Properties of fuel-containing materials of the Shelter object of the Chernobyl Nuclear Power Plant

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About accident

The event occurred during a late-night safety test which simulated a station blackout power-failure, in the course of which safety systems were intentionally turned off. A combination of inherent reactor design flaws and the reactor operators arranging the core in a manner contrary to the checklist for the test, eventually resulted in uncontrolled reaction conditions. Water flashed into steam generating a destructive steam explosion and a subsequent open-air graphite fire.This fire produced considerable updrafts for about nine days. These lofted plumes of fission products into the atmosphere. The estimated radioactive inventory that was released during this very hot fire phase approximately equaled in magnitude the airborne fission products released in the initial destructive explosion. This radioactive material precipitated onto parts of the western USSR and European countries.

The worst world accident in the nuclear power history occurred at Unit 4 of Chernobyl NPP on April 26, 1986.

- The **7th** level of the INES scale was assigned to the accident
- About **50 MCi** of radioactivity was released within 10 days
- **200,000** square kilometers were contaminated

“Shelter” Object

The Shelter Object was constructed within 206 days. The accelerated time of its construction led to appearance of design flaws, in particular:

- The bearing structures of the supporting walls (survived constructions of the Power Unit 4) and their junctions were significantly damaged, overloaded with the weight of the building structures that were dropped on them, and materials used during the accident elimination
- Exposed reinforcing bars of the reinforced concrete structures and metal structures are corroded
- The structures constructed after the accident are freely supported on the bearing structures without a physical connection and are retained without welded or bolted connections

The current status of the OS is classified as follows:

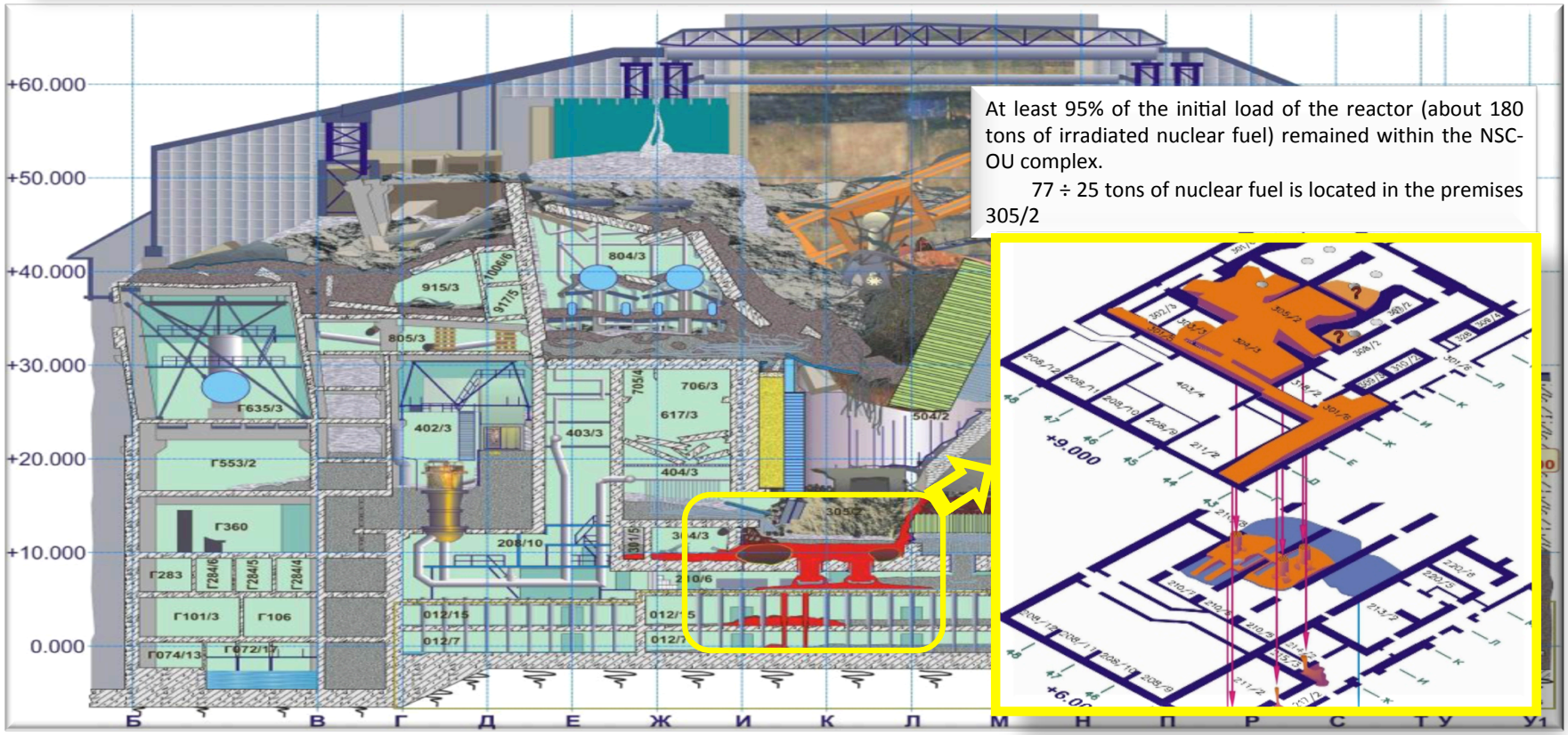
1. Object “Shelter” (OS) is destroyed by the Chernobyl accident Unit 4, which has lost all the functional properties of the Unit and which has carried out priority measures to reduce the consequences of the accident, as well as ongoing work to ensure its **nuclear and radiation safety**.
2. The OS in its present state should be classified as “the storage site of unorganized radioactive waste (“temporary storage of unorganized radioactive waste under stabilization and reconstruction ”)” [1, 2, 3]

From the following provisions it follows:

1. *Activities on OS are activities related to radioactive waste management. Accordingly, the regulation of its safety should be carried out on the basis of NPAs and NTDs [4,5] acting in the field of radioactive waste management.*
2. *The NSC-OS complex is subject to the "Nuclear Safety Rules" [6,7] and the basic principles and nature of technical and organizational measures aimed at achieving nuclear and radiation safety [8].*

Fuel Contemned Material in “Shelter” Object

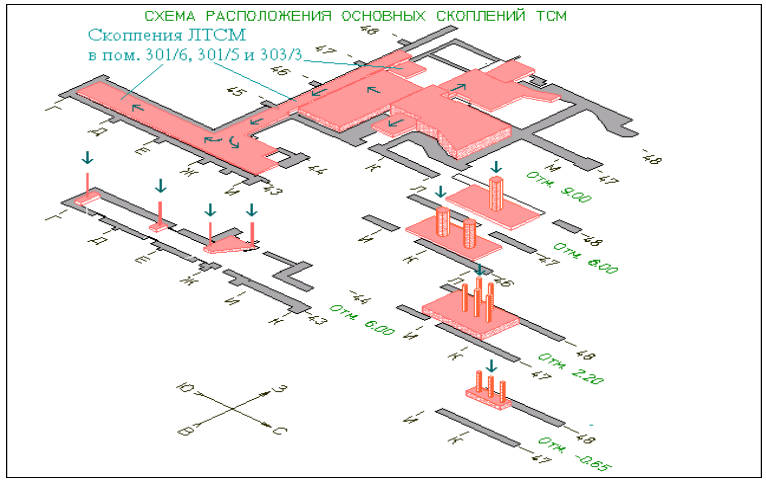
The section of the destroyed fourth power unit of the ChNPP (along the axis "46 + 2500"), as well as the scheme of spreading lava-like products of interaction of the melt of the active zone with structural materials

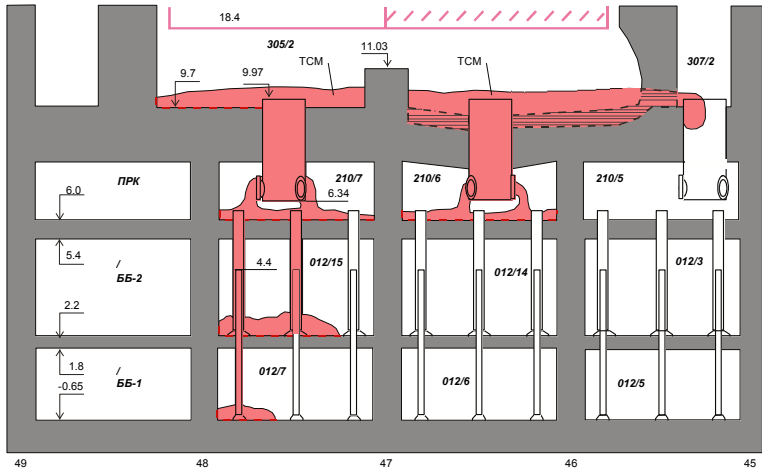


At least 95% of the initial load of the reactor (about 180 tons of irradiated nuclear fuel) remained within the NSC-OU complex.

77 ÷ 25 tons of nuclear fuel is located in the premises 305/2

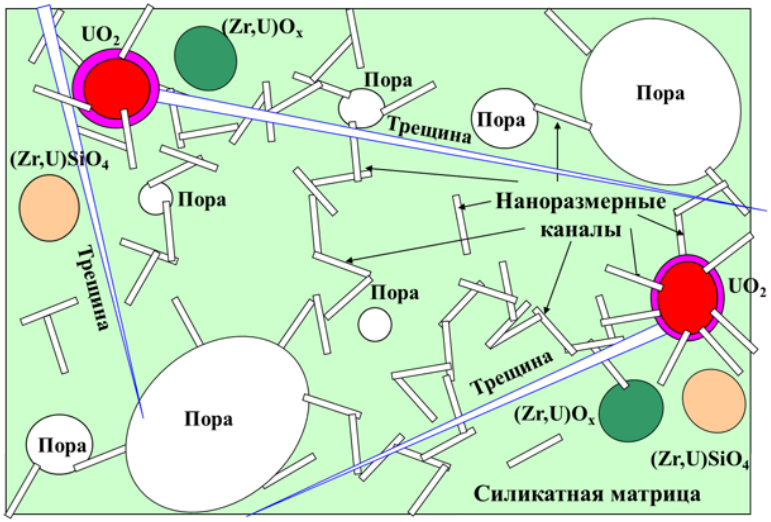
Location of Fuel Contemned Material inside “Shelter” Object





№	Location of FCM	Volume of FCM(m^3)
1.	the premises. 305/2, southeast mark. 9.7	55
	First stream	46.4
2.	the premises. .305 / 2, southwest mark 9.7	13
3.	the premises. . 210/7 mark 6.00	15
4.	the premises. .012 / 15 mark 2.20	12
5.	the premises. .012 / 7 mark -0.65	1.4
	Second stream	14
6.	the premises. .210 / 7 mark. 6.00	14
	Third stream	57.5
7.	the premises. .304 / 3 mark 9.3	31.5
8.	the premises. 301/5, 303/3, 301/6 mark 9.3	23
9.	the premises. .217 / 2 mark 6.00	2.5
	Total:	**172.9**

Structure and materials balance of FCM



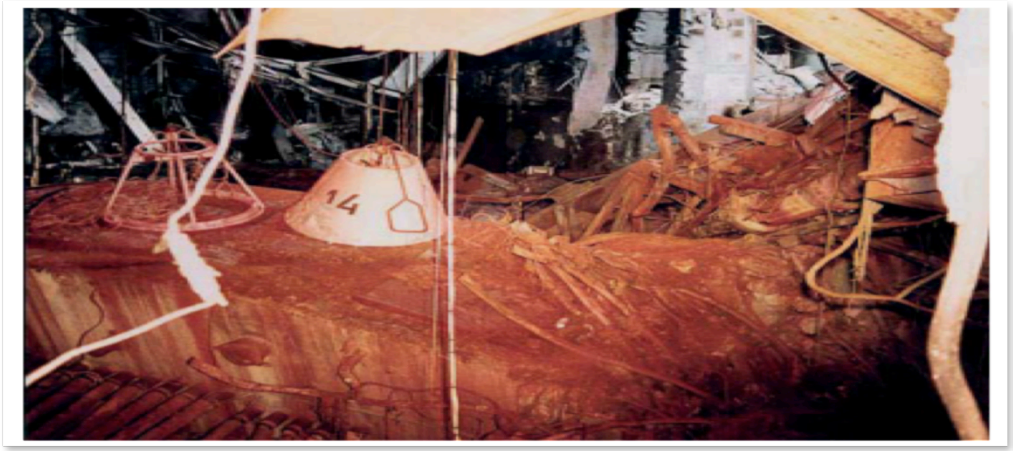
The weighted average concentration of the main chemical elements in LFCM,% wt.

Element	LFCM	
	Brown	Black
Si	32,2 (30,0 - 35,5)	30,9 (28,5 - 33,0)
Al	3,3 (3,0 - 3,6)	4,0 (3,9 - 4,6)
Mg	5,2 (4,2 - 6,1)	2,5 (2,3 - 3,0)
Ca	4,5 (3,9 - 4,8)	5,1 (4,5 - 6,1)
Na	3,1 (1,7 - 4,0)	4,2 (3,9 - 4,6)
U	9,7 (8,3 - 10,5)	4,6 (3,8 - 5,7)
Zr	4,5 (4,2 - 4,9)	4,2 (4,0 - 4,3)
Fe	1,0 (0,9 - 1,4)	1,2 (0,35 - 5,5)

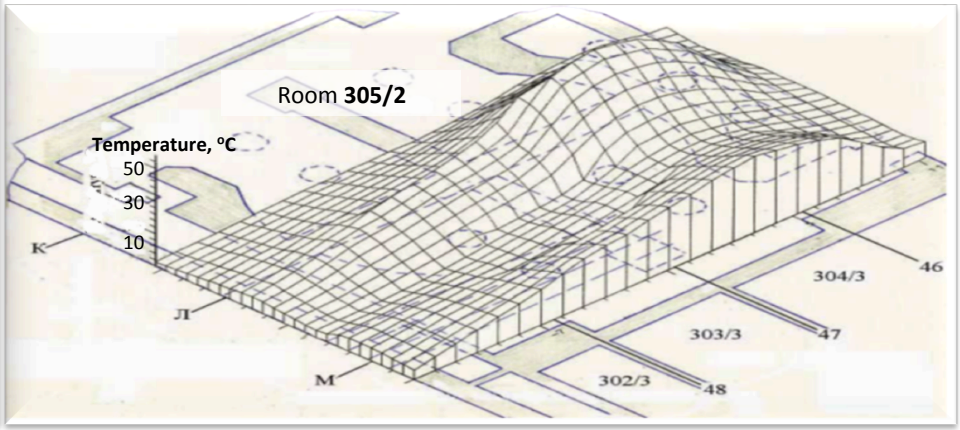
The ratio of the concentration of the main chemical elements LTSM						
Premises	Si/Mg	Si/Al	Si/Ca	Si/Na	Mg/Al	Si/Zr
			Brown LFCM			
02/15 (BB-2)	5,8	11,8	9,1	20,9	2,0	8,3
012/7 (BB-1)	5,8	9,8	6,5	8,9	1,7	7,3
210/7	7,1	8,3	6,3	7,5	1,2	6,1
Average:	6,2	9,8	7,2	10,4	1,6	7,2
			Black LFCM			
217/2	14,2	6,8	5,1	7,6	0,5	7,2
210/6	9,5	7,1	6,3	7,3	0,8	7,1
304/3	14,3	8,5	6,9	7,2	0,6	7,7
Average:	12,4	7,7	6,1	7,4	0,6	7,4

Thermometric measurements and the defining of the mass and volume of FCM cluster

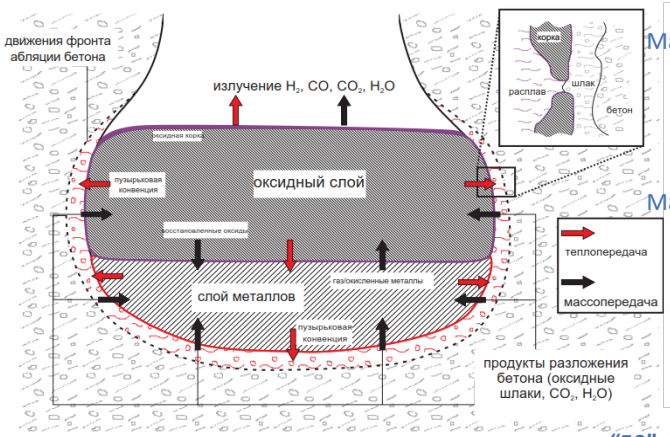
The "Bui“ device, installed in the collapse of the central hall of the ChNPP unit 4



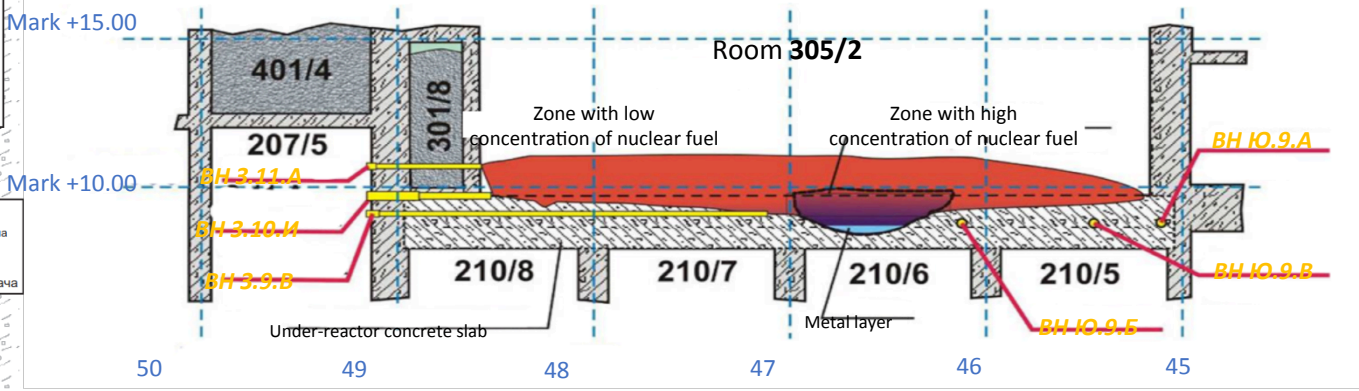
The temperature (results of measurements in research boreholes and by portable instruments) at zone of localization of nuclear dangerous cluster (room 305/2)



Simulation (using the ASTEC code) of the interaction of corium melt with concrete

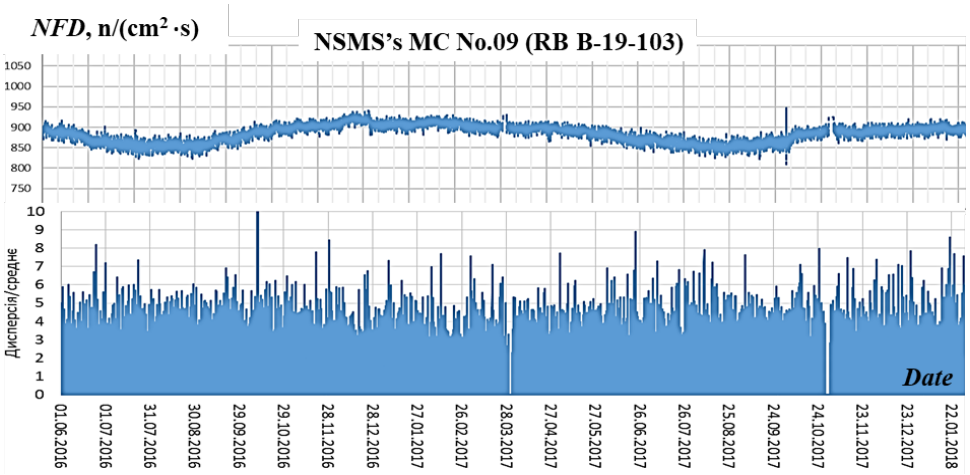


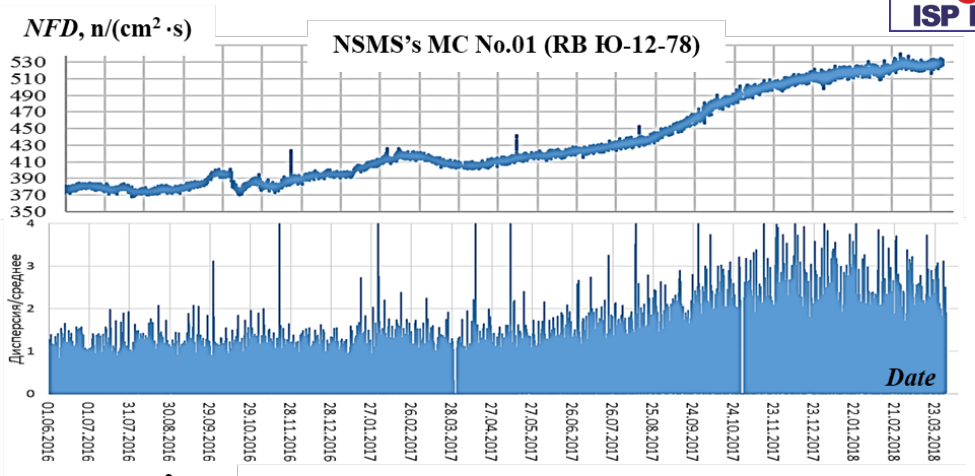
The determination of volume of the zone with high concentration of nuclear fuel, localized in under-reactor slab

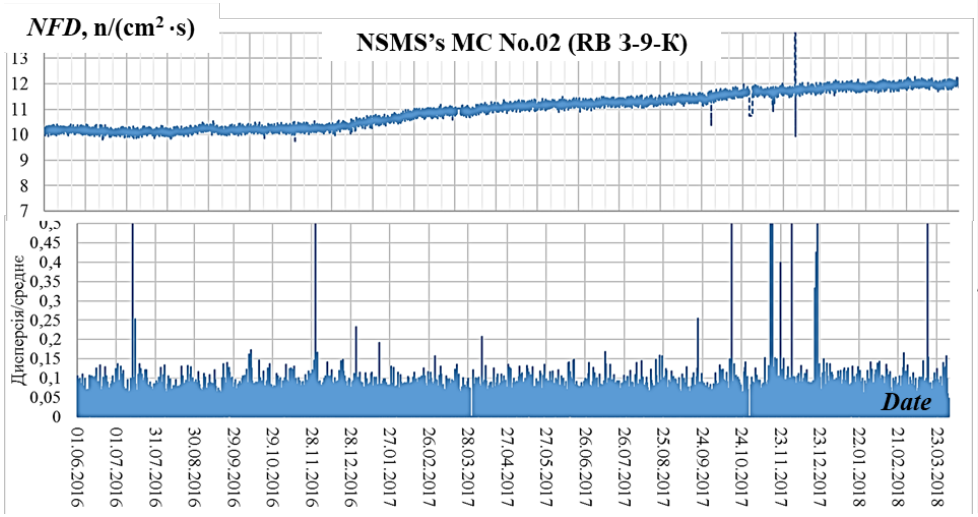


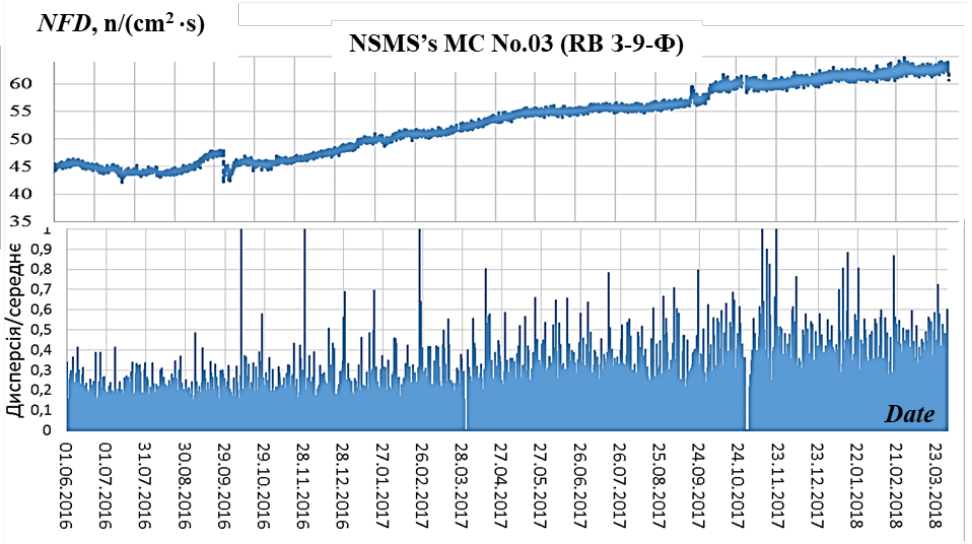
“50” – name of *construction axle* **“210/7”** – *name of room* **ВН *3.9.В*** – name of *research boreholes*

Analysis of statistical parameters of neutron measurements









Motivation

Transformation “Shelter” object to ecological safe system

Shelter Implementation Plan

- **Reduce the OS collapse potential**:
  - **Task 1 Stabilization design integration and mobilization;**
  - **Task 2 Stabilization of the Western section;**
  - Task 3 Stabilization of “Mammoth” Beam and Southern section;
  - **Task 4 Stabilization 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 investigations;**
  - **Task 8 Seismic characterization and monitoring;**
- **Reduce the OS structural collapse consequences:**
  - **Task 9 Emergency preparedness;**
  - **Task 10 Dust management;**
  - **Task 11 Emergency dust suppression system;**
- **Improve nuclear safety:**
  - **Task 12 Criticality and nuclear safety;**
  - Task 13 Contained water management;
  - **Task 14 FCM characterization;**

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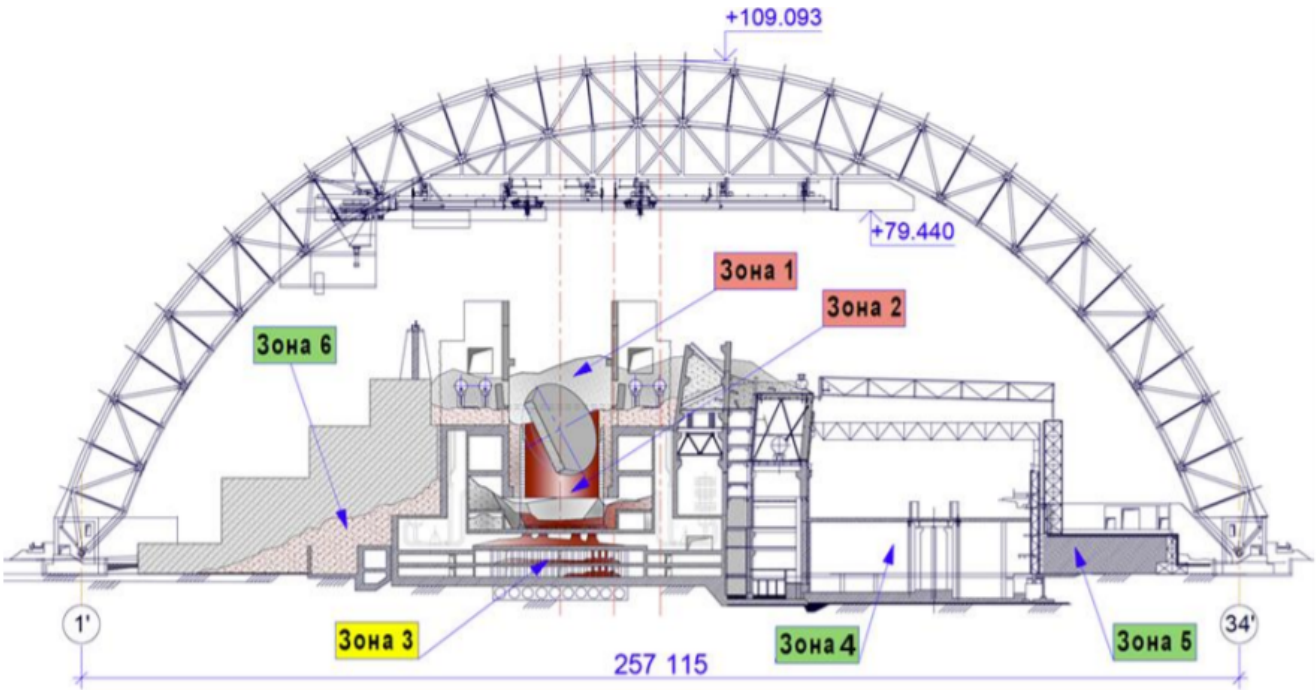
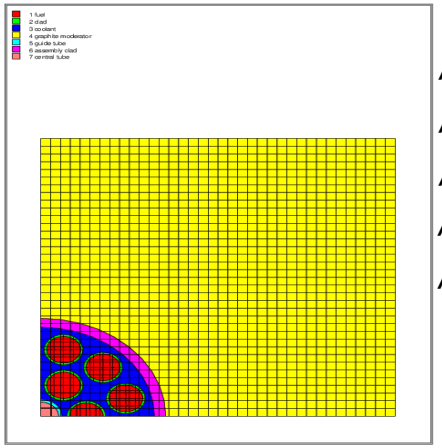
- **Improve worker and environmental safety:**
  - **Task 15 Radiological protection program;**
  - **Task 16 Industrial Safety, fire protection and access control;**
  - Task 17 Integrated monitoring system;
  - Task 18 Integrated database;
- **Develop the long-term strategy and study for Object Shelter conversion into an environmentally safe system:**
  - Task 19 FCM removal and waste management strategy;
  - Task 20 Development of FCM removal technology;
  - **Task 21 Safe Confinement strategy;**
  - **Task 22 Safe Confinement construction;**

Why you need to remove FCM?



- This is required by the law of Ukraine "On general principles of further exploitation and decommissioning of Chornobyl NPP and transformation of the destroyed the fourth power unit of this NPP ecologically safe system ";
- All nuclear materials of the Shelter Object must be kept under constant account IAEA control;
- There is a positive experience in the removal of FCM at the Three-Mile Island NPP in the USA;
- In Japan, the Fukushima NPP was adopted strategy for extracting nuclear materials and research works are under way in this direction.

Results of calculations isotopic composition



ρ(fuel) =9.393 g/cm^3; T=873 K

ρ(clad) =6.45 g/cm3: T= 558 K

ρ(coolant) =0.76 g/cm3 T= 558 K

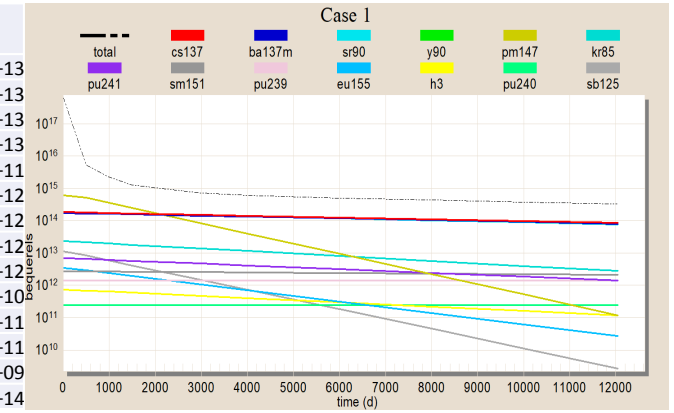
ρ(graphite moderator) =1.65 g/cm3 T= 558 K

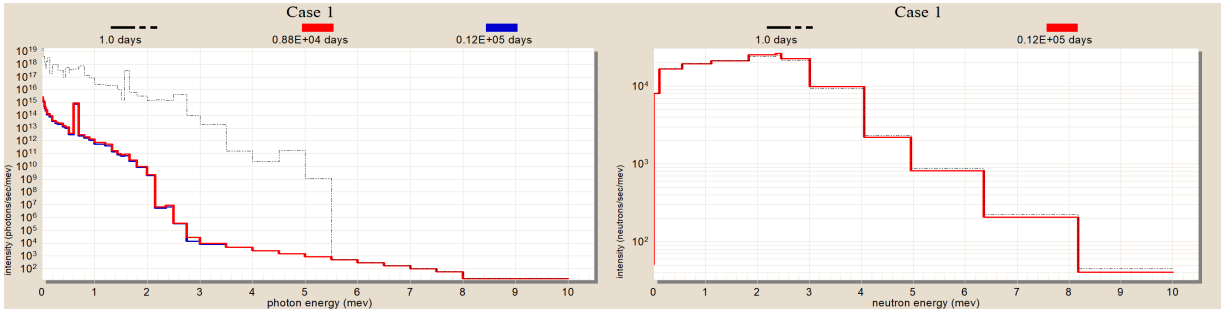
ρ(guide tube) =6.45 g/cm3; T= 558 K

ρ(assembly clad) =6.45 g/cm3; T= 558 K

ρ(central tube) =0.00125 g/cm3; T= 558 K

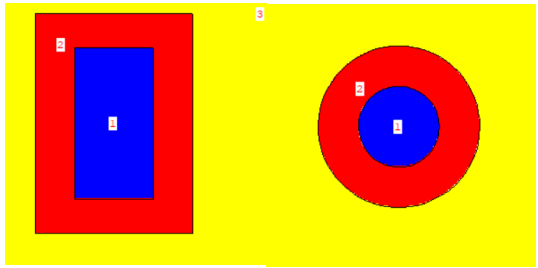
Nuclides	Activity, Bq (1986)	Activity, Bq/g (2019)
cs137	1.834E+14	8.56E+13
ba137m	1.731E+14	8.08E+13
sr90	1.755E+14	7.79E+13
y90	1.712E+14	7.79E+13
pm147	6.017E+14	1.20E+11
kr85	2.338E+13	2.77E+12
pu241	6.990E+12	1.42E+12
sm151	2.676E+12	2.11E+12
pu239	1.382E+12	1.43E+12
eu155	3.527E+12	2.67E+10
h3	7.462E+11	1.17E+11
pu240	2.414E+11	2.41E+11
sb125	1.116E+13	2.72E+09
total	6.747E+17	3.31E+14





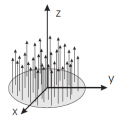
Photon spectrum

Neutron spectrum



Monodirectional Disk Source

```
c --- Disk source perpendicular to z-axis uniformly emitting
c     1.2-MeV neutrons monodirectionally in the +ve z-direction.
c
SDEF  POS=0 0 0  AXS=0 0 1 EXT=0  RAD=d1  PAR=1  ERG=1.2
      VEC=0 0 1  DIR=1
SI1  0   15      $ radial sampling range: 0 to Rmax (=15cm)
SP1 -21  1       $ radial sampling weighting: r^1 for disk
```



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Thank you for your attention!
Question?

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