;
5. for the box option, the means of access to the roof are more limited than that for the arch. This is due to the fact that the location of bearing devices at the top of the north wall and south wall obstruct direct access to the roof void.
3.4.1 The final design

3.4.1.1 Foundations
The ground level varies across the proposed sites for the various foundations for Shelter 2 due to varying deposits of material placed following the accident. It is, however, intended to remove all material to reduce the ground level to that existing prior to the accident and thus limit the amount of radioactive contaminated arising from the foundation excavations themselves.

Various sources of information have provided evidence as to the true nature of the ground beneath the proposed foundations. However, in some cases this information is insufficient to provide the conclusive parameters required for these foundations, and in others it is contradictory. A conservative approach has therefore been taken in the choice of preliminary design parameters.

The chosen solutions are a short pile or a deep spread foundation. The short pile scheme comprises a close spaced group of piles installed to a depth that allows load transfer to the quaternary sand strata without risk of bearing capacity failure, or unacceptable settlement. The deep spread foundation alternative comprises the provision of mass concrete, partly placed under water in a sheet pile cofferdam. The mass concrete transfers the load from the footing to an appropriate bearing stratum. This method may provide greater spoil arising than the short pile.

3.4.1.2 Construction methodology
In order to complete the erection of Shelter 2 in the most favorable conditions regarding the effects of the existing radioactivity, we have planned to pre-cast the roof to the west of Ukrine, it is then to be moved from west to east to its final location over the damaged Unit 4, and the adjacent Unit 3 which requires previous closure. The west gable wall is thus erected first and acts as a shield for the assembling yard located to its west. Prior to the start of construction, all the working areas (temporary and permanent) are to be cleaned by removing the soil down to a level 30 cm below that existing before the accident.

The facilities required for the work to be performed are located into two areas: the support area and the assembling yard. The general policy is to perform the maximum work in the support area, which is located to the west, and at a distance of approximately 1000 m from Unit 4. The overall plan dimensions are 400 m by 190 m. The traffic allocated to each area are separated totally in order to avoid the possible spread of contamination. The assembling yard has overall plan dimensions of 300 m by 200 m and is sited adjacent and to the west of Unit 4.

3.4.1.3 Fixed equipment and services
For the functioning of Shelter 2 as a containment, little equipment and services apart from cranes are to be provided within the Shelter 2 inner skin. Most of the provisions, such as ventilation and power supply, will be carried in the roof and wall voids. The main items of fixed equipment are the overhead traveling cranes provided for the future dismantling task, which are fixed to the roof.

It is assumed that active water within the Ukrine is to be removed before leakage becomes a significant problem and water usage within the shelter generally will be strictly controlled. This will eliminate any requirement for the collection of water and discharge to active drainage.

The Service Annex is provided principally for the purpose of housing the access airlock into Shelter 2, the main control room and the major plant. Provision will also be made for a future despatch facility for the waste arising from dismantling of the Ukrine. The building is 78 x 48 m in plan and operates on two floors. Earth fill and or mass concrete is
used to raise the level of the ground around the building to the threshold level of the Shelter 2 access opening. The ventilation services provided at this stage are for operation of Shelter 2 as a containment, where no specific dismantling operations are performed. For the Shelter 2 internal space, therefore, only a very minimal air renewal rate is necessary. Conventional nuclear ventilation is provided for the services rooms, service annex and ventilation plant annexes.

3.4.1.4 Underground containment

The function of an underground containment is defined as the prevention of the migration of radioactive material, below ground level, that would represent a significant risk to human health and the environment. It was concluded that it is not necessary to provide a complete cut-off for ground water around and under the Uzbekiyé to fulfill such a containment function.

This recommendation is based on the lack of evidence that harmful quantities of radionuclides from the Uzbekiyé are entering the ground water. The major mechanism by which radioactive material can enter the ground water is by surface water draining down through the upper soil layers. As the main source of surface water is rain water, this will be prevented by the provision of Shelter 2.

It is also considered that a cut-off will in fact be detrimental to the containment function, because of local changes in the level of the water table could lead to the flooding of areas contaminated with radioactive material or settlement of other buildings in the area.

It is therefore considered that only measures designed to maintain the existing steady state with respect to the Uzbekiyé should be undertaken. These conclusions were supported by a mathematical modeling study of the hydrogeology of the Chernobyl area, conducted by the Institute of Geological Sciences of the Ukrainian Academy of Sciences. Certain aspects of the design and implementation philosophy for Shelter 2 have to include safeguards to ensure that the underground containment argument holds true. Active water, presently held within the Uzbekiyé, must be removed before it has a chance to leak into the subsoil should deterioration occur of the basement concrete and waterproofing. Furthermore, any addition of water to the interior of the shelter (e.g. dust suppression or fire fighting provisions) must be of sufficiently low incidence and high dispersion as to provide an insignificant risk with respect to surface water seepage.

3.4.1.5 Alternative option for the east wall

The design presented locates the East wall to the east of Uzbekiyé and it is clear that, during the dismantling operations of Uzbekiyé or in the event of its collapse, there is potential for the spread of radioactive dust to all the existing buildings covered by Shelter 2 including those not yet contaminated, most notably parts of Unit 3. In order to reduce this risk, an alternative solution has been devised which would locate the East wall further towards the west, that is, as close as possible to Uzbekiyé. This reduces the length of Shelter 2 by about 100m.

As a result, the East wall would successively cross, from north to south the BCPO Block, block "D" and Turbine Hall. It will be necessary to demolish most of BCPO Block down to its existing raft in order to build the new wall. The foundation will consist of a reinforced concrete footing cast on top of the existing raft. It is not viable to demolish totally block "D" and to replace it by the new wall because block "D" provides support to the Uzbekiyé. It must therefore be strengthened, stabilized and increased in height up to top of Shelter 2.

In the event of extreme conditions, such as the collapse of Uzbekiyé or the maximum earthquake, some increase in risk to the containment function must be accepted with this
alternative option. These risks come from the collapse of block "D" or the part of the Turbine Hall causing damage to the east wall of Shelter 2.

3.4.2. The cost

The table below presents the cost estimate for Shelter 2, with the two proposed solutions to the position of the East wall.

<table>
<thead>
<tr>
<th>ITEMS</th>
<th>BASIC SOLUTION Millions US $</th>
<th>ALTERNATIVE SOLUTION Millions US $</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Preparatory works</td>
<td>185</td>
<td>185</td>
</tr>
<tr>
<td>2. Shelter 2 construction</td>
<td>700</td>
<td>600</td>
</tr>
<tr>
<td>3. Shelter 2 - Equipment &amp; Services</td>
<td>200</td>
<td>100</td>
</tr>
<tr>
<td>TOTAL 1, 2 and 3</td>
<td>1085</td>
<td>885</td>
</tr>
<tr>
<td>4. Project Management</td>
<td>250</td>
<td>250</td>
</tr>
<tr>
<td>5. Stabilization of Ukrinite</td>
<td>Between 75 and 150</td>
<td></td>
</tr>
</tbody>
</table>

All costs were valid in June 1995; they take no account of price escalation, direct or indirect taxes, profit taxes, personnel taxes and custom duties. The breakdown shown above is split into items corresponding to:

1. Preparatory works which provide for common facilities offered to all contractors on site such as housing, roads, labour and staff camps, bases for personnel, etc., as well as the cleaning of all radioactive materials in the areas of work.

2. Shelter 2 construction, which provides for the civil works of Shelter 2.

3. Shelter 2 equipment and services, which provides for traveling cranes, ventilation and the services amounts in the Shelter.

4. Project management of the overall project.

5. Stabilization of the Ukrinite for which a range can be given because of the technical uncertainty of the works.

The total of the first three items is subject to an uncertainty of 20% because of the early stage of the estimate.

It should be noted that the difference between the costs of the basic and the alternative solutions appears relatively small, although not insignificant. This is essentially because the investment costs remain more or less the same for the two solutions and also because of the increased cost of the East Gable Wall in the alternative solution.

Nevertheless, it should be noted that this difference applies to the construction only. When working on the dismantling phase, it is evident that the alternative solution will offer potentially significant savings in terms of radioactive and contaminated waste volumes and the operating and maintenance costs.

It is important to recognize that the cost of the new containment building itself is less than half the total project costs and that, while some costs will reduce in proportion to the shelter costs, some are fixed. A significant fixed cost is the management of the 350,000 tons of radioactive waste that already exists around the Ukrinite and will need to be treated whatever works are carried out.
4. A way forward

Following the presentation of the Alliance feasibility study to a panel of Ukrainian and international experts, it was agreed between the Ukrainian Authorities and the European Commission that the results and conclusions of the study were to be considered as a technical element for a decision of the Ukrainian Authorities about the future of Chernobyl NPP Unit 4. On that occasion, both parties agreed that Alliance had fulfilled its duty on the basis of the Terms of Reference and data coming from and endorsed by the Ukrainian Authorities and that its report should be considered as a valuable basis.

On the 11th of September 1995, a meeting took place in Brussels between the European Commission and a Ukrainian delegation headed by Mr. Khlochea, Minister of Chernobyl, and composed of representatives of Ministry of Chernobyl, the Ministry of Environment and Nuclear Safety, Goskomatom and the Academy of Sciences of Ukraine. It appeared very clearly that the solution of the Chernobyl Unit 4 issue was considered by the Ukrainian authorities as a high priority while it was agreed that the assumptions which had formed the basis of the Alliance study could be revised and that alternative solutions should be explored before searching for financing solutions.

As a result of the meeting, the following actions were agreed upon and entered into a protocol signed by both parties:

1. Definition of safety objectives and design criteria for the stabilization of the existing shelter;
2. Establishment of terms of reference for the stabilization of the existing shelter;
3. Definition of safety objectives and design criteria for a new encasement;
4. Establishment of terms of reference for the construction of a new encasement.

These four actions are financed by the European Commission within the framework of its Tactic programme.

RiskoNet, a grouping of Technical Safety Organization of the European Union, namely the Institut de Protection et de Sûreté Nucléaire of France and the Gesellschaft für Anlagen und Reaktorsicherheit of Germany, has been awarded a contract to provide assistance to the Ukrainian Nuclear Regulatory Administration (NRA) for the definition of the safety objectives for the stabilization of the existing shelter and the construction of a new encasement.

On the other hand, a group of organizations and experts of the European Union shall assist the Ukrainian operator, Goskomatom, for the establishment of terms of reference for the stabilization of the existing shelter and the construction of a new encasement.

These actions aiming at a solution for the Chernobyl Unit 4 issue should not be considered in isolation. Actually, they are placed within the general framework of the G7 Action Plan for Ukraine Energy Sector.
This Action Plan, put forward and proposed to the Ukraine by the European Council at Corfu and the G7 Summit at Naples in 1994, consists of a set of measures aiming at the early closure of the Chernobyl Nuclear Power Plant while ensuring that sufficient electricity is available to meet Ukrainian demand and taking into account the economical, financial and social constraints. It includes in particular proposals for substantial reforms in the energy sector at large.

As a first important step in the implementation of the Action Plan, a Memorandum of Understanding on the closure of Chernobyl Nuclear Power Plant was signed on December 20, 1995 in Ottawa by Deputy Prime Minister of Canada, Mrs. Sheila Copps, on behalf of G7 leaders, and by Ukrainian Minister for Environmental Protection and Nuclear Safety, Mr. Yuriy Kostenko. This Memorandum calls for the creation of a Comprehensive program to support the decision of the Ukraine to close the Chernobyl Nuclear Power Plant by the year 2000, as stated by President Kuchma. It covers the following aspects:

1. Power sector restructuring;
2. Energy investments program;
3. Nuclear Safety;
4. Social impact plan;

It is foreseen that representatives of the Ukraine, of the G7 and of International Financial Institutions shall meet annually to review the implementation of the a.m. Comprehensive Program based on the critical linkage between energy sector reform and the achievement of Ukraine's economic and social reform, as well as the complementarity between Chernobyl NPP closure and the development of a long term strategy for the energy sector in Ukraine.

The European Commission is actively involved in the following activities, related to:

1. the completion to internationally acceptable standards of two new VVER 1000 reactors presently under construction;
2. the phased decommissioning of Chernobyl units 1, 2 and 3;
3. assessment of the social impact of the closure of Chernobyl NPP;
4. the Chernobyl unit 4 issue.

Within this framework, the European Commission has already pledged:

1. 100 million ECU in grants from its Taxis programme, spread over three budgetary years (1994: 28.5 MECU; 1995: 37.5 MECU; 1996: 37.5 MECU);
2. 400 million ECU to be raised in Euratom loans for the completion of two VVER 1000 new reactors presently under construction.