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THE INTERNATIONAL PROJECTS TO DEVELOP AND SUPPORT SHORT AND LONG TERM MEASURES AT CHNPP UNIT 4 SITE

Based on a "Memorandum of Understanding between the Governments of the G7-countries, the European Commission and the Government of Ukraine on the Closure of the Chornobyl Nuclear Power Plant", signed in 1995, joint international efforts were initiated to develop *"a cost effective and environmentally sound approach to the shelter for Chernobyl Unit 4"* and the Study "Chernobyl Unit 4: Short and Long Term Measures" was prepared in 1996 with a recommended course of actions. Based on the recommendations of the study the "Shelter Implementation Plan (SIP)" was prepared and its implementation started in 1998. After its soon expected successful completion, the options for the next steps need to be analysed and decided.

Keywords: nuclear accident, fuel containing materials, remedial measures, decision processes, option analysis.

1. Background and Introduction

During the Chornobyl Unit 4 accident of April 26th 1986 the reactor and reactor building of Unit 4 of Chornobyl Nuclear Power Plant (ChNPP) were completely destroyed and radioactive material was spread over the site and released to the environment. Immediate emergency and accident liquidation measures were undertaken to combat the consequences of the accident including, among others, the creation of the Chornobyl Exclusion Zone (ChEZ), and erection of the Shelter building, so called "Sarcophagus" (also called "Ukritiye"), to re-establish new barriers for the reactor remains which is still containing the major part of the former Unit 4 fuel. Decontamination of territory, roads and premises was part of the accident liquidation measures performed to reduce radiation levels at the contaminated territory as well as at the plant site: it was a prerequisite for workers to restart the 3 adjacent reactor units one after another till the end of 1987.

In 1991 Ukraine became independent after the breakdown of Soviet Union, and consequences of Chornobyl accident became a solely nuclear legacy of Ukraine which sought for international support. In 1992 the G7 and EU initiated a support programme to increase nuclear safety within the transition countries in which Ukraine was part of. Based on a "Memorandum of Understanding between the Governments of the G7-countries, the European Commission and the Government of Ukraine on the Closure of the Chornobyl Nuclear Power Plant", signed in December 1995, joint international efforts were undertaken to develop *"a cost effective and environmentally sound approach to the shelter for Chernobyl Unit 4"*.

A project "Chernobyl Unit 4: Short and Long Term Measures" was initiated in early 1996, to analyse options and provide recommendations. Together with Ukrainian experts, an international expert team was formed to analyse needs and possible approaches. A final report summarizing the findings was issued on 29 November 1996. It included a recommended course of action as a main result of the joint effort.

Based on this report findings Ukraine, G7 countries and European Commission instructed the international expert team to prepare a "Shelter Implementation Plan (SIP)". The SIP was drafted in June 1997, approved at the G7-Denver Summit in 1997 and implementation preparation initiated in 1998 - including establishing of funding mechanisms with the "Chernobyl Shelter Fund (CSF)", administered by the European Bank of Reconstruction and Development in London. The effective implementation of the SIP started in 1998 and is currently in its final implementation phase.

2. Situation at Chornobyl NPP Unit 4 Site in 1996

The "Sarcophagus" has been erected in less than 6 months under exceptionally difficult conditions as part of the immediate accident response actions to create new barriers around the remains of the reactor. After its erection, one of the controversially discussed options was the further approach necessary to establish a longer term safe structure. Initially, the aim was entombment. For reasons highlighted below, this project was deemed unrealistic and was therefore never realized. The following diagram illustrates some key challenges encountered in 1996.

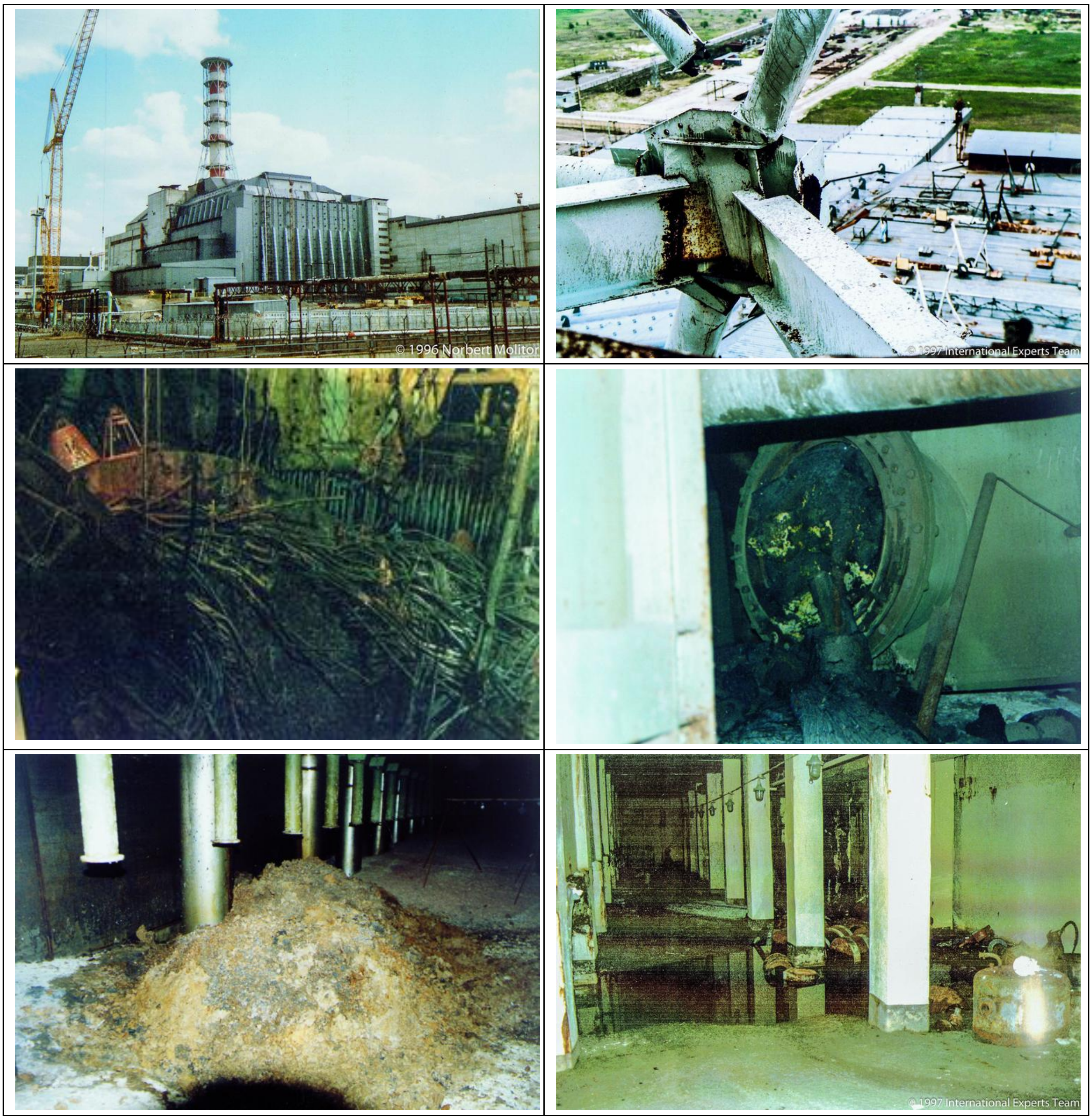


Diagram: Selected pictures to illustrate the situation at Chornobyl Unit 4 site in 1996.
Captions: 1 - Shelter in 1996; 2 - Destroyed node of ventilation stack; 3 - Destroyed reactor vessel; 4 and 5 - Examples of Fuel Containing Materials; 6 - Water in the lower premises (picture source: SIP Pledging Conference Brochure 1997).

The main challenges encountered in 1996 can be summarised as follows:

The unreliable and unstable conditions of the Chornobyl Unit 4-Shelter structure

- The construction was built under extreme radiation conditions: prefabricated steel elements were simply stacked on overstressed building ruins which could only be partially reinforced with the cast concrete (such as the cascade wall made of concrete or the ventilation shafts poured with concrete). As a result, the structural reliability of supporting elements could not be proved. Furthermore, the steel elements piled on these supporting elements with doubtful stability were not connected properly, between each other (most elements are merely stacked and most of the joints were not welded, bolded or fixed in any way together), with the result, that the overall stiffness, stability and consistency of the roof structure was unsatisfactory.
- Moreover, the construction was built on a destroyed building without the support of deep foundations, such that settlements as wellas a a tilting of the "Sarcophagus" structure were observed. One of the main concerns was therefore the on-going weakening of the structure stability.

- Corrosion and weathering deteriorated the existing structure further, which was never meant to be a sufficient long term solution (e.g. on December 22, 1988, Soviet scientists announced that the sarcophagus would only last 20–30 years before requiring restorative maintenance work).

- The "Sarcophagus" was not airtight, nor watertight, and although a complex dust suppression system was operated, the release of radioactive dust through openings to the environment and ingress of waters was not fully preventable.

- The ventilation stack on the joint service building between Unit 4 and Unit 3 was severely damaged and unstable. A potential collapse of this ventilation stack with falling on the "Sarcophagus" could have led to severe damage or even collapse of the "Sarcophagus" itself.

Radioactive inventory of the Unit-4-Shelter

- The inventory contained enormous amounts of radioactivity (estimated to about 20 MCi – Mega-Curie) with a high proportion of gamma emitters and transuranics (estimates indicated that the sarcophagus may have locked in some 200 tons of radioactive corium, some 30 tons of highly contaminated dust, several tons of uranium and plutonium and substantial amounts of radioactive reactor core graphite).

- The inventory contained substantial amounts of fissile materials under unacceptable conditions (damaged fuel elements, various types of fuel containing materials (FCM), such as lava-like materials, undefined admixtures of concrete and fissile materials, and dispersed fissile materials). Furthermore, localisation of a substantial part of the original fuel could not be performed because of limited physical access and very high radiation levels and the conditions of remaining fuel and fuel containing materials could not be sufficiently controlled.

- The few existing and operational monitoring and control equipment registered fluctuating neutron flux events, meaning that 'local critically' of nuclear materials could not be excluded.

- The lower premises contained water from the immediate response activities, precipitation water (snow and rain) could penetrate through opening in the roof and the wet dust suppression system was based on aqueous liquid spraying: all of this led to the presence of the major amounts of water in a direct contact and interaction with the radioactive and fissile inventory altering and changing the conditions of the latter.

Industrial safety/ working conditions

- Access ways and corridors to the different reactor compartments and inventories in them were radiologically and physically unsafe and inadequate or even not existing: ensuring safety of works inside the "Sarcophagus" under these conditions was practically not possible.

- The immediate neighbourhood of the "Sarcophagus" was highly contaminated: radiation protection was a problem for works not only inside but also outside of sarcophagus.

Interfaces with adjacent nuclear facilities

- The immediately adjacent Unit 3 with a similar 1000 MW RBMK reactor was still operational and raised additional safety concerns for situation and possible works at Unit 4.

- Other nuclear facilities were either operated or planned to be constructed at the site (e.g. new interim spent fuel storage facilities, radioactive waste treatment facilities).

3. Recommended Course of Action

With the overall safety objective being protection of public, workers and the environment, many heated arguments were exchanged between the experts on how these objectives could be reached by addressing the encountered situation and risks. After the discussion, a common understanding was reached: Chornobyl Unit 4 could not be converted to a safe final disposal facility for nuclear materials. Consequently, this implied that the removal of the nuclear inventory is a challenge to be resolved ultimately which has to be achieved - e.g. in a graded approach step by step - to reduce risks and re-establish and increase safety. This result was in compliance with the „National Program for Transformation of the Object 'Ukritiye' into an ecologically safe ecological system".

Once the objectives and measures with their priorities were identified, a safety-based risk mitigation decision tree was prepared. By abstraction 3 top decisions were to be taken:

- Short term risks which can be addressed with urgent measures in a short timeline should be funded. This led to decision of funding of top priorities (decision no. 1).

- In a next step, a principle decision no.2 had to be taken: could the inventory remain were it is according to common and international standards or not? In case of Chornobyl Unit 4, there was common understanding that the site could not be converted into a final repository.

- If the site cannot be converted into a repository, the next decision would be about timing of recovery, implying that if an appropriate disposal site would not be available at the time of recovery, there will be the need of interim storage until disposal would be possible.

The corresponding different phases for implementation of measures were defined and described. It was noted by the international expert team that with no decision taken at an early stage, the measures needed to remain flexible with decisions taken at a later stage with limited possibility of optimisation.

These main results were reflected by the international expert team to develop the ‘Recommended Course of Action’, which is illustrated and are summarized in the following diagrams.

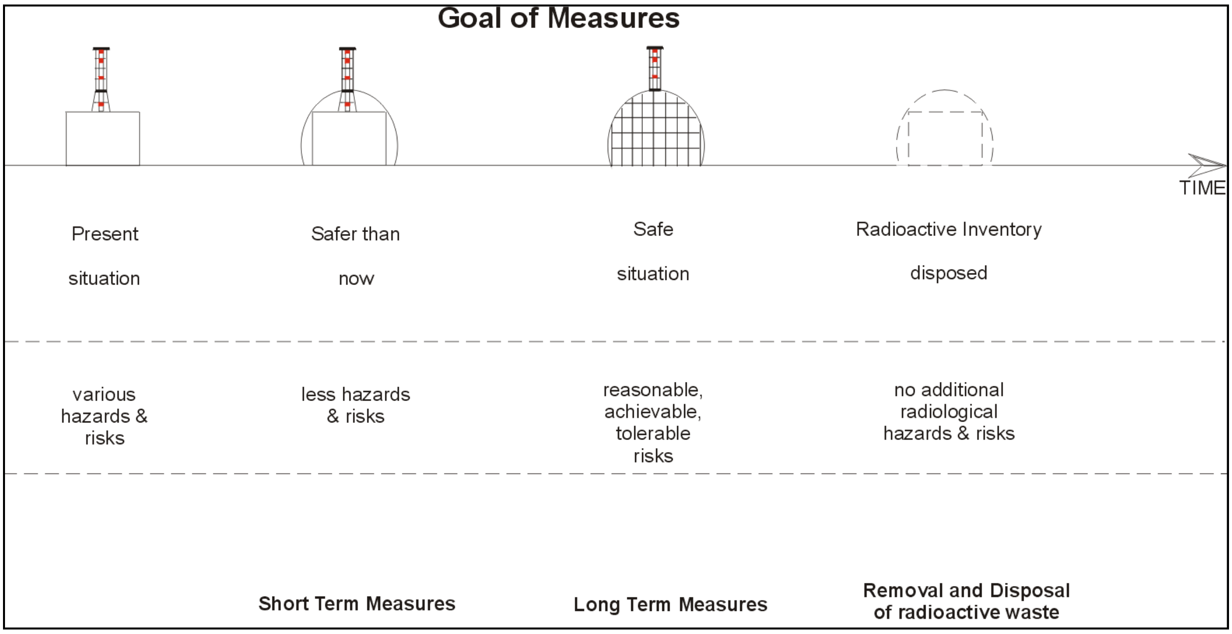


Diagram: Graded approach to reestablish safety and eliminate risks at ChNPP Unit 4 site
(source: international expert team 1996)

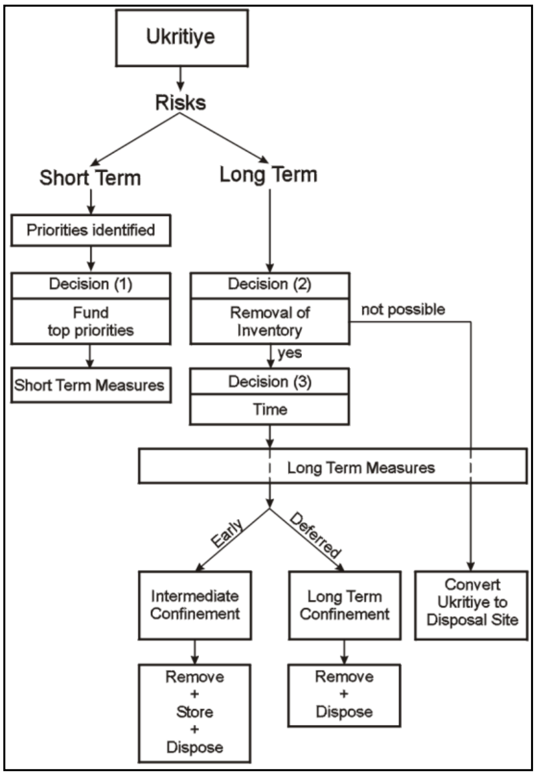
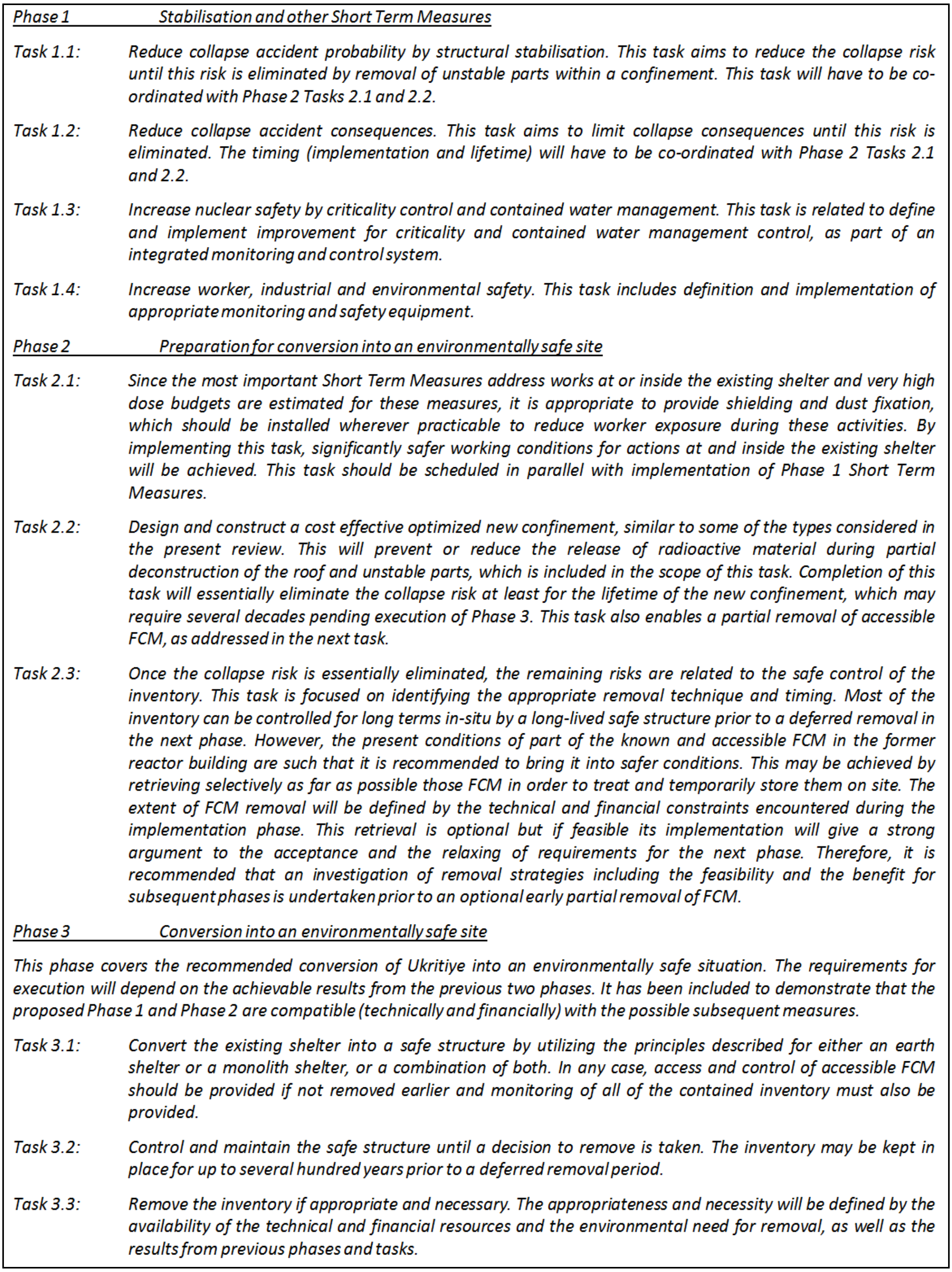


Diagram: Decision Tree for Recommended Course of Action
(Source: international expert team 1996).



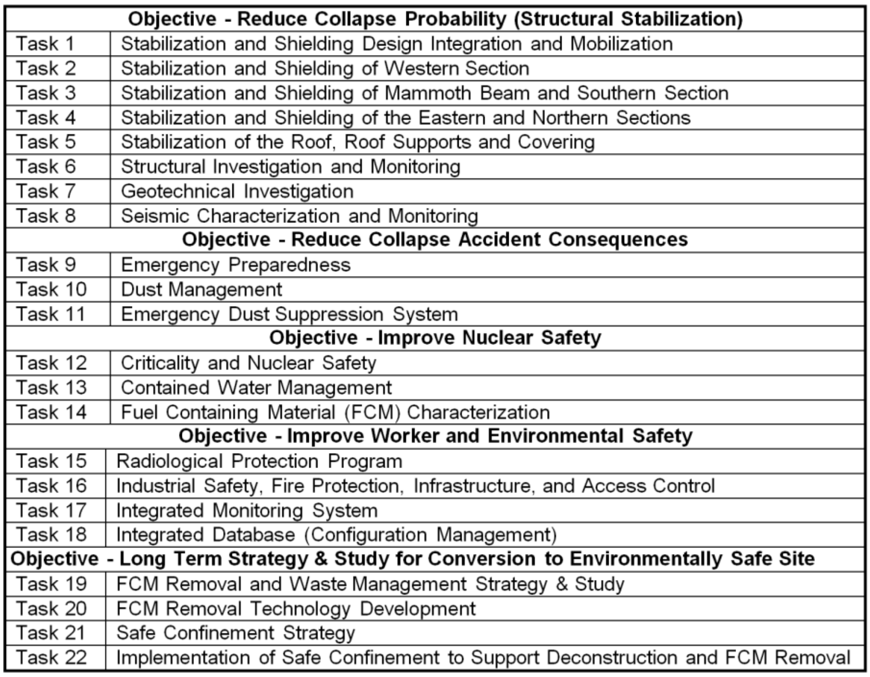
Phase 1	*Stabilisation and other Short Term Measures*
Task 1.1:	*Reduce collapse accident probability by structural stabilisation. This task aims to reduce the collapse risk until this risk is eliminated by removal of unstable parts within a confinement. This task will have to be co-ordinated with Phase 2 Tasks 2.1 and 2.2.*
Task 1.2:	*Reduce collapse accident consequences. This task aims to limit collapse consequences until this risk is eliminated. The timing (implementation and lifetime) will have to be co-ordinated with Phase 2 Tasks 2.1 and 2.2.*
Task 1.3:	*Increase nuclear safety by criticality control and contained water management. This task is related to define and implement improvement for criticality and contained water management control, as part of an integrated monitoring and control system.*
Task 1.4:	*Increase worker, industrial and environmental safety. This task includes definition and implementation of appropriate monitoring and safety equipment.*
Phase 2	*Preparation for conversion into an environmentally safe site*
Task 2.1:	*Since the most important Short Term Measures address works at or inside the existing shelter and very high dose budgets are estimated for these measures, it is appropriate to provide shielding and dust fixation, which should be installed wherever practicable to reduce worker exposure during these activities. By implementing this task, significantly safer working conditions for actions at and inside the existing shelter will be achieved. This task should be scheduled in parallel with implementation of Phase 1 Short Term Measures.*
Task 2.2:	*Design and construct a cost effective optimized new confinement, similar to some of the types considered in the present review. This will prevent or reduce the release of radioactive material during partial deconstruction of the roof and unstable parts, which is included in the scope of this task. Completion of this task will essentially eliminate the collapse risk at least for the lifetime of the new confinement, which may require several decades pending execution of Phase 3. This task also enables a partial removal of accessible FCM, as addressed in the next task.*
Task 2.3:	*Once the collapse risk is essentially eliminated, the remaining risks are related to the safe control of the inventory. This task is focused on identifying the appropriate removal technique and timing. Most of the inventory can be controlled for long terms in-situ by a long-lived safe structure prior to a deferred removal in the next phase. However, the present conditions of part of the known and accessible FCM in the former reactor building are such that it is recommended to bring it into safer conditions. This may be achieved by retrieving selectively as far as possible those FCM in order to treat and temporarily store them on site. The extent of FCM removal will be defined by the technical and financial constraints encountered during the implementation phase. This retrieval is optional but if feasible its implementation will give a strong argument to the acceptance and the relaxing of requirements for the next phase. Therefore, it is recommended that an investigation of removal strategies including the feasibility and the benefit for subsequent phases is undertaken prior to an optional early partial removal of FCM.*
Phase 3	*Conversion into an environmentally safe site*
	This phase covers the recommended conversion of Ukritiye into an environmentally safe situation. The requirements for execution will depend on the achievable results from the previous two phases. It has been included to demonstrate that the proposed Phase 1 and Phase 2 are compatible (technically and financially) with the possible subsequent measures.
Task 3.1:	*Convert the existing shelter into a safe structure by utilizing the principles described for either an earth shelter or a monolith shelter, or a combination of both. In any case, access and control of accessible FCM should be provided if not removed earlier and monitoring of all of the contained inventory must also be provided.*
Task 3.2:	*Control and maintain the safe structure until a decision to remove is taken. The inventory may be kept in place for up to several hundred years prior to a deferred removal period.*
Task 3.3:	*Remove the inventory if appropriate and necessary. The appropriateness and necessity will be defined by the availability of the technical and financial resources and the environmental need for removal, as well as the results from previous phases and tasks.*

Diagram: Summary Description of Recommended Course of Action (1996).

The Phase 3 (from 3.1 to 3.3) was associated with many uncertainties that should be resolved during the tasks from 1.1 to 2.2. Thus, there was consensus to decide and implement first tasks 1.1 to 2.2 which should improve safety considerably and provide a better decision basis for the tasks 2.3 to 3.3. The international expert team was instructed accordingly in 1997 to prepare a “Shelter Implementation Plan (SIP)” covering phase 1, and tasks 2.1 and 2.2.

4. Shelter Implementation Plan (SIP)

The international expert team developed accordingly a detailed decision plan, work break down structure, work sequence, provisional time tables and budgets by defining 22 main tasks.



Objective - Reduce Collapse Probability (Structural Stabilization)	
Task 1	Stabilization and Shielding Design Integration and Mobilization
Task 2	Stabilization and Shielding of Western Section
Task 3	Stabilization and Shielding of Mammoth Beam and Southern Section
Task 4	Stabilization and Shielding of the Eastern and Northern Sections
Task 5	Stabilization of the Roof, Roof Supports and Covering
Task 6	Structural Investigation and Monitoring
Task 7	Geotechnical Investigation
Task 8	Seismic Characterization and Monitoring
Objective - Reduce Collapse Accident Consequences	
Task 9	Emergency Preparedness
Task 10	Dust Management
Task 11	Emergency Dust Suppression System
Objective - Improve Nuclear Safety	
Task 12	Criticality and Nuclear Safety
Task 13	Contained Water Management
Task 14	Fuel Containing Material (FCM) Characterization
Objective - Improve Worker and Environmental Safety	
Task 15	Radiological Protection Program
Task 16	Industrial Safety, Fire Protection, Infrastructure, and Access Control
Task 17	Integrated Monitoring System
Task 18	Integrated Database (Configuration Management)
Objective - Long Term Strategy & Study for Conversion to Environmentally Safe Site	
Task 19	FCM Removal and Waste Management Strategy & Study
Task 20	FCM Removal Technology Development
Task 21	Safe Confinement Strategy
Task 22	Implementation of Safe Confinement to Support Deconstruction and FCM Removal

Diagram: Main Tasks of SIP (International Expert Team 1997).

The SIP was prepared between February and May 1997 to be completed and available for consideration by the G7 countries. Decision to proceed was formally taken at the Denver 1997 G7 Summit in June 1997 where the creation of a Chernobyl Shelter Fund (CSF) as funding mechanism for the SIP implementation under administration of the European Bank for Reconstruction and Development (EBRD) in London was also agreed upon. The EBRD prepared all necessary rules for th 'Chernobyl Shelter Fund' and arrangements to make the CSF mechanism operational, and a first international pledging conference was organised for November 1997 in New York to feed the CSF.

The SIP implementation started in 1998 and most of the tasks including the major stabilization were completed in 2008. The contract for the new safe confinement (NSC) was signed in 2007. The NSC, which is to support partial deconstruction of sarcophagus and FCM removal, is currently constructed and under commissioning which is expected to be completed in 2019. After completion of the NSC, the partial deconstruction of unstable parts of the old sarcophagus shall be commenced and completed within a few years. This sequence is illustrated in the following diagram within the overall framework of graded approach, stipulated by the international expert team in 1996.

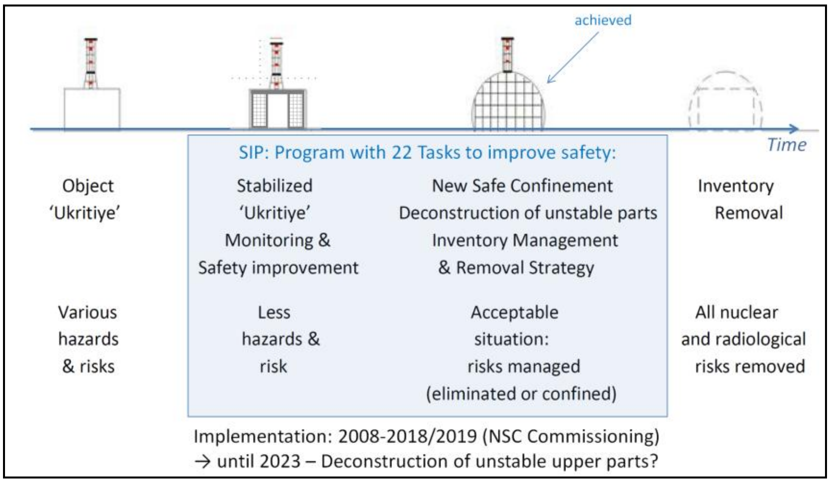


Diagram: Implementation of the SIP.

5. Achievements and Next Steps

In summary, the main technical achievements of the SIP are the following:

the unreliable structures of the old 'Sarcophagus' are stabilized such to reduce collapse risk;

an integrated monitoring system is put in place to ensure much better control of structures, inventory and impacts on the environment;

a new reliable confinement structure is constructed to allow essential elimination of collapse risk related to old "Sarcophagus" structures by dismantling upper unstable parts;

further, when the upper unstable parts are removed, a much safer and technically more efficient access to the inventory from the top will be allowed.

The SIP is a success reaching an important milestone for safe site management until safe inventory removal will be possible. However, during project implementation it became clear that a major essential boundary condition remained unresolved: the availability of a deep geological disposal was so uncertain that it was decided to postpone the fuel removal strategy and configuration and to conclude that the lifetime of NSC should be 100 years in order to allow sufficient time to resolve the FCM removal strategy - including for inventory disposal.

Therefore, the logical and consistent way forward, is the development of the FCM strategy based on the necessary studies and pilot tests which are part of the 'Recommended Course of Actions'. To initiate them after the completion of the SIP has the advantage to take into account the improved knowledge on the inventory and further development of technologies available, which have been improved further over the last 20 years since the 'Recommended Course of Action' was developed and the SIP initiated.

Over the last two decades, the site conditions and site infrastructure have improved and a lot of valuable experience has been collected at the site and its context, including among others:

stabilization of the old "Sarcophagus" (e.g. organization of the safe work in highly contaminated environment);

clearing and cleaning for new safe confinement construction site (e.g. including removing of wastes and high level wastes from the site);

implementation of the Industrial Complex for Solid Radwaste Management (ICSRM);

implementation of other radioactive waste disposal facilities at VEKTOR complex site;

better understanding of type, distribution and properties of the site inventory.

Further, over the same two decades, substantial technologies have been developed and know-how was acquired during dismantling of highly contaminated facilities in different countries. The occurrence of another large-scale nuclear accident in 2011 in Japan, also contributed to fostering of approaches and technologies for managing highly contaminated sites, including the necessity of damaged fuel and debris removal with the new technologies.

In practical terms, when the upper parts of the sarcophagus including the roof are dismantled below the NSC, there will be a flexible and efficient access to the Unit 4 inventory from the top. NSC equipped

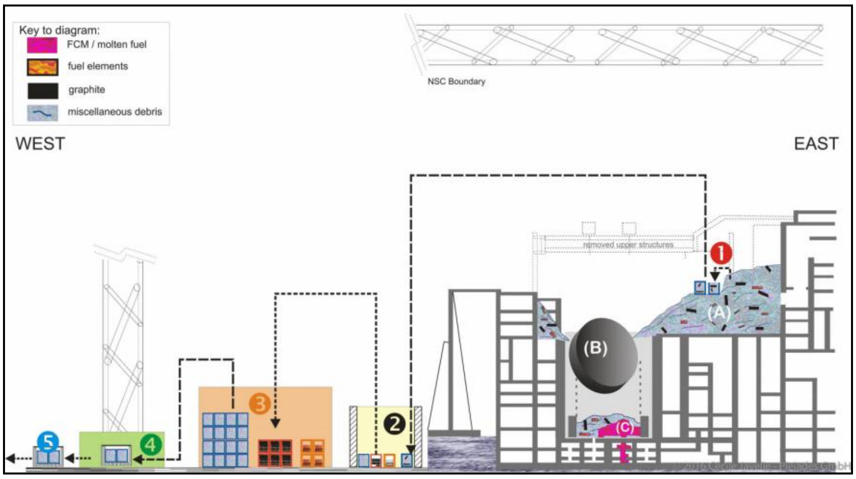


Diagram: Possible approach and elements for retrieval of inventory within NSC after upper part dismantling. Legend: 1 - recover the inventory and load it into a handling container; 2 - optional preliminary sorting of recovered inventory, which may be possibly combined with segregation by fragmentation or cutting processes; 3 - storage of preliminary waste containers within the NSC until it can be locked; 4 - locking out waste containers e.g. with the use of clean over-packs; 5 - transport to the next process step e.g. to treatment/processing and/or interim storage.

with remotely operated cranes that will allow the moving of materials, equipment or containers vertically and horizontally with only few restrictions into and out of the former Sarcophagus compartments which are also available for retrieval.

The inventory will consist of different types requiring different configuration for retrieval, e.g.:

bulk type inventory in the upper areas (A) (e.g. dropped materials during immediate accident fighting as well as FCM and moderator graphite from liquidation efforts when cleaning the Unit 3 roof);

large or massive inventory which can only be retrieved by using segmentation and/or fragmentation technologies (e.g. reactor bio-shield “Elena” (B), building walls and other building structures) when moving downward during removal;

lava type fuel containing materials (C) (e.g. in the lower part of former unit 4 premises).

Besides retrieval, the processing of FCM with conditioning and/or packaging in the final disposal ready form is one of the most important challenges for a long term sustainable safety. Although the final form/package for that waste stream will be dependent on geological and engineering barriers of the geological disposal site (Waste Acceptance Criteria), it is more than prudent to start technology development work for conditioning (including packaging) of such waste in parallel with removal and segregation of the inventory of the Shelter. The pilot tests for detailed characterization, chemical processes for extraction and separation of different elements and investigation of appropriate stable matrices and processes to develop industrial scale facilities, should be a logical way forward. Experiences collected in research and testing of real FCM samples over the last 30 years by the scientific organisations located and working in Chornobyl context, are a valuable asset for this task and should be used further. This would require configuration and implementation of an appropriate test and development facility, able to handle high radiation fields. Since the problem of conditioning fuel debris is not unique only to Chornobyl, an international cooperation effort should be considered for resolution of the challenges related to FCM and fuel debris processing and conditioning at Chornobyl and elsewhere.

Configuration of the inventory management and retrieval process steps will be a challenge and should follow Key Performance Indicators (KPI) to be set in line with desired safety objectives (in terms of nuclear safety, industrial safety, and/or radiation protection), such as:

safe access and exit corridors and locks (e.g. for remote equipment, occasional staff or materials);
dose uptake (in terms of ALARA-principles);
waste volumes generated (in terms of waste reduction);
path forward for FCM conditioning/packaging for long term storage or disposal;
releases and environmental impacts (in terms of impact reduction);
effectiveness (in terms of overall safety levels achieved);
efficiency (in terms of efforts – including costs – and times vested to achieve effectiveness).

Configuration and implementation of the inventory recovery measures, supported by the KPI, might lead to the conclusion that it only makes sense to recover parts of the inventory in the nearer term future (e.g. the easily accessible inventory in the upper part) and that the remaining part of the inventory may be better removed later after long in-situ control time.

Shall that be the case, the NSC would be instrumental for further improvement of the conditions of the residual inventory prior to removal (e.g. shrink size, optimize geometry, install long term monitoring and control means) and for eventual implementation of a further optimized confinement which would last longer, would be easier and cheaper to be maintained and operated than the NSC.

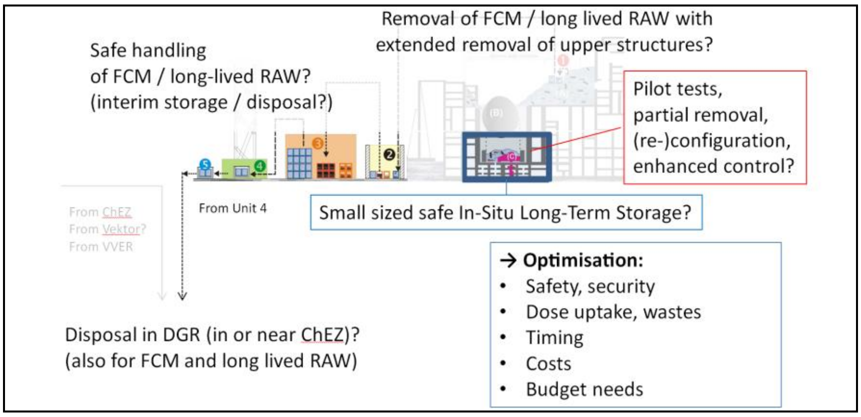


Diagram: Optimisation options for inventory management and removal.

The challenge is more than developing a technical solution: Besides the availability of a technical solution with appropriate technologies and disposal option, the availability of an appropriate funding will be a crucial boundary condition for optimised technically and financially feasible solutions within the overall decision process requiring a coordinated interaction with interested and involved stakeholders.

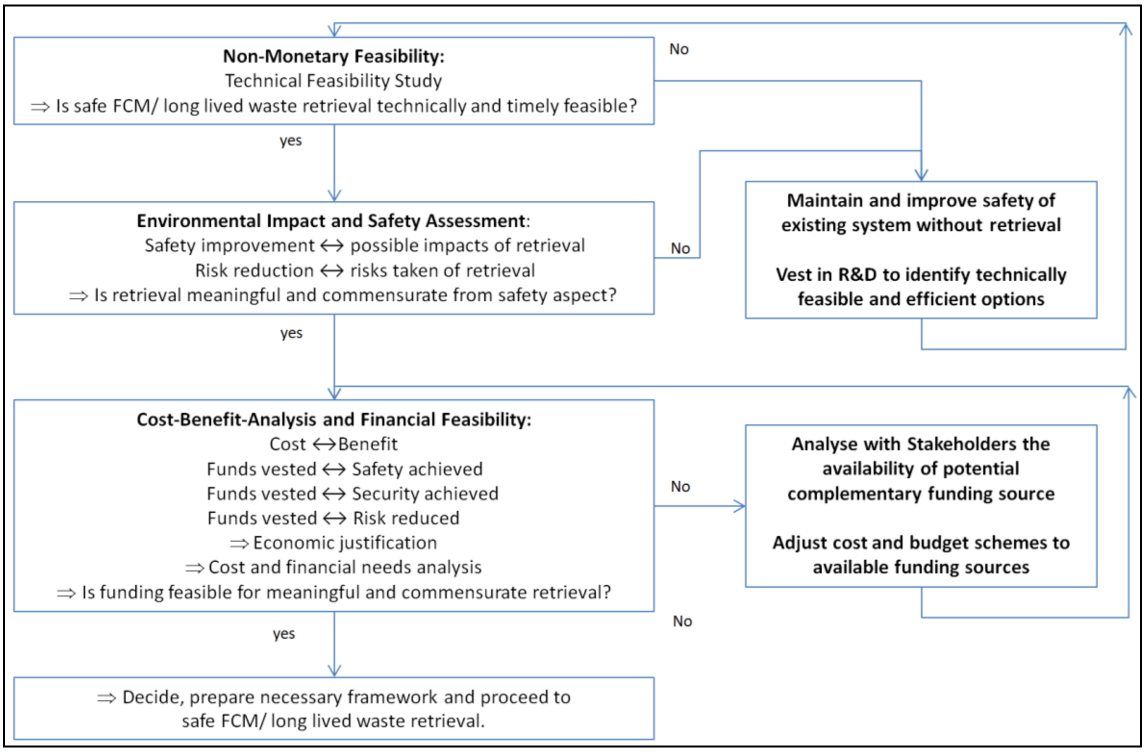


Diagram: Possible development and decision map for a technically and financially feasible solution.

6. Summary

In summary, the SIP including the NSC is a major milestone in the very challenging site remediation works that is still to be done at ChNPP Unit 4: it has to start with deconstruction of upper unstable parts, provision of safe access corridors for the daunting task of safely managing the inventory including FCM contained since 30 years in the ruins of the reactor hall until it can be safely retrieved, conditioned and disposed. In an optimised approach, there will be the option to proceed with retrieval for the accessible and retrievable parts of the inventory and to create a sufficiently safe, cost-effective smaller in-situ storage for the parts of inventory which are difficult to retrieve under the current boundary conditions. For the latter parts of inventory the retrieval may postponed until boundary conditions can and will be changed favourably.

Such approach will require a sequence of detailed studies, pilot tests and a project framework which needs to be developed step by step addressing the technical and financial aspects such to ensure an overall consistent, safe, technically and financially feasible process for the conversion of the unit 4 site into sustainably environmentally safe conditions.

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МЕЖДУНАРОДНЫЕ ПРОЕКТЫ ПО РАЗРАБОТКЕ И ПОДДЕРЖКЕ КРАТКО- И ДОЛГОСРОЧНЫХ МЕРОПРИЯТИЙ НА ПЛОЩАДКЕ ЧЕТВЕРТОГО БЛОКА ЧАЭС

На основании «Меморандума о взаимопонимании между правительствами стран «Большой семерки», Европейской комиссии и правительства Украины о закрытии Чернобыльской АЭС», подписанного в 1995 г., были предприняты совместные международные усилия для разработки «экономически эффективного и экологически обоснованного подхода для создания укрытия Чернобыльского блока № 4», а в 1996 г. было подготовлено исследование «Чернобыльский блок № 4: краткосрочные и долгосрочные мероприятия» с рекомендуемым планом действий. На основе рекомендаций исследования был подготовлен «План осуществления мероприятий (ПОМ - SIP)», его реализация началась в 1998 г. Вскоре ожидается его успешное завершение, после чего необходимо проанализировать и определить варианты следующих шагов.

Ключевые слова: ядерная авария, топливосодержащие материалы, мероприятия по восстановлению, процесс принятия решения, анализ альтернатив.

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МІЖНАРОДНІ ПРОЕКТИ З РОЗРОБКИ ТА ПІДТРИМКИ КОРОТКО- І ДОВГОСТРОКОВИХ ЗАХОДІВ НА МАЙДАНЧИКУ ЧЕТВЕРТОГО БЛОКА ЧАЕС

На підставі «Меморандуму про взаєморозуміння між урядами країн «Великої сімки», Європейської комісії та уряду України про закриття Чорнобильської АЕС», підписаного в 1995 р., були зроблені спільні міжнародні зусилля для розробки «економічно ефективного та екологічно обґрунтованого підходу для створення укриття Чорнобильського енергоблока № 4», а в 1996 р. було підготовлено дослідження «Чорнобильський блок № 4: короткострокові і довгострокові заходи» з рекомендованим планом дій. На основі рекомендацій дослідження був підготовлений «План здійснення заходів (ПЗЗ - SIP)», його реалізація почалася в 1998 р. Незабаром очікується його успішне завершення, після чого необхідно проаналізувати й визначити варіанти наступних кроків.

Ключові слова: ядерна аварія, паливовмісні матеріали, заходи по відновленню, процес прийняття рішення, аналіз альтернатив.

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