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Ukraine

THE IMPACT
of the Russian Drone Attack on the Chornobyl New Safe Confinement

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Initial Assessment of the Impact of the Russian Drone Attack on the Chornobyl New Safe Confinement

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1. Executive Summary

On 14 February 2025, a Russian Geran-2 drone with a high-explosive warhead struck the roof of the New Safe Confinement (NSC) at the Chornobyl Nuclear Power Plant. The NSC contains what remains of the destroyed reactor unit 4 that exploded on 26 April 1986 and the Shelter Object or Sarcophagus that was built immediately after the disaster began.

Although Russia denied having targeted the NSC, military analysts reported that this was almost certainly a deliberate act of its armed forces. In March 2025, Greenpeace Ukraine contracted engineer Eric Schmieman to conduct an ongoing assessment of the drone strike and its impact on the Chornobyl nuclear plant and specifically the functional status NSC. From 1998 Schmieman led one of the main contractors in the conceptual design of the NSC and was Senior Technical Advisor during its construction.

This initial assessment for Greenpeace Ukraine will be submitted to the Office of the Prosecutor General of Ukraine.

From Shelter Object to New Safe Confinement

In the immediate months after the start of the Chornobyl accident in 1986, the Soviet authorities constructed the Shelter Object, also known as the Sarcophagus, over the destroyed reactor 4. It was designed to reduce the release of radionuclides into the atmosphere, prevent the infiltration of water, and reduce radiation levels at the site. Under severe radiological conditions, 90,000 workers or 'liquidators', built the concrete and steel structure between May and November 1986. Due to the extreme radiological conditions, it was impossible to construct the Shelter Object to the highest engineering standard. Consequently, it was never intended to be a permanent structure, but with a design life estimate of 20 years after which it would be at high risk of collapse. In 1995 the European Bank for Reconstruction and Development (EBRD) set up the Chornobyl Shelter Fund to support Ukraine at Chornobyl. A long-term strategy, the Shelter Implementation Plan (SIP), was initiated in 1997 to stabilize the damaged reactor and develop a permanent containment solution. The total SIP budget reached €2.1 billion funded by forty-five nations.

Among many SIP projects, it was decided to cover the Shelter Object with a new building: the New Safe Confinement (NSC). Designed and constructed between 1998 and 2016, due to high radiation levels emitted from the reactor 4, the NSC was assembled 500 metres away and moved on a unique rail system over the site in 2016. The NSC was designed to provide a 100-year safe and secure environment for the dismantlement of the Shelter Object and the control of highly radioactive materials inside the building – nuclear fuel, lava-like melted fuel, radioactive dust, and all structural debris. The design and functioning of the NSC was intended to prevent the release of radioactive materials during the many decades required to conduct this work. The NSC was formally commissioned in 2019 under the authority of Ukraine's State Specialized Enterprise Chornobyl NPP (SSE ChNPP).

The immediate consequences of the Russian drone attack

Six years after becoming operational, the Russian drone strike of February 2025 destroyed the main functions of the New Safe Confinement. The impact of the drone on the north-west side of the NSC caused an opening of approximately 15m2 which penetrated both the outside and inside arch shells. Critical structural elements of the NSC have been deformed and damaged including the Main Crane System, making their load-bearing capability impossible to assess. Shrapnel from the explosion caused numerous smaller penetrations of the arch shells distributed over an area of about 200m^2. Fires caused by the initial explosion were extinguished with water relatively quickly, but fires continued to break out over several days. Burning of critical layers inside the roof space continued inside the outer arch shell for three weeks.

Emergency repairs initiated during 2025 included a temporary patch placed on the exterior surface of the NSC, however the confinement function could not be fully restored; this increases the risk of radioactivity release in the environment especially in the case of a collapse of the Shelter Object. The dismantlement of the vulnerable Shelter Object is not possible without repairs to the NSC. A collapse of the Shelter Object would have significant consequences, including for radiation issues inside the NSC, additional financial costs and in terms of the total collective radiation dose to workers.

A major consequence of the drone strike and the burning of the membrane layer inside the roof space is the loss of humidity control, which in turn increases the risk of corrosion of steel components. The NSC was designed to last 100 years on the basis that its low humidity control was maintained. Accelerated corrosion may reduce the 100-year design life of the structure if humidity control is not restored by 2030.

The road ahead: thinking outside the box

In response to the Russian drone attack, the EBRD has initiated a new funding program with international donors to secure financing of 500 million euros for the restoration of the functionality of the NSC. The current plans include targeted investigations and the development of initial repair concepts, followed by engineering solutions and development of an overall repair strategy, in consultation with Ukraine's nuclear regulator. A timetable of 2030 for completion of comprehensive repair work has been set.

Perhaps the largest obstacle to initiating physical repairs to the NSC is the continuation of the war. The Chornobyl nuclear plant is on the frontline of a war-zone and as long as the war continues international construction activities at the site are unlikely. Off-site activities such as design and procurement of long lead-time material can be started before the war ends.

The author of this analysis offers two suggestions for consideration during these early phases of the project:

1. **Reexamine underlying strategies that drove original NSC design and will also drive NSC repair schedule and cost.** For example, the NSC enables removal of contaminated debris from the top of the Shelter Object down toward the bottom. An alternative strategy might be to remove the most hazardous material first, proceeding toward the least hazardous.

2. **Explore out-of-the-box construction methods and materials while we have the freedom to do so.** For example, rather than removing the NSC outside surface to replace the insulation and membrane, consider adding insulation and sealant from the annular space to the inside surface of the outside arch shell. Specifically consider spray-applied fire block materials. Application might be accomplished by drones or other robotic means working inside the annular space, reducing total collective dose as well as time and material costs.

2. Purpose of this Analysis

Since March 2025 I have been instructed by Shaun Burnie and Jan Vande Putte of Greenpeace Ukraine to assaess the impact and consequences of the 14 February 2025 Russian drone strike on the New Safe Confinement (NSC) at the Chornobyl nuclear plant in Ukraine. The purpose of this analysis is threefold:

- collecting and organizing relevant information,
- assisting in a possible criminal investigation, and
- assessing the impact of the drone attack.

Chornobyl unit 4, April 1986 - Credit ChNPP

3. Introduction

3.1. A brief description of the Chornobyl Accident

The Chornobyl Atomic Energy Station consisted of four nuclear power plants[1] situated in a low population area adjacent to the Pripyat River, about 94 km by air[2] north-northeast of Kyiv, Ukraine. The plants were the Soviet RBMK 1 000 Mwe design, graphite moderated, fueled with low enriched uranium[3,4]. The four units were chronologically (1977-1983) constructed in a line, first Unit-1 to the east and lastly Unit-4 to the west[1]. Unlike the reactors at Three Mile Island or Fukushima, the Chornobyl reactors were not enclosed within a containment building[5].

On 26 April, 1986 at approximately 01:26AM Chornobyl Unit-4 underwent a beyond design basis accident. The initial explosion blew off the 1,000 tonne reactor head[6], Schema Elena, and ejected radioactive debris from the reactor core into the environment. Radioactive gases and materials reached 15km into the stratosphere settling to the ground and first measured in Sweden and later at many locations in Europe and beyond[7]. The largest amount of fallout fell on Ukraine, Belarus and Russia[8].

Within three months twenty-eight people died of acute radiation sickness caused by the accident[9]. Soviet military authorities began evacuating people from the area around Chornobyl 36 hours after the accident began. By May 1986, all those living within a 30km radius of the plant (about 116,000 people) had been relocated[10].

3.2. Enclosing the Destroyed Reactor

The Soviet Union constructed a large structure to temporarily enclose the destroyed reactor, called the "Sarcophagus" in the West and "Shelter Object (SO) ["объект укрытия / об'єкт укриття Russian/ Ukrainian (OY)] in the Soviet Union.

The purposes of the temporary[11] structure was to reduce the uncontrolled release of radionuclides to the atmosphere, to reduce infiltration of water, and to reduce radiation levels near the site. The Shelter Object was designed and constructed on the extremely hazardous site in 206 days, and commissioned on 30 November, 1986[12].

Emergency workers ("liquidators") were drafted into the area from across the Soviet Union to clean up the plant premises and the surrounding area. The exact number of liquidators is unknown because complete records were not taken during the emergency situation. The Russian registries listed approximately 400,000 liquidators as of 1991, and more than 600,000 people were subsequently awarded the status of "liquidator".

1. https://www.history.com/articles/Chornobyl
2. https://www.distance.to/Chornobyl/Kyiv,Kiev,UKR
3. https://www.nei.org/resources/fact-sheets/Chornobyl-accident-and-its-consequences
4. US Nuclear Regulatory Commission, *et al.*, NUREG-1250 *Report on the Accident at the Chornobyl Nuclear Power Station*, Chapter 2, January, 1987, PDF
5. Ibid.
6. Ibid.
7. https://www.davistownmuseum.org/cbm/Rad8.html Section-10, Chornobyl Plume Data
8. World Health Organization, 2006, Health Effects of the Chornobyl Accident and Special Health Care Programs, page iii, PDF
9. Belyi, David, Kovalenko, Alexander, Bazyka, Dimitry, Acute Radiation Syndrome Survivors after Chernobyl Accident: History of Irradiation, Diagnostic Mistakes and Death Reasons in Long-term Period, Radiation Emergency Medicine, 10 October 2013, see https://www.researchgate.net/publication/257303274_Acute_Radiation_Syndrome_Survivors_after_Chernobyl_Accident_History_of_Irradiation_Diagnostic_Mistakes_and_Death_Reasons_in_Long-term_Period
10. IAEA Publication 1239, Environmental Consequences of the Chornobyl Accident and Their Remediation: Twenty Years of Experience. (disclosure: Schmieman is a co-author)
11. State Nuclear Regulatory Inspectorate of Ukraine, New Safe Confinement Above Design Event Caused by RF Military UAV With High-Explosive Projectile Strike, presentation to EBRD et al., 18 February, 2025, slides 5, 13
12. https://chnpp.gov.ua/en/infocenter/news/5696-20-interesting-facts-about-the-shelter-object

Demag cranes during construction of shelter in 1986 – Credit ChNPP

Liquidators worked on decontamination and major construction projects, including: the establishment of settlements and towns for plant workers and evacuees; built waste repositories, dams, water filtration systems and the Object Shelter[13]. About 90,000 workers were involved in the construction of the Shelter Object[14,15].

During construction of the Shelter Object, about 345,000 cubic metres of concrete were placed, and 7,000 tonnes of steel structures were assembled[16]. The Shelter Object dimensions were roughly 200 metres long, about 160 metres in width and more than 60 metres high[17]. Simultaneous with construction of the Shelter Object, highly radioactive fuel elements were being removed from the Unit-4 roof and tossed into the open reactor Central Hall and contaminated soil from the surrounding area was used as fill.

Foundations were not placed for the new building, instead the metal structures were placed upon piles of rubble, partially destroyed walls and ventilation shafts. Because of the high radiation areas, it was not feasible to inspect and characterize the load bearing capacity of these locations. To mitigate the continuing effects of the accident, speed was prioritised over durability or conformance to building codes. This decision increased the risk of collapse of parts of the Shelter Object structures.

The risk of collapse increases with time, primarily due to high humidity inside the building accelerating the rate of corrosion of both metal and

13. International Atomic Energy Administration, Chornobyl Frequently Asked Questions, FAQ-7, https://www.iaea.org/newscenter/focus/Chornobyl/faqs

14. Chornobyl Nuclear Power Plant, “History of the Accident of 1986”, https://chnpp.gov.ua/en/about/history-of-the-chnpp/accident-of-1986

15. Chornobyl Nuclear Power Plant, “20 Interesting Facts about the Shelter Object”, https://chnpp.gov.ua/en/infocenter/news/5696-20-interesting-facts-about-the-shelter-object

16. Chornobyl Nuclear Power Plant, “History of the Accident of 1986”, https://chnpp.gov.ua/en/about/history-of-the-chnpp/accident-of-1986

17. Chornobyl Nuclear Power Plant Sarcophagus, https://grokipedia.com/page/Chornobyl_Nuclear_Power_Plant_sarcophagus

concrete components. Two high level collapse risks were chosen to be addressed first: stabilization of the damaged ventilation exhaust stack for Units 3 and 4 in 1998 and the stabilization of Beam B1 and B2 supports in 1999.

Braces for the ventilation stack had been damaged by the accident, and the 75m tall 300-tonne vent stack was in danger of collapsing on the roof of the Unit-4 reactor Central Hall which could cause an uncontrolled release of contaminated dust and fuel-containing material. A tri-lateral funding agreement between the USA, Canada, and Ukraine enabled the project to be quickly addressed.

Beams B1 and B2 carry the Shelter Object's heavy roof above the reactor Central Hall. The beams weigh approximately 1,000 metric tonnes each and are supported on one end by the western wall of Unit-4. The supports for the beams had shifted during the decade since the beam supports are located high in the Shelter Object, where temperature and radiation dose rates are high. Concreting and welding were practiced in a mockup built in the local zone.

Engineers and workers gained valuable experience by performing these two immediate stabilization measures before working on more complex issues. An additional eight stabilization measures were carried out under the Shelter Implementation Plan during 2004-2008. The largest of these was Stabilization Measure-2, "Reinforcement of the Shelter Object Western Fragment".

Inspection revealed that cracks near the top of the western wall had increased in width with time. The B1 and B2 beams, which carry the heavy roof above the reactor Central Hall, transfer their load to the western wall. Measure-2 is necessary to reduce the load on the western wall. Measure-2 consists of two 50m-tall steel towers immediately west of the Shelter Object that rest on a new reinforced concrete foundation. Two 23m steel long cantilevers extend east from the tower. The cantilevers reach above the buttress wall and under the heavy steel roof. Hydraulic jacks were placed at the east end of each cantilever. Hydraulic pressure was increased until 80% of the load of the heavy roof was transferred from the western wall on axis-50 to the steel towers.

The two towers of Stabilization Measure-2 are the first things you see when you enter the New Safe Confinement.

3.3. Hazardous Inventory of the Shelter Object

The mass of fuel that was loaded in the reactor core at the time of the accident is widely agreed to

Shelter Object/Sarcophagus at Chornobyl unit 4, 1996 Credit Clive Shirley/Greenpeace

be 190.2 tonnes.18 Estimates of the fuel remaining inside the Shelter Object range up to about 95% of the original fuel, or 180 tons.19 The important thing to understand is this a very large amount of extremely hazardous material.

Nuclear materials accountancy has been brought under international safeguards at Chornobyl Nuclear Power Plant (ChNPP) since 1986. Because the location and mass of all the material cannot be adequately verified, the safeguards approach has been based upon containment and surveillance.[20] Nuclear material accountancy is the primary means of preventing diversion of fissile elements to produce nuclear weapons.

Inside the Shelter Object the hazard of fissile material such as U^{235} is an inadvertent nuclear chain reaction. To initiate and sustain a chain reaction you must have a critical mass of fissile material and a moderator (water or graphite) in a very special geometric organization. All these materials exist in large quantities inside the Shelter Object but are not, to the best of our knowledge, in close enough proximity to one another to initiate a chain reaction. The amounts and location of these materials have been extensively studied since the 1986 accident, and must continue to be studied as the locations of material change over time.

In a nuclear reactor, uranium fissions into predictable amounts of hazardous radioactive fission products. Radioactive fission products decay into non-radioactive chemical species with time. The amounts of radioactive fission products inside the Shelter Object today could be calculated, but the calculation is a function of time and starting amount of fission products, so the results of the calculation would vary as widely as the estimates of uranium discussed in the preceding paragraph. Again, the important fact is that the result will be a very large amount of very hazardous material.

The nuclear and radioactive material inside the Shelter Object exist in various physical forms and the physical forms change over time. Different physical forms present different hazards. For example, fission products contained inside of a fuel pellet present a radiation hazard – strong gamma rays that give a lethal dose in a short length of time if you are close to the pellet.

Lava-like melted fuel and structural debris exist inside the Shelter Object and present a radiation hazard like the fuel pellet. However, the exposed surface of the lava-like material oxidizes with time and forms very fine particulate matter that becomes airborne dust or aerosol. Many tonnes of this dust remain on surfaces and suspended in the air inside the Shelter Object. The radioactive dust presents an extreme inhalation hazard. The roof space of the Shelter Object where a Modernized Dust Suppression System (MSPP) operates, contains from 4 to 5 tonnes of uranium fuel dust[21].

Workers inside the Shelter Object wear respirators to avoid this hazard.

The radiation conditions inside some parts of the Shelter Object have been measured, modelled, and well documented. As the Shelter Object is deconstructed, the radiation conditions in it and surrounding it will change dramatically. The changes can be modelled before specific deconstruction steps are performed. Areas that workers occupied for hours without harm one day may be too radioactive to occupy for even short periods of time after deconstruction activities another day.

This is not an exhaustive or nearly complete inventory of hazards inside the Shelter Object. The hazards are many and will change with time.

3.4. New Safe Confinement

3.4.1.Genesis

Following Ukraine's independence and the breakup of the Soviet Union, it was recognized that the Ukraine needed international support for nuclear safety and environmental restoration at Chornobyl. The Chornobyl Shelter Fund (CSF) was established by the European Bank for Reconstruction and Development (EBRD) in 1997 to finance the Shelter Implementation Plan (SIP). Forty-five nations donated more than €1.6 billion to the CSF.[22]

18. Krasnov, V.O., Nosovsky, A. V., Paskevich, S.A., Rudko, V.M., Object Shelter in the conditions of a New Safe Confinement, 2021, Institute of Nuclear Power Plant Safety Problems, National Academy of Sciences of Ukraine, Chapter 2, page 55

19. Ibid.

20. IAEA-TECDOC-2085, *Experiences and Lessons Learned in Managing Severely Damaged Spent Fuel and Corium*, April, 2025, Section 2.2, page 17.

21. Krasnov, V.O., Nosovsky, A. V., Paskevich, S.A., Rudko, V.M., Object Shelter in the conditions of a New Safe Confinement, 2021, Institute of Nuclear Power Plant Safety Problems, National Academy of Sciences of Ukraine

22. https://www.ebrd.com/home/what-we-do/focus-areas/nuclear-safety/Chornobyl-shelter-fund.html


Chornobyl Stabilization Measure-2, Reinforcement of the Shelter Object Western Fragment, 22 September 2024 - Credit Shaun Burnie/Greenpeace

The primary object of the SIP was to transform the Shelter Object into a stable and environmentally secure state by the execution of 22 projects. The largest single project in SIP was the New Safe Confinement (NSC).[23]

Because of the harsh conditions during construction of the temporary Shelter Object, it contained more than 1,000m^2 of openings which allowed precipitation to percolate through the radioactive debris inside, and then to contaminate groundwater. The building was collapsing with age. The collapse of the Shelter Object would disperse another cloud of radioactive particles.

23. Ibid.

The main objective of the New Safe Confinement (NSC) in accordance with the Law of Ukraine On General Provisions for Further ChNPP Operation and Decommissioning and Conversion of ChNPP Unit 4 Into Environmentally Safe System includes:

- **Ensure protection of workers, public, and environment from the impact of nuclear and radiation hazards inherent in the existing Shelter Object (Shelter);**
- **Ensure the required conditions to support practical activities for conversion of the Shelter into an environmentally safe system, including, removal of the remainder of the nuclear fuel and FCM (fuel-containing material), RAW (radioactive waste) management activities, and deconstruction/stabilization of the unstable Shelter structures."[24]**

24. *NSC Design Criteria and Requirements*, SIP-P-TM-21-330-DC-101-01, 03 October 2003, page 6 (**disclosure**: Schmieman is a co-author)

3.4.2. New Safe Confinement Design Features

This section provides a brief, high level overview of the New Safe Confinement (NSC) design, followed by more detailed descriptions of NSC systems and capabilities affected by the drone attack. Detailed descriptions of unaffected systems are not provided.

3.4.2.1. Overview

The NSC is an arch, the shape was chosen to reduce the amount of construction material required to enclose the space. Its internal dimensions are approximately 250 metres north-south, 150 metres east-west, and 95 metres high[25].

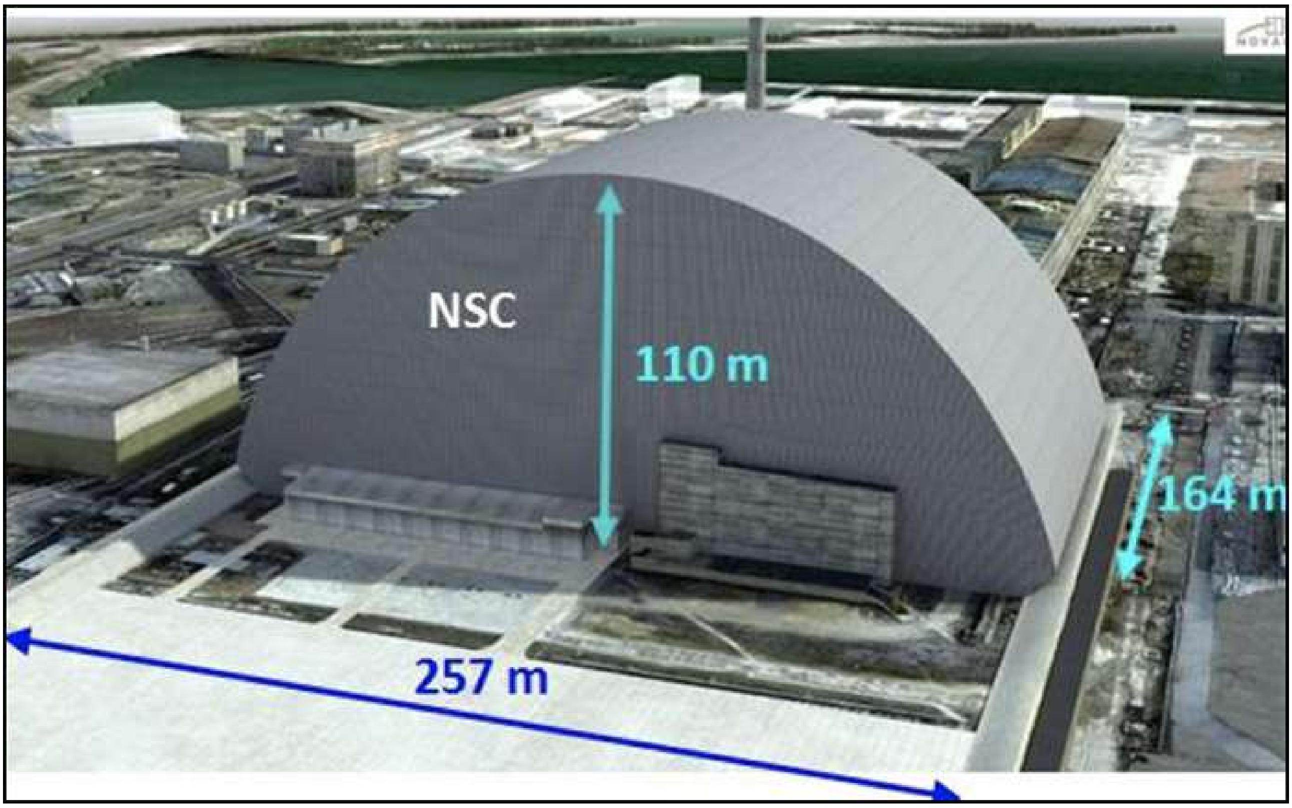
The east and west ends of the arch are closed by vertical walls. The main structural members are painted carbon steel tubes joined in bolted connections. The design life of the structure is 100 years[26].

The NSC was constructed in an erection area approximately one-half kilometre west of the Unit-4 reactor to reduce radiation exposure to construction workers. The assembled arch was slid east on concrete foundations to its final operational position. The foundations in the erection area and sliding area are different from the foundations in the operational area. The foundations in the erection area and sliding area were not removed after construction was completed to support possibly moving the structure west at some point in the future.

The arch has an internal and an external shell. Carbon steel structural members are enclosed within the annular space between the two surfaces. A ventilation system dehumidifies air recirculated in the annular space to less than 40% relative humidity. This value of humidity was chosen to prevent corrosion of structural members enclosed within the annular space.

Suspended from the arch structure at an elevation of about 85 metres is a Main Crane System. Functions of the Main Crane System are to first transport components of the Shelter Object to the NSC laydown area, then to transport components and debris of the Unit-4 reactor building to the laydown area. These components will then be reduced in size and prepared for safe disposal.

25. Ibid., page 7
26. Ibid., page 39



New Safe Confinement Outside Dimensions from SNRIU presentation to EBRD 18 February 2025, Credit State Nuclear Regulatory Inspectorate of Ukraine

Primary components of the Main Crane system are two sets of bridges running east-west, four carriages (two 50- tonne lifting capacity "classic carriages", one 40- tonne secure carriage for human transport, and one carriage carrying a tensile truss that supports a remotely operated tool and vacuum kit), and two garages (a shielded maintenance garage in the north-west quadrant of the arch and a smaller carriage storage garage in the south-east quadrant.

3.4.2.2. Arch Structural Members

The carbon steel structural members of the arch are 1-metre diameter tubes. Each tube terminates in welded flat plates. Plates are joined in bolted connections.

The surface of all the carbon steel members were painted before erection to prevent corrosion.

3.4.2.3. Outside Arch Shell

The outside arch shell separates the annular space from the external environment. It is designed to withstand external natural events and external man-made events.

External natural events considered during design of the outside arch shell included[27]:

- Seismic impact (design basis earthquake magnitude-5 and maximal basis earthquake magnitude-6, MSK-64 scale),
- Heavy wind load, sum of average and pulse,
- Snow load (10 000-year recurrence period),
- Tornado class EF-3,
- Ambient air temperature (-22°C, +26°C)
- Lightning, and
- Precipitation (10 000-year recurrence).

External man-made events considered during design of the outside arch shell included[28]:

- Explosion (analysis demonstrated that impacts are exceeded by tornado),
- Aircraft fall (not addressed in design because of probability and Ukrainian normative documents),
- Fire (minimum distances to potential fire sources specified), and
- Events related to existing ChNPP units (Unit 3&4 vent stack removed, existing structures forming part of NSC east and west end walls were reinforced).

27. Ibid., pages 10-15
28. Ibid., pages 15-17

NSC structural members and inner/outer shells during construction - Credit EBRD

NSC tubes, plates and bolts during construction - Credit EBRD

Outside arch shell components are attached to purlins which rest on the main arch structure. The outside arch shell consists of major components illustrated in the figure below:

1) galvanized steel metal decking

2) 1st insulation layer (hard mineral wool slabs)

3) top hat profiles (galvanized steel)

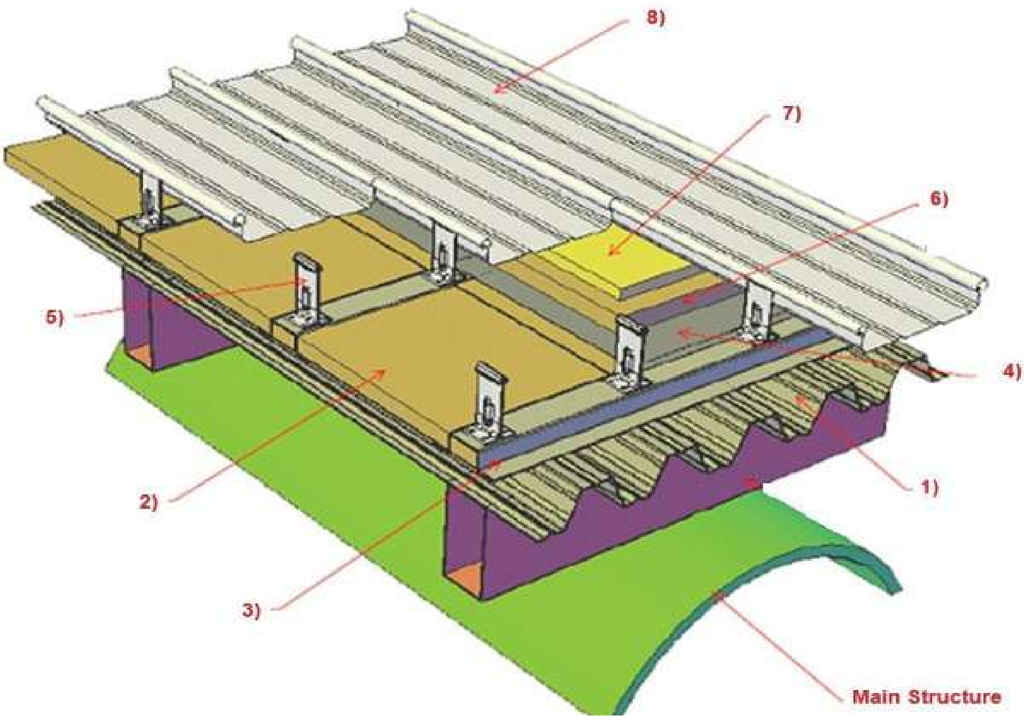
4) EPDM sheeting (Ethylene Propylene Diene Monomer)

5) stainless steel clip (galvanized steel)

6) 2nd insulation layer (hard mineral wool slabs)

7) 3rd insulation layer (soft mineral wool)

8) standing seam panel (stainless steel)



Outside shell components from SNRIU presentation to EBRD 18 Feb 2025

The outer shell is insulated to permit temperature and humidity control of the annular space as described in the section below. The EPDM sheeting minimizes air leakage from the annular space to the external environment.

A maintenance walkway is provided at east-west length of the external highest surface of the NSC. Stanchions are provided at period intervals along the walkway to secure climbing gear for workers to descend/ascend along the outer surface of the NSC.

3.4.2.4. Inside Arch Shell

The inside arch shell separates the annular space from the internal environment. It is designed to withstand external natural events and internal man-made events.

The external natural event applicable to the inside arch shell is seismic impact (design basis earthquake magnitude-5 and maximal basis earthquake magnitude-6, MSK-64 scale)[29].

Internal man-made events considered during design of the internal arch shell included:

- Fire (internal fire loads specified[30] and fire alarm[31] and firefighting[32] systems designed to mitigate potential events),
- Explosion[33] (not addressed in design because of low probability and low consequences),
- Structural collapse inside the NSC,
- Load drop inside the NSC, and
- Flooding from pressurized water systems and drainage systems inside the NSC.

The innermost layer of the internal shell is stainless steel sheet metal to facilitate surface decontamination which is expected to occur during deconstruction of the Shelter Object.

Unlike the outside arch shell, the inside arch shell is NOT insulated for reasons explained in the following section on Annular Space Ventilation.

Motorized platforms are attached to the inner shell to carry maintenance workers and their tools from ground level to the inside top of the NSC.

3.4.2.5. Annular Space Ventilation

As the EBRD states, "The main functions of the heating, ventilation, and air conditioning systems (HVAC) are to confine contamination by assuring that airflow is always from areas of lower potential for contamination towards areas of higher potential for contamination…[34]". Thus, air pressure in the annular space must be higher than air pressure inside the NSC main volume so that any air leakage would be from the annular space to the NSC main volume.

Another function of the annular space ventilation system is to prevent corrosion of NSC structural elements. Corrosion of steel structures exposed to the elements is usually prevented by painting the surfaces. The surfaces must be periodically repainted to maintain effective corrosion prevention. Large steel structures such as the Paris Eiffel Tour and the San Francisco Golden Gate Bridge are continually repainted. However, high radiation levels prohibit such maintenance inside the annular space.

Since carbon steel does not oxidize in environments below 40% relative humidity, the annular ventilation system dehumidifies the air it recirculates in that space. Fans draw air from the annular space and external environment, then force the air through a rotating desiccant wheel that absorbs moisture from the air. Dry air leaves the desiccant wheel and flows into the annular space. The desiccant wheel then rotates through a heated space that drives the absorbed water out of the desiccant and the wheel continues rotating back to its starting position.

The air in the annular space is lightly heated for two reasons: (1) it helps lower relative humidity in the annular space and (2) keeping the annular space air temperature a few degrees above NSC main volume air dew point temperature prevents condensation from occurring on the surface of the Inside Arch Shell facing the main volume of the NSC. If condensation were to occur on the surface of the Inside Arch Shell facing the main volume of the NSC, the water would uncontrollably spread radioactive contaminants around the NSC main volume. The uncontrolled spread of radioactive contaminants would increase the risk of radioactive contamination of NSC workers and increase decontamination work.

29. Ibid., pages 10-11
30. Ibid., pages 17-18
31. Ibid., pages 99-100
32. Ibid., page 112
33. Ibid., pages 18-19
34. Ibid., page 103

3.4.2.6. Main Crane System Maintenance Garage

A Main Crane System Maintenance Garage is located inside the NSC at the northwest. The service area is located at the same level as the Main Crane System quadrilaterals, at approximately 85 metres elevation above the NSC laydown area, to transfer carriages from the quadrilaterals into the garage[35].

The garage is equipped with:

- Shielding to reduce the radiation dosage rate to maintenance workers.
- A hoist in the upper level of the garage to facilitate handling of main carriage components in the event of a disassembly (lifting gearbox, motor, etc.), including lowering the components to NSC floor level.
- A rack for the storage of maintenance tools.
- Decontamination equipment.
- Provision for personnel access to all sides of the carriage for maintenance activities.

The garage is supported by NSC structural members and accessed by stairways and walkways.

35. TS-301, Technical Specifications – Main Crane System, Revision 06.07.2007. pages 22-23

Emergency workers on NSC Shell penetration on day of Russian drone strike - 14 February 2025 Credit Shaun Burnie Greenpeace

NSC north side drone strike - Credit ChNPP


Recovered drone pieces - Credit ChNPP

4. Drone Attack on NSC

On Friday, 14 February 2025, at 01:59AM36 a HESA Shahed-136/Garen-2 type drone with a high-explosive warhead37 struck the northwest side of the New Safe Confinement (Fig. 6). Pieces of the drone were recovered (Fig. 7). The pieces had markings "ы15480 and ГЕРАНЬ-2"38. The color of the pieces and the markings indicate the drone was most likely manufactured in Russia under license from Iran[39].

Analysis from former UK military analysts reported that the UAV drone impact was almost certainly a deliberate targeting of the Chornobyl plant by Russian armed forces.[40] Ukraine's military reported that Russia launched 133 drones across the country in its overnight attack, 73 of which were shot down and 58 of which did not reach their target[41]. Russia denies that it targeted the Chornobyl Nuclear Plant[42].

The impact of the drone and subsequent explosion at an elevation of approximately 85 metres above the NSC floor caused an opening of approximately 15 m^2 through both the outside and inside arch shells.

The explosion also caused damage to bolted connections of the arch structural elements and deformed structural joints on the upper part of the Main Crane System Maintenance Garage[43]. Shrapnel from the explosion caused numerous smaller penetrations of the arch shells distributed over an area of about 200 m^2.

A fire ignited at the site of the drone impact. It appears that the only combustible material used in the construction of the inside and outside arch shells may have been sheeting made of Ethylene Propylene Diene Monomer (EPDM) in the outside arch shell. There are many EPDM formulations for sheeting available, each with different flammability specifications[44]. The formulation of EPDM sheeting used in the NSC is not known by the author.

Firefighters responded to the fire within minutes of the initial explosion[45]. Flames at the site of the explosion were extinguished with water relatively quickly, but fires continued to break out and smoldering continued inside the outer arch shell problematically. Thermal imaging[46] by sensors on UAVs revealed hot spots which were extinguished with water after cutting access holes into the outside arch shell.

Extinguishing smoldering areas with water continued for three weeks following the attack. During this period 332 openings were made in the outer shell and end walls of the NSC to extinguish

36. Barker, Kim, New York Times, 15 February 2025, page A-7

37. Ibid.

38. Novikov, Illia and Lukatsky, Efrem, A drone pierced the outer shell of Ukraine's Chornobyl nuclear plant: Radiation levels are normal, Associated Press World News, https://apnews.com/article/russia-ukraine-war-Chornobyl-zelenskyy-71d781dbd-66754d0a548edd388f3447a

39. Wikipedia (English language), HESA Shahed 136, accessed 15 April 2025

40. McKenzie Intelligence Services , Analysis of Unmanned Aerial Vehicle (UAV) strike against the Chornobyl Nuclear Power Plant Sarcophagus Commissioned by Greenpeace Ukraine 14 February 2025 McKenzie Intelligence Services, www.greenpeace.org/static/planet4-ukraine-stateless/2025/02/3d163c50-20250214_mis_chornobyl-analysis-of-drone-strike_v1_2-2.pdf

41. Tarasova-Markina, Daria, et. al., CNN World, https://www.cnn.com/2025/02/14/europe/russia-ukraine-drones-Chornobyl-intl-hnk/index.html

42. Saric, Ivana, Russia denies its drone targeted Chornobyl nuclear power plant in Ukraine, Axios, https://www.axios.com/2025/02/14/Chornobyl-drone-strike-russia-nuclear-plant-ukraine.

43. ChNPP Infocenter, Information on the status of the damage elimination on the external and internal cladding of the New Safe Confinement (NSC) Arch as a result of a direct hit by a russian UAV into the protective shell of the NSC as of 16:00 on 05/03/2025, https://chnpp.gov.ua/en/infocenter/news/6354

44. Wikipedia (English language), EPDM rubber, accessed 17 April 2025

45. International Nuclear Energy Agency, Update 275, https://www.iaea.org/newscenter/pressreleases/update-275-iaea-director-general-statement-on-situation-in-ukraine

46. ChNPP Infocenter, Information on the status of the damage elimination on the external and internal cladding of the New Safe Confinement (NSC) Arch as a result of a direct hit by a russian UAV into the protective shell of the NSC as of 13:00 on 21/02/2025, https://chnpp.gov.ua/en/infocenter/news/6337

Firefighters and water hose on NSC roof walkway – Credit ChNPP

Inside NSC damage to structure and main crane maintenance garage - Credit ChNPP

Cladding material removed from Chornobyl New Safe Confinement – 28 February 2025 Credit Siromenko Pavlo Greenpeace

the smoldering EPDM membrane[47]. It has been estimated that 50% of the EPDM membrane on the north side of the NSC and 10% on the south side burned. The total amount of water injected and degree of damage to insulation is unknown at this time[48]. Some of the water injected into the outer shell quickly drained out and some continued to drip from the mineral wool as of late June 2025. After a 10-day period with no new fires, the site event was downgraded on 07 March 2025 from an "emergency" to a "controlled situation"[49, 50].

Further damages may be identified by future inspections.

47. Hnatchuk, Ruslan, Deputy Head of NSC Operations Shop, video interview by Jan Vande Putte, Greenpeace Ukraine, taken at Chornobyl Nuclear Power Plant on 21 June 2025

48. Ibid.

49. American Nuclear Society NuclearNewswire, 13 March 2025, https://www.ans.org/news/2025-03-13/article-6852/fires-extinguished-at-Chornobyl-following-drone-strike/

50. Ministry of Environmental Protection and Natural Resources of Ukraine, press release, 07 March 2025 https://www.facebook.com/EnvironmentalofUkraine/posts/pfbid032wa5P4bZvs9uJZqS7hiZxGpaYTd7PbKidWJPpFPuPLLBySZ9QhtYpcyKbe5dGqJUl?locale=uk_UA

Firefighting inside New Safe Confinement after Russian drone strike, 18 February 2025 – Credit ChNPP

5. Immediate Impacts of the Attack and Temporary Actions

The three most consequential immediate impacts of the explosion, fire, and firefighting are:

- loss of the NSC confinement function,
- loss of humidity control in the NSC annular space, and
- unknown load-bearing capability of the NSC structure and the Main Crane System.

5.1. Loss of NSC Confinement Function

The NSC was designed to confine uncontrolled radiological releases of contaminated dust and aerosols that might be produced by Object Shelter deconstruction activities or by the collapse of the Object Shelter.

Before the drone attack, uncontrolled radiological releases were prevented because air flowed into the NSC from the annular space through minor leaks in the Inside Arch Shell and from the outside atmosphere through minor leaks between the NSC and interfacing structures, while an exhaust fan forced air through filters and out of the NSC.

Air flow through the NSC has changed dramatically because of the drone attack.

After the attack, until a temporary patch was placed on the hole in the NSC exterior surface, almost all air flowing into the NSC was exhausted, unfiltered, through the 15m^2 hole created by the drone explosion[51]. Thus, the confinement function of the NSC had been completely lost. The containment function has not been fully restored even following Temporary Actions, discussed below. As explained below the loss of the NSC confinement function will limit deconstruction activities on the Shelter Object.

5.2. Loss of Humidity Control in the NSC Annular Space

Loss of annular space humidity control and water used for fire extinguishment may lead to corrosion of structural components. The corrosion of uncoated structural components and joints may occur when annular space relative humidity is above 40%. Accelerated corrosion, which is predicted to occur from 2030, may reduce the 100-year design life of the structure.

NSC structural members were coated with an anti-corrosion layer during fabrication and inspected upon delivery to the construction site. Assembly and sliding of the NSC may have caused some degradation of the coating. Damage to the coating of structural elements was caused by the drone attack and perhaps by firefighting.

Small samples of the structural steel, coated and uncoated, were suspended in the annular space to be periodically removed during the life of the facility to study corrosion rates. One set (coated and uncoated) was removed in 2025. The coated sample showed no changes, but corrosion was already visible on the uncoated sample[52].

5.3. Unknown Load-Bearing Capability

The shock of the drone strike and explosion was sufficient enough to be recorded on the NSC Seismic Monitoring System (0.896 g horizontal, 0.545 g vertical)[53]. Deformed joints of structural elements in the vicinity of the Main Crane System Garage have been visually observed and photographed[54].
The load-bearing capability of NSC structural

51. Kurkovskyi P., Skliarenko, Kondratenko S, Kuzmenko V., Institute of Engineering Thermophysics, National Academy of Science, Ukraine, Violation of the Design Regime of Ring Space's Ventilation Under Arch as a Result of Direct Drone's Strike onto the NSC Arch, presented at conference INUDECO, Slavutich, Ukraine, 29 April 2025

52. Hnatchuk, Op. Cit.

53. Poplygin. Serhyi, SE Chornobyl NPP, Russian Drone Strike on the NSC, Consequences and Further Strategy, presented at conference INUDECO, Slavutich, Ukraine, 29 April 2025

54. Ibid.

elements and Main Crane System must be determined by additional inspection and test before their use. Alignment of Main Crane rails is critical.

5.4. Temporary Actions

The IAEA reported[55] on 03 October, 2025 that urgent repairs to the NSC had been completed by ChNPP. These repairs primarily consisted of installing a temporary covering over the 15 m^2 opening on the external cladding, minimizing the entry of rain and snow into the Annular Space and Main Volume of the NSC. However, as the IAEA noted, "the confinement function of the NSC remains compromised, increasing the risk of radioactive material being released into the environment in the event of a collapse of unstable structures within the Shelter Object.[56]"

The Director of ChNPP reported in March, 2026, that, "in order to fully restore the functioning of the New Safe Confinement, it is necessary to carry out a whole range of measures, including the replacement of all damaged membranes; repair of the main cranes maintenance system and other damaged equipment, as well as steel supporting structures; restoration of full tightness of the outer cladding. All this is an extremely difficult technical task, given the high radiation fields in the work area."[57] Repairs of the NSC are scheduled to be completed by 2030.

55. Timeline of the IAEA's response activities to the situation in Ukraine, 03 October 2025, https://www.iaea.org/interactive/timeline/169792

56. Ibid.

57. ChNPP, On the eve of the Assembly of the International Chornobyl Cooperation Account, Chornobyl NPP, EBRD and French companies Bouygues and Vinci discussed key tasks for restoring the NSC functionality, Serhii Tarakanov, Director General of Chornobyl NPP, 10 March 2026, see https://chnpp.gov.ua/en/infocenter/news/6536-on-the-eve-of-the-assembly-of-the-international-chornobyl-cooperation-account-chornobyl-npp-ebrd-and-french-companies-bouygues-and-vinci-discussed-key-tasks-for-restoring-the-nsc-functionality#:~:text=He%20added%20that%20in%20order,IAEA%20mission%20in%20November%202025.

Firefighters cut through NSC to extinguish smoldering material with water - March 2025 Credit ChNPP

6. Potential Long-Term Impacts of the Attack

Radiation exposure of workers during the emergency response to the attack and Temporary Actions did not exceed statutory limits. It is expected that the same will be true of workers involved in the longer-term recovery efforts. Even low levels of radiation exposure may result in adverse health outcomes in a population, but the effects may not be apparent until a substantial length of time after the exposure. Therefore, Ukraine should prepare for long-term tracking and medical observation of workers.

Any long term impacts of the attack must be considered in the framework of the long term functions of the NSC: to enable deconstruction of unstable structures and removal of nuclear fuel containing materials[15].

Deconstruction of unstable structures in the Object Shelter is necessary to prevent their uncontrolled collapse which would redistribute large amounts of radioactive dust inside the NSC. Large-scale decontamination following a collapse would be expensive in terms of financial cost and total collective dose to workers.

Unstable structures have been divided into two categories for deconstruction: early dismantling and delayed dismantling. Unstable structures with a probability of collapse of less than 10^{-2} per year are scheduled for early dismantling. A recent analysis of unstable structures in the Object Shelter scheduled for early dismantling concluded that their load-bearing capacity was adequate to sustain seismic events through the year 2029[58]. Unstable structures with a probability of collapse between 10^{-2} and 10^{-4} per year are scheduled for delayed dismantling.

The only estimated duration of time, known to this author, for early dismantling of unstable structures is about 40 months[59], assuming the waste produced can be placed in containers and removed from the NSC buffer storage at a rate equal to its production[60]. The only estimated duration of time, known to this author, for Object Shelter delayed dismantling is about 14 months[61], assuming the waste produced can be placed in containers and removed from the NSC buffer storage at a rate equal to its production[62].

Assuming that delayed dismantlement commences immediately after completion of early dismantlement, the total length of time for them is about 54 months. If dismantling of unstable structures commences upon full restoration of NSC functionality in 2030, then the dismantling should be completed in the year 2035.

58. SE NDIBK, UTEM Engineering, SE ChNPP, and IPB National Academy of Sciences Ukraine, Pre-Design Solutions for “Early Dismantling” of SE ChNPP Object “Shelter” Unstable Structures, presented at Conference INEDUCO-2025

59. Dismantled Element Process Equipment and Related RAW Management, Document Number DD-306, Revision B dated 24.04.2003, pages 90 and 93 (disclosure: Schmieman is a co-author)

60. Op. cit., Section 10.4, pages 98-99

61. Op. cit., Section 10.4, pages 96 and 97

62. Op. cit., Section 10.4, pages 98-99.

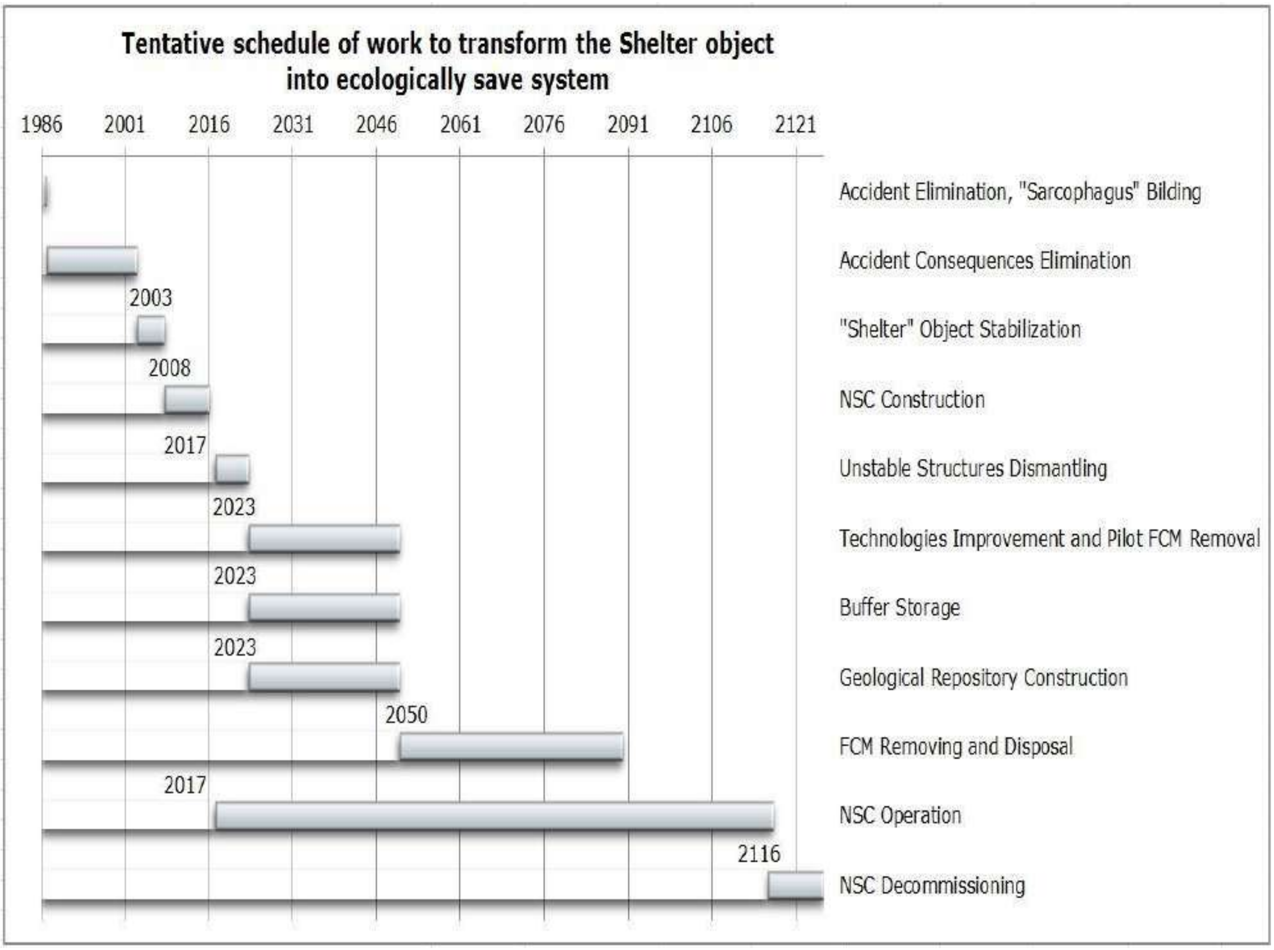
The removal of fuel-containing materials (FCM) is more complex, more hazardous, and has more uncertainties than the deconstruction of unstable structures. An analysis[63] of ten scenarios for the removal of FCM includes the removal and packaging for disposal of FCM from the Central Hall of the Unit-4 reactor building as the first step in all ten scenarios.

Ultimately, a deep geological storage facility is needed for disposal of FCM. Currently, only Finland is operating a deep geological repository for spent nuclear fuel (Onkalo). All other nations with spent nuclear fuel place the fuel in casks that reside in interim storage facilities, often outdoors. If Chornobyl fuel containing waste is placed in casks similar to those used for spent nuclear fuel, the concrete pad used for erection of the NSC would make a convenient interim storage location.

One tentative schedule for transformation of the Shelter Object into an ecologically safe system was published in 2017[64] and is reproduced below. It includes a similar time estimate for the deconstruction of unstable structures and does not place a geological repository on the critical path. Adjusting this schedule's start date for FCM removal and disposal from 2023 to 2035 to account for delays due to covid and the Russian drone attack, FCM removal and disposal would finish in about 2102. The 100-year life of the NSC is assumed to have started at commissioning in 2019 and would end in 2119.

63. Krasnov, V.O., Nosovsky, A. V., Paskevich, S.A., Rudko, V.M., Op. cit, Chapter 6, 2021, 344 p. ISBN 978–966–02–9577–3

64. Kuchynskyi, V., Decommissioning Efforts on Chornobyl NPP site –Past, Present and Future Activities, presented at IAEA International Decommissioning Network Annual Meeting, 2017 Session 5



7. Recovery Plans and Funding

"In November 2020, at the request of the Ukrainian government, a new multilateral fund was established to support the development of a comprehensive plan for Chornobyl. Named the International Chornobyl Cooperation Account (ICCA), it is managed by the EBRD.

Following Russia's occupation of the Chornobyl Exclusion Zone (CEZ) at the start of the war on Ukraine, the scope of the ICCA was broadened to support the restoration of safety and security within the CEZ, as well as wider nuclear safety measures across Ukraine.

Following the Russian drone attack, contributions to the ICCA by the European Union, France, Norway, United Kingdom, Canada, Germany, Taiwan Business-EBRD Technical Cooperation Fund, Belgium and Italy have brought the total available funds to more than €70 million which will contribute to ongoing international efforts to support the restoration of the NSC's key functions[65].

In early March 2026, ChNPP reported that the repairs completed in October 2025 had permitted the facility, "to get through the autumn-winter period relatively smoothly and to prevent excessive ingress of precipitation into the structure. However, this solution was only temporary. Now it is necessary to undertake comprehensive repairs and full restoration of the NSC functionality."[66]

"It is very important to restore the function of containing radioactive substances within the NSC, as well as active anti-corrosion protection to ensure the functioning of the Confinement for the designed 100 years. After completing the comprehensive repair work within the specified time frame (by 2030), we will be able to move on to the implementation of the main task for which the New Safe Confinement was built - dismantling the unstable structures of the Shelter Object and transforming it into an environmentally safe system.[67]"

EBRD convened an Assembly of Donors at the end of March, 2026. At the meeting the donors endorsed a three phase plan for proceeding forward with decision making and construction to restore NSC functionality[68]:

Phase 1 will consolidate existing technical data, carry out targeted investigations and develop initial repair concepts.

Phase 2 will transform these concepts into engineering solutions and develop the overall repair strategy, in consultation with Ukraine's nuclear regulator.

Phase 3 will prepare the plan for potential implementation through detailed engineering, procurement documentation and, where justified, early procurement of long-lead items.

Donors approved EBRD's recommendation to allocate €30 million for this purpose.[69] The Ukraine Ministry of Energy reported a preliminary estimate of €412 million for full repair of the arch[70].

Perhaps the largest obstacle to initiating physical repairs to the NSC is the continuation of the war. The Chornobyl nuclear plant is on the frontline of a war-zone and as long as the war continues international construction activities at the site are unlikely. Off-site activities such as design and procurement of long lead-time material can be started before the war ends.

65. Bitsadze, Rezo, EBRD Donors Back Plan to Repair Chornobyl's Protective Shield, https://www.ebrd.com/home/news-and-events/news/2026/ebrd-donors-back-plan-to-repair-chornobyl-s-protective-shield.html, 01 April 2026

66. Tarakanov, S., "On the eve of the Assembly of the International Chornobyl Cooperation Account, Chornobyl NPP, EBRD and French companies Bouygues and Vinci discussed key tasks for restoring the NSC functionality", https://chnpp.gov.ua/en/infocenter/news/6536-on-the-eve-of-the-assembly-of-the-international-chornobyl-cooperation-account-chornobyl-npp-ebrd-and-french-companies-bouygues-and-vinci-discussed-key-tasks-for-restoring-the-nsc-functionality

67. Tarakanov, Serhii, "Full restoration of Chornobyl shelter's function targeted for 2030", World Nuclear News, 10 March 2025, https://www.world-nuclear-news.org/articles/full-restoration-of-Chornobyl-shelter--function-targeted-for-2030

68. Bitsadze, op. cit.

69. Ibid.

70. Interfax-Ukraine, Donors allocate EUR 30 mln for initial restoration work on New Safe Confinement at Chornobyl NPP, https://en.interfax.com.ua/news/economic/1155901.html, 01 April, 2026

The author offers two suggestions for consideration during these early phases of the project

Reexamine underlying strategies that drove original NSC design and will also drive NSC repair schedule and cost.

For example, the NSC enables removal of contaminated debris from the top of Object Shelter down toward the bottom.

An alternative strategy might be to remove the most hazardous material first, proceeding toward the least hazardous.

Explore out-of-the-box construction methods and materials while we have the freedom to do so. For example, rather than removing the NSC outside surface to replace the insulation and membrane, consider adding insulation and sealant from the Annular Space to the inside surface of the outside arch shell. Specifically consider spray-applied fire block materials. Application might be accomplished by drones or other robotic means working inside the annular space, reducing total collective dose as well as time and material costs.

8. Biosketch of Author

Eric Schmieman contributed to the design and construction of the New Safe Confinement in several capacities from 2001 to 2014: he led the Battelle Memorial Institute team during conceptual design of the NSC, served as the Manager of Environmental Safety and Health Department of the Project Management Unit (PMU), and was the Senior Technical Advisor to the PMU Director. He lived in Slavutych from 2006 to 2013.

While employed at Pacific Northwest National Laboratory he contributed to projects funded by the US Department of Energy, the US Nuclear Regulatory Commission, the International Atomic Energy Administration, and other government agencies.

Eric completed Senior Reactor Operator training at the Trojan Nuclear Power Plant in Oregon and stood control room watches as Shift Technical Advisor. He led the design and installation of the Remote Shutdown Station, the largest design change in the plant's operating history.

Earlier in his career he worked as a startup engineer, performed Containment Integrated Leak Rate tests at domestic and foreign (Yugoslavia) nuclear power plants, and wrote the operating license technical specifications for Angra-1 Nuclear Power Plant (Brazil).

Eric earned a MS in Civil Engineering and PhD. He has registered as a Professional Engineer by exam in multiple US States in multiple engineering disciplines.

Eric and Susan have been married for 49 years.

Greenpeace protest at Chornobyl Shelter Object/Sarcophagus against Russian drone attack on Chornobyl NSC, 9 April 2026