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HALF AN HOUR AFTER THE BEGINNING OF THE ACCIDENT

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Abstract

S. Bogatov, A. Borovoi, S. Gavrilov, A. Lagunenko, E. Pazukhin "Half an hour after the beginning of the accident".

Keywords:
Chernobyl accident, nuclear fuel, fuel containing materials (FCM), Lava formation, reactor core, reactor vault, under reactor premises.

In the paper some source data necessary for the generation of a model of the Chernobyl accident Phase 2 progression are considered. This phase has began after Unit 4 destruction by explosion(s), a many-day process of nuclear fuel–constructional material interactions, corium generation and spreading is understood.

By convention, the time 30 minutes after the explosions was taken, and an attempt was made on reconstructing the data characteristic for that moment.

Data accumulated during the investigation at the Shelter since 1986 till 2004 were used.

Аннотация

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Через полчаса после аварии

Ключевые слова:
Чернобыльская авария, ядерное топливо, топливосодержащие материалы (ТСМ), образование лавы, активная зона, шахта реактора, подаппаратное помещение.

В работе рассматриваются исходные данные, необходимые для создания модели протекания второй стадии Чернобыльской аварии. Эта стадия начинается с момента, когда после взрыва (взрывов) 4-ый блок был уже разрушен, и включает в себя многодневный процесс взаимодействия ядерного топлива с конструкционными материалами, образование и распространение кориума.

Условно было выбрано время, через 30 минут после взрывов, и для этого момента определены данные о состоянии ядерного топлива и окружающих его материалах, находящихся в шахте реактора и подаппаратном помещении (305/2).

Для такого создания исходной картины была использована информация, накопленная в результате исследований на объекте «Укрытие», проводившихся в 1986 – 2004гг.

Contents

1. Introduction

In this paper some source data necessary for the generation of a model of the Chernobyl accident Phase 2 progression are considered. Under the "second phase of the accident", which began after Unit 4 destruction by explosion(s), a many-day process of nuclear fuel–constructional material interactions, corium generation and spreading is understood.

By convention, the time 30 minutes after the explosions was taken, and an attempt was made on reconstructing the data characteristic for that moment and necessary for further simulations. Such data may be subdivided into the following three categories: mechanical data (data on geometry and materials), chemical data and heat data.

Mechanical data describe 3D disposition of constructions in both the reactor vault and the under-reactor room (305/2) at the beginning of the second accident phase. Information on constructions' materials is also considered under this category.

These data are based on information on RBMK structure before the explosion (see Figs. 1 and 2) and the results of investigations at the destroyed Unit 4 performed in 1986 through 2004.

Those investigations allowed obtaining detailed information on the post-accident geometry in: Central Hall (CH), reactor vault, under-reactor room #305/2, etc. (see Figs. 3 and 4 and References [1 – 6]).

After that, using the extrapolation method, the initial geometry was reconstructed under which the development of corium-generation processes had begun (Fig.5).

From our standpoint, the available today data allow performing such an extrapolation in a rather unambiguous way.

Chemical data determine the processes of fuel-constructional material interactions and corium generation and will be considered in the second part of this paper.

Heat data describe heat sources and the dynamics of their behavior along with heat transfer conditions in the destroyed reactor during the second accident phase will be considered in the third part of the Report.

2. Before-the-Accident Status of Unit 4 Rooms

A schematic profile of RBMK-1000 is demonstrated in Fig.1. In Figure 2 the main structures of reactor vault and under-reactor room #305/2 before the accident are shown.

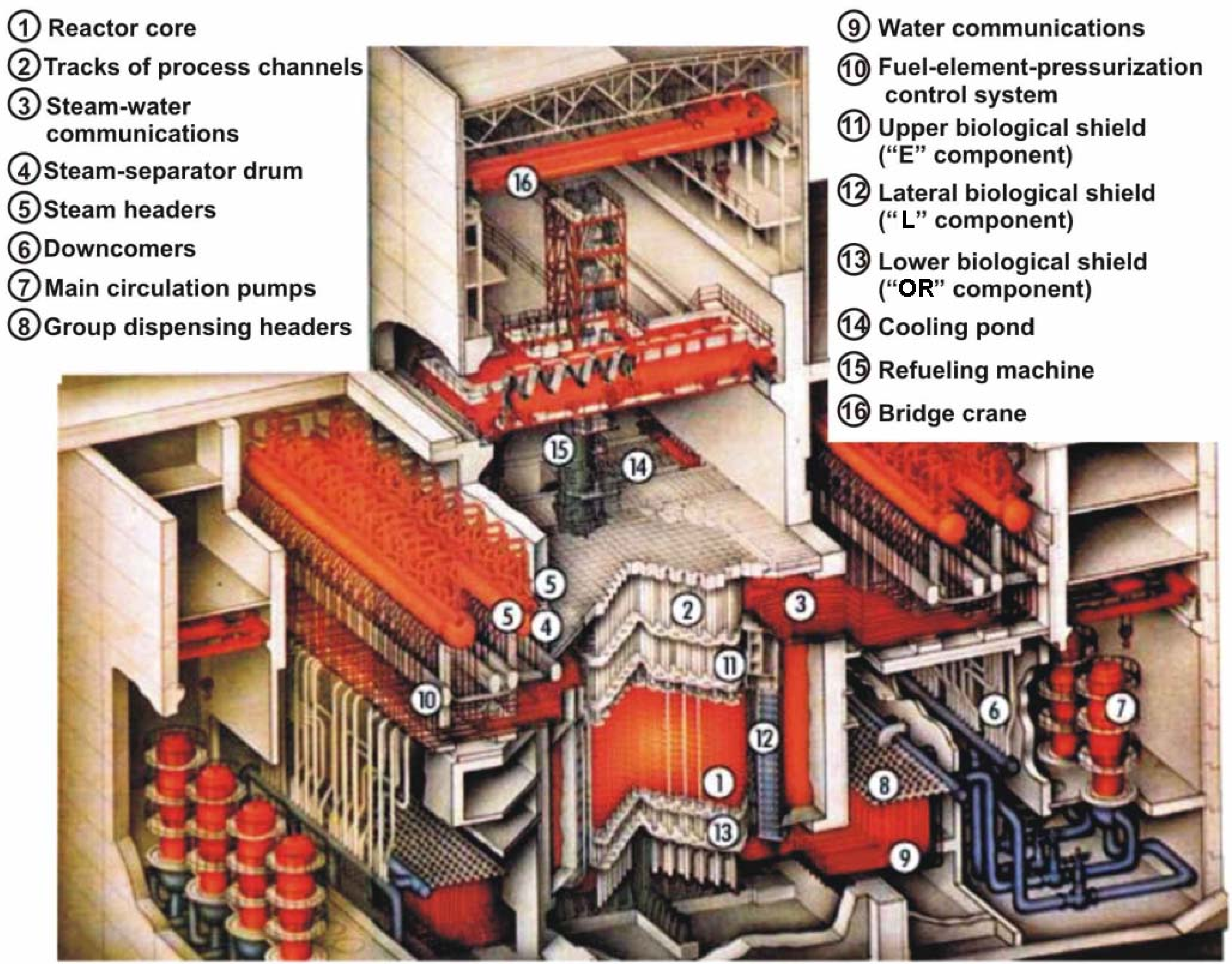


Figure 1. Schematic profile of RBMK-1000

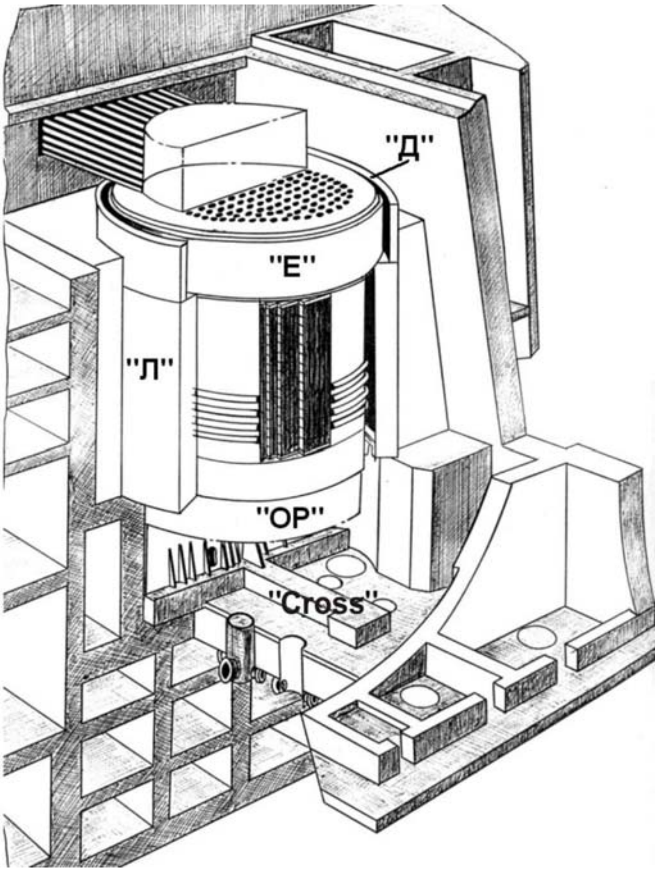


Figure 2. Main constructions of the reactor vault and the under-reactor room #305/2 before the accident.

"E" – upper plate of biological shield (∅=17.4 m, H=3 m)

"Д"(D) – lateral (water) biological shield
"Л"(L) – lateral (water) biological shield

"OP"(OR) – lower plate of biological shield

"Cross" - metal construction of "C" component and a reinforced-concrete "cross"(Room #305/2)

As long as the main post-accident LFCM generation processes occurred within the under-reactor room #305/2, its view from above and a brief description are given below.

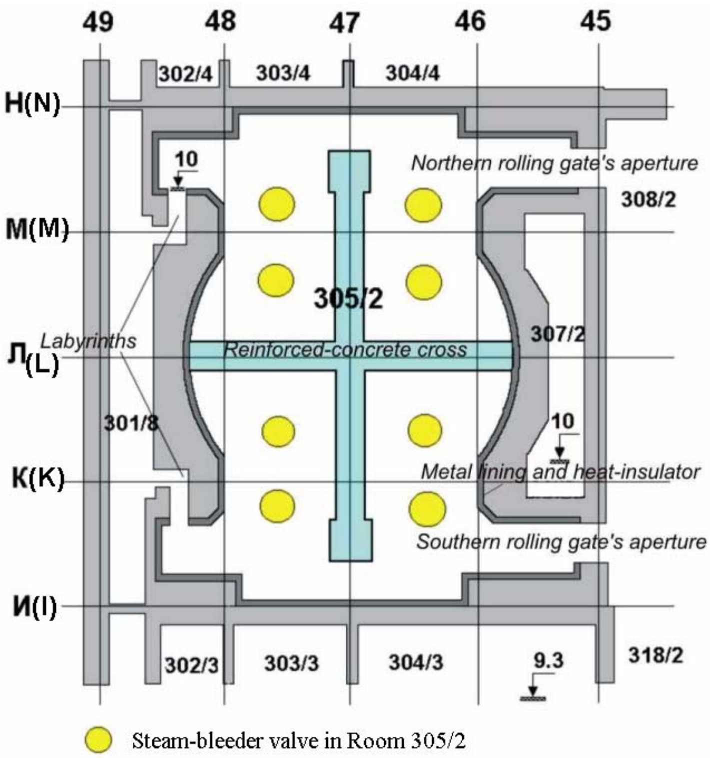


Figure 3. View from above of Room #305/2 and the adjacent rooms (Chernobyl NPP Unit 4).

Before the accident Room #305/2 was confined on top by the bottom metal construction of the reactor – the so-called "reactor basement" or "OR" component.

On the north and on the south Room #305/2 sided with Rooms #404/4 and #404/3 (lower water-communication boxes). Room #305/2's floor represented a steel sheet in 0.3–0.35 m above the structural floor (there is a heat shielding between them). The room's walls were also faced with steel sheets.

The northern and the southern rolling gates leading to Room #308/2 were installed at the southeastern and the northeastern corners of Room #305/2. Special "labyrinths" connecting the under-reactor room with Corridor #301/8 were located at the southwestern and the northwestern corners of Room #305/2.

"OR" component bore on "C" component – a metal structure assembled of steel beams 5.3 m in height that formed a "cross" which center passed via "OR" component's center.

In its turn, "C" component bore on a reinforced concrete "cross" with a beam width (viewed from above) of 1.4 м and 1 m height above the floor level.

There were inlet openings of 8 steam bleeder valves in the floor of Room #305/2 arranged symmetrically relative to axis #47 and row "L". Communications of the reactor bottom were concentrated in Room #305/2. Tubes of Bottom Water Communications (BWC), which number corresponded to that of process channels, got out of the bottom edge of "OR" component.

3. Status of Unit 4 Rooms after the Active Accident Phase Completion (based on the investigations of 1986 – 2004

A variety of investigations performed since the accident time have allowed establishing quite reliably the degree and the geometry of destruction of building structures and the condition of Unit 4 materials including those of the reactor.

The data obtained for CH, reactor vault (room #504/2) and under-reactor room #305/2 are presented in this paper.

The post-explosion geometry of these rooms is demonstrated in Figs. 4 and 5. The Shelter sectional view along the axis 46 (south – north) in Fig. 4 illustrates large-scale destructions inside Unit 4. In particular, due to descending by about 4 m of metal construction of "OR" component, the under-reactor room #305/2 became spatially unified with the reactor vault.

Fragments of the former core, Lava-like FCM (LFCM) and fuel dust are the main modifications of Fuel Containing Materials (FCM) in these rooms.

Let us now describe in more detail the rooms we are interested in.

3.1 Central Hall above the Reactor Vault

The upper plate of the reactor biological shield ("E" component) - together with tubes of Steam-Water Communications (SWC), the rest of technological channels and debris of reinforced-concrete structures stuck between the upper steel extension channels - is located on the edge at 15° angle from vertical bearing on metal construction of "D" component on the north-east, and on a reinforced-concrete plate lying on "D" component on the south-west. The bottom edge of "E" component has a level mark of +25.000, the upper one +43.000. This means that its geometric center was lifted up to ~ 5 m, as compared to the before-accident level.

Virtually all space between "E" and "D" components and reactor vault walls on the northwest is filled with the upper steel extension channels and twisted SWC tubes with stuck fragments of building structures and equipment. The central part of the former bottom surface of "E" component seems to have lost virtually all its process channels. Those channels were torn off at the very basement, only a minor fragment over the peripheral ring of "E" component being available. The visually observed fragment of process channels (the "Elena's hair") is located in the area with the following coordinates: 44-46, L-N About 40 channels hang down into the reactor area from "E" component.

In total, 10 to 30 t of fuel (U) can be located on "E" component.

The bridge of the refueling machine leans against the CH's western wall. Its flank is found on the section of the southern steam-separator drum's wall. The refueling machine's container was broken, its bottom fragment lying on the floor above Room #2005/2 in "K"-row area.

The steam-separator drum's walls facing CH were destroyed. No reinforced-concrete panels that formed the CH's northern wall below +46.000 level mark and in the axes 45 – 49 are presently available on their standard places. The remainder of the wall of the northern steam-separator drum (axes 45 - 49) was pressed towards Room #804/4.

A wall fragment (reinforced-concrete plate), which had separated the northern steam-separator drum's room from CH, moved into the reactor vault together with lining.

3.2. Reactor Vault and Under-reactor Room (level marks 9 - 24 m)

As said above, as a result of the accident the bottom plate or the reactor basement ("OR" component) descended, and the reactor vault became unified with the under-reactor room #305/2.

At present "OR" is located 3.85 m below its "normal" position (direct measurement [7]). Its upper generatrix close to the northern additional support is at +14.100 level mark. The bottom generatrix is at +12.100 level mark, correspondingly.

While creation the Shelter, large amounts of concrete (the so-called "fresh concrete") flew into the reactor vault and Room #305/2, solidified and hided a portion of constructions' debris and FCM.

Information on Room #305/2 was collected in 1988 – 91 using special holes and remote-control mechanisms. Due to high radiation fields survey teams could stay in Room #305/2 for an extremely limited period of time. Only after 1996 specialists managed to make a detailed video filming of the room, take many FCM samples, generalize and verify previous information. As the result, it has become possible to pass from general descriptions of the room to characteristics of individual fuel accumulations therein. However up to present several rather extended areas in Room #305/2 still remain a "*terra incognito*".

The available so far information on Room #305/2 is demonstrated in Fig.6.

For purposes of this work it is rather important that no southeastern sector of "OR" component is presently available because during the second accident phase that component fully melted. Today a flat concrete pad is found on its place (level marks +11.000 - +11.500). The missing sector area is: 100° – 110°.

An obstruction (marks +14.100 - +17.000) is being at the remaining part of "OR" (see red dotted line in fig. 6), that is the space filled with graphite blocks, fragments of technological channels, debris of building structures poured by the concrete at northwestern part. Southwestern sector of "OR" is free from concrete.

On top of "OR" component (on the "wreckage") in the northeastern sector a reinforced-concrete plate, fallen from CH, is found at 60°-angle (point *7* at Fig.6).

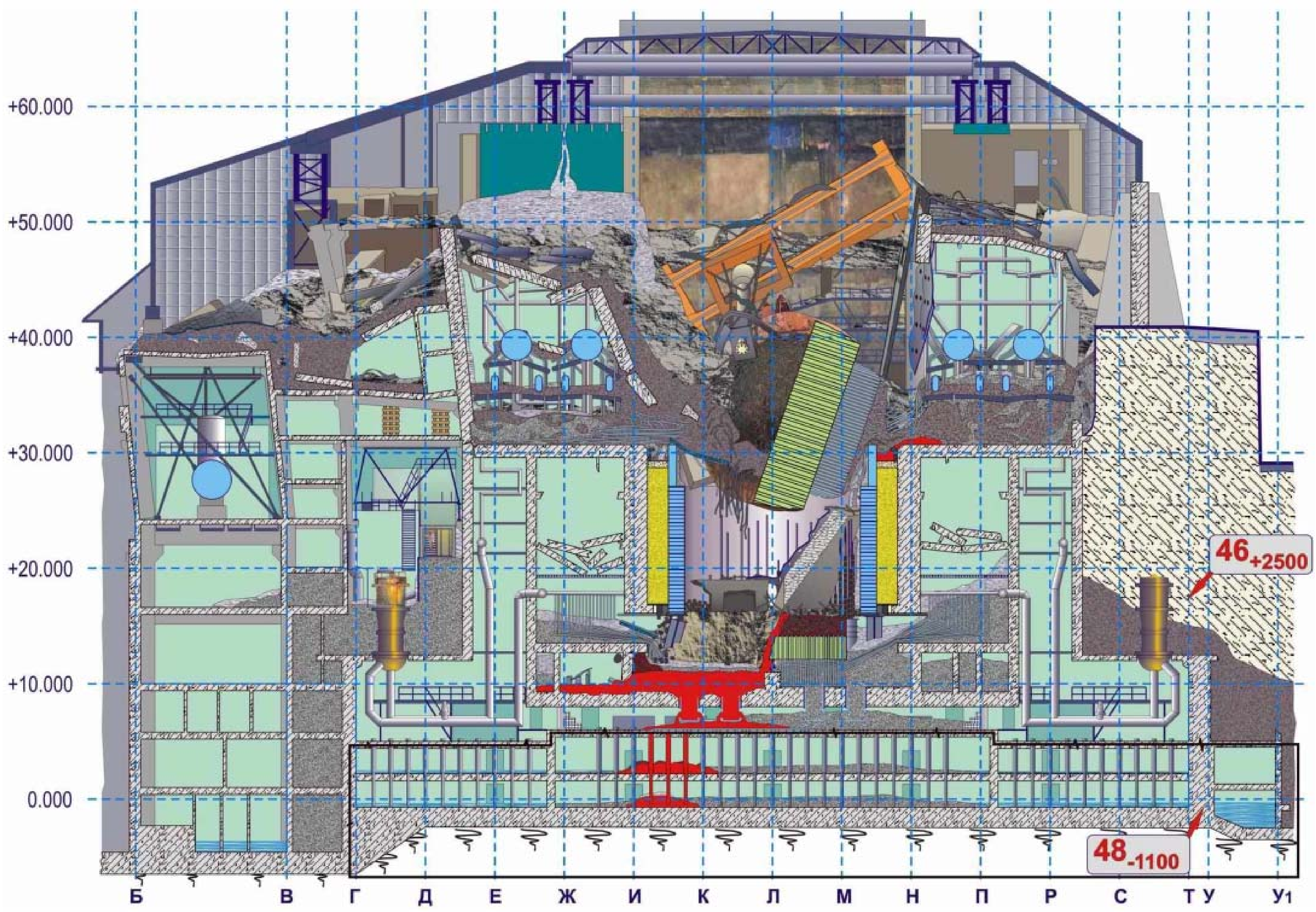


Figure 4. Sectional view of the Shelter (south-north). Solidified LFCM flows are indicated in red.

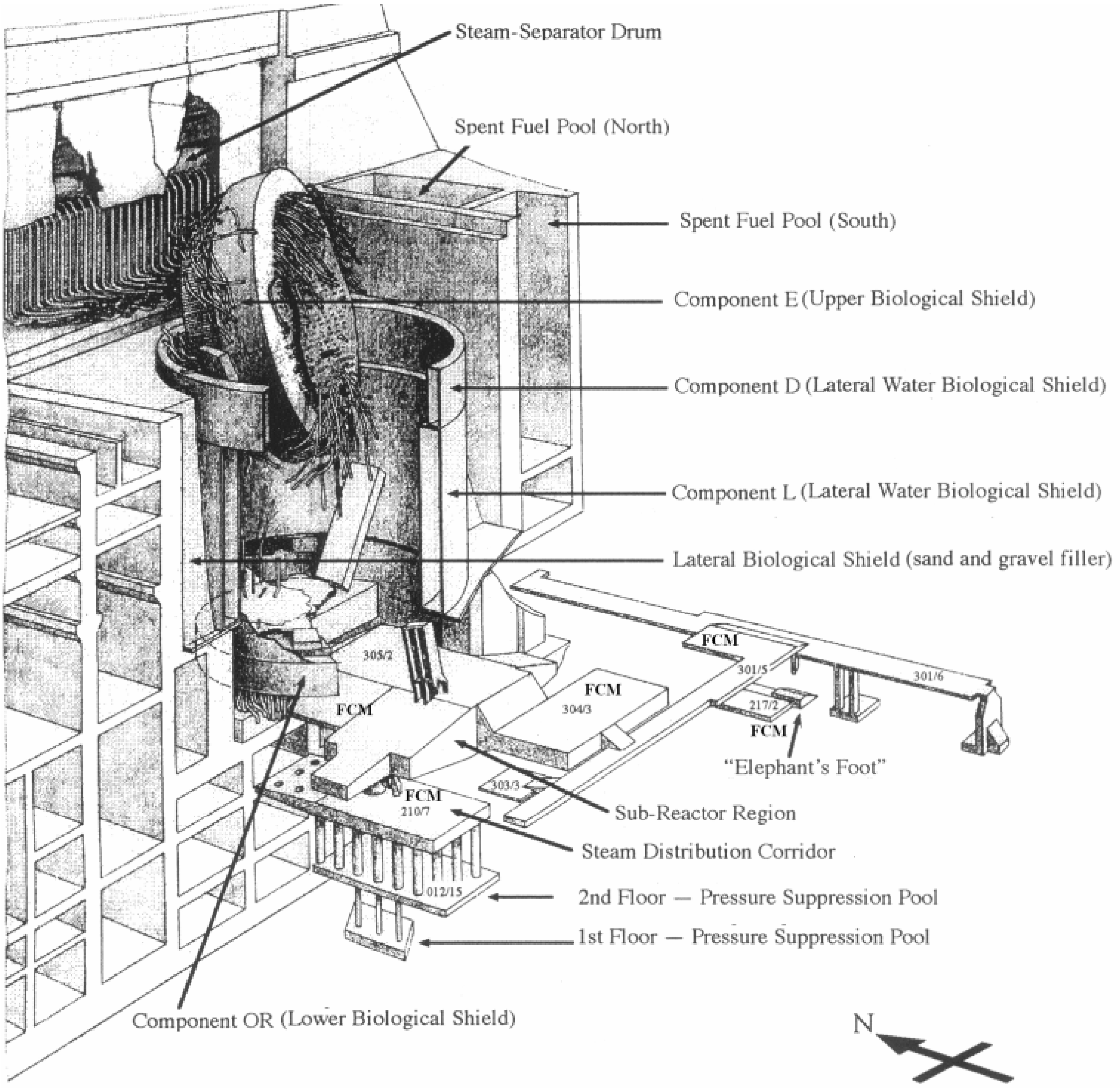


Figure 5. Unit 4 constructions after the accident (based on the results of investigations). Several FCM accumulations are indicated.

A deformed metal sheet (metal lining of the inner surface of walls of steam-separator drum's room that fell into the reactor vault together with a reinforced-concrete plate) is found on the plate; this sheet covers the center of "OR" component (point *8* at Fig.6).

Under the aslant standing concrete plate at intersection of axis 46 and row M, at the folded part of scheme "KZh", FCM leakage is present, that is "stalagmite" (point *4* at fig. 6) of 1 – 1.2 m height and diameter of 0.2 – 0.5 m, being the extension of FCM column hanging from concrete plate ("stalactite").

Along the edge (break) of remaining ¾ "OR", covering the break, the wall of melt loose substance, "loose FCM", is situated.

Reinforced concrete structure by size (in plan), approximately, of 5x3 m and about 2 m of height (point *14* at fig.6) lies at wall verge in southeastern sector.

Rolling gate is teared off from its place.

"Gravel" pile is located opposite rolling gate (point *23* at fig. 6). This is sand subjected to thermal action, spilled from a space between tank "L" and reactor shaft walls (shaft backfilling).

Steel coating of the eastern semicircular wall of room 305/2 is lacking, concrete wall is smoked, and a burn-through in wall to room 307/2 in grotto-shape is found.

Southwestern part of room 305/2 is covered with graphite blocks, metal structures from scheme "OR" and southern box of NSC (room 404/3), and with debris of building structures. Concrete filled the spaces between the elements of this obstruction and reached the mark +13.000 near western wall.

Southern door of labyrinth, leading from room 305/2 to room 301/8, is covered under concrete.

Northern additional support is being at regular vertical position. Southern support (point *18* at fig.6) was burned at mark +12.000 and inclined at angle of 15° towards "OR".

The wall separating Rooms #304/3 and #305/2 is arched towards Room #304/3 and cracked; at some spots in Room #304/3 the outer layer of concrete was spilled, and the reinforcement is bared. The upper wall fragment is destroyed and inclined towards Room #305/2, the maximum inclination being about 5°. In the area of axis 45_{+2000} on Room #304/3's side the wall has a deep vertical fracture.

3.3. Condition of fuel in Room 305/2

The most complete and detailed description of FCM accumulated after the accident in Room #305/2 is found in References [1 and 2]. For convenience of description, 7 fragments (accumulations) are distinguished, large amounts of fuel-containing materials being expected in each of them (Fig. 7).

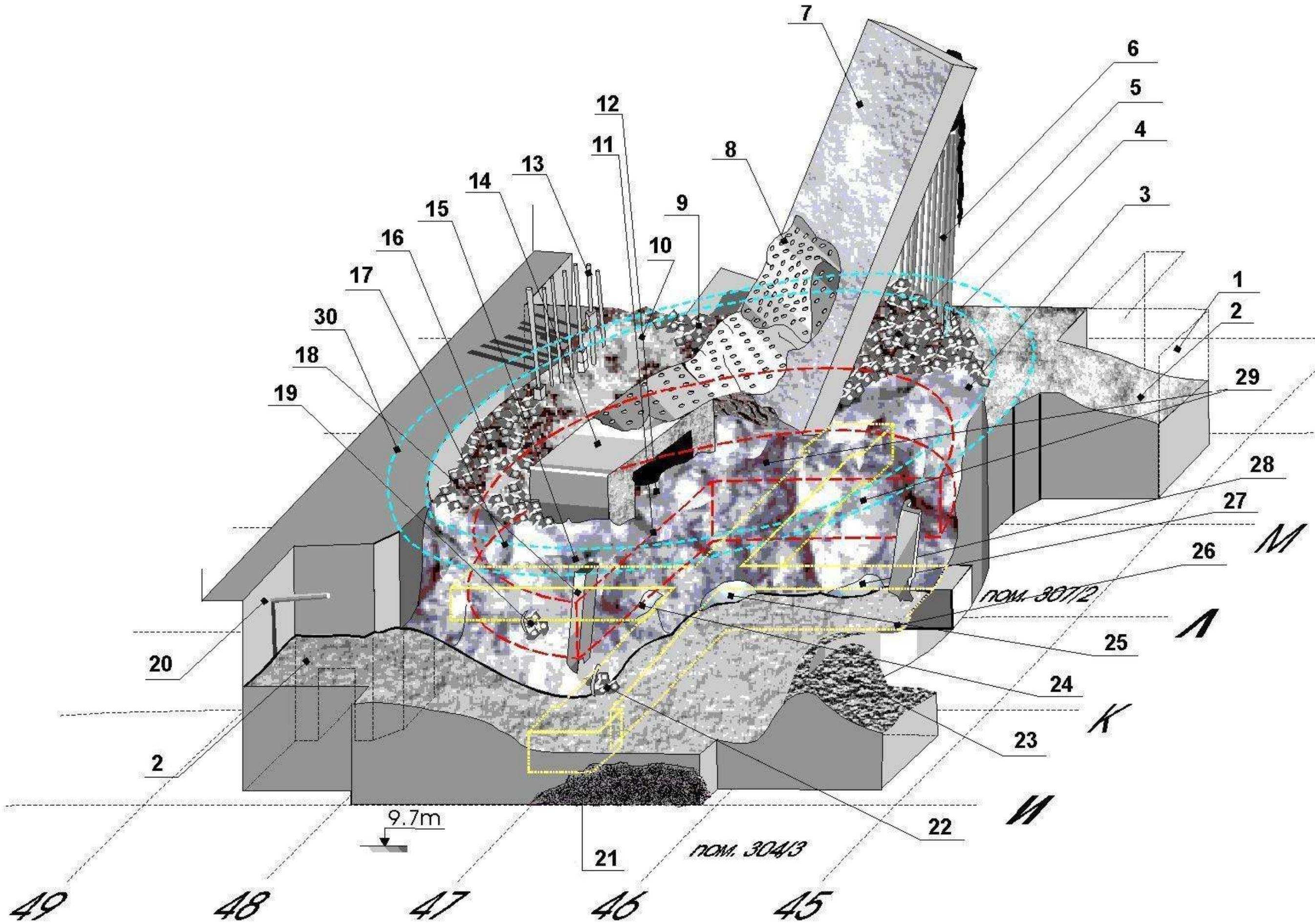
*Accumulation #1- t*he melted southeastern sector of OR plate. It is the place of the major LFCM part formation. The area boundaries: reinforced-concrete cross and walls of Room #305/2. Coordinates: 45/47, И/Л; level marks: +9.000 – +11.500. In this area FCM are hidden under a layer of concrete 0.3 - 0.5 m in width and debris of constructions. Concrete of the under-reactor plate under a lava layer down to +9.00 level mark and a fragment of reinforced concrete cross along the axis #47 are destroyed due to thermal effects, their components becoming lava constituents. LFCM type: black ceramics and brown ceramics.

Accumulation #2 - the southwestern part of the room. The area boundaries: reinforced-concrete cross and walls of Room #305/2. Coordinates: $47/49_{-2000}$, И/Л, level marks: +9.000 - +12.000.

In this area FCM are located under "OR" component and "wreckage" situated along the southern room's wall. Concrete of the under-reactor plate is destroyed, and lava could reach +9.000 level mark and below. LFCM type: mainly black ceramics and brown ceramics.

Accumulation #3 consists of debris along the southern wall of Room #305/2 formed as the result of both collapse of metal construction and BWC tube displacement. Coordinates: $46_{-2000}/48_{+3000}$, $І/К_{-1000}$; level marks +11.000 - +14.000. The debris contains reactor core fragments. The western part of the debris is partly concreted. LFCM type: core fragments, ceramics.

Accumulation #4 - a half-round wall of loose FCM. It was generated during re-melting of the southeastern "OR" sector and initial lava components. The area boundaries: above the reinforced-concrete cross along the boundary of the lacking southeastern part of "OR" component. LFCM type: porous ceramics.



1 – Northern rolling gate's aperture
2 –"Fresh concrete" surface
3 – Filling material from the inter-compensatory gap
4 - "Stalagmite"
5- Area filled with core fragments
6 – Cooling channels
7 – Inclined reinforced-concrete plate
8 – Deformed metal sheet
9 - Wreckage fragment (reinforced concrete construction?), (level mark +17.000)
10 - "Trench"
11 - "OP"(OR) component
12 – Hole (level mark +13.000)
13 – Reflector's cooling channels
14 –Reinforced-concrete construction
15 - Wreckage element's fragment (reinforced concrete construction?)
16 –Fuel assemblies with survived fuel elements
17 – Edge of "OP"(OR) component
18 – Southern additional support
19 –Fragments of fuel assemblies
20 – Western wall of Room #305/2
21 – FCM (break in the wall)
22- Graphite blocks and tube fragments (process channels?)
23 – Gravel pile;
24,25,27 – Breaches in the wall from re-melted substance
26 – Burned area in the wall
28 - Column
29 – Wall of a loose re-melted substance
30 – Projection of tank "L" to +15.950 level mark

Figure 6. Location of constructions and FCM in Room #305/2.

Accumulation #5 - component "OR" and debris behind it. Expected FCM type: fuel assemblies (no less than 50 pieces), LFCM.

Accumulation #6 - so-called "stalagmite" – a solidified LFCM accumulation generated in the area of the upper part of the large reinforced-concrete plate. Coordinates: 46, M; level mark – +16.000.

Accumulation #7 -the least-studied northeastern area of Room #305/2. Boundaries: area under "OR" component and the stalagmite. Coordinates: $46_{-2000}/47_{-1000}$, L/M, level mark +9.70. LFCM presence is possible.

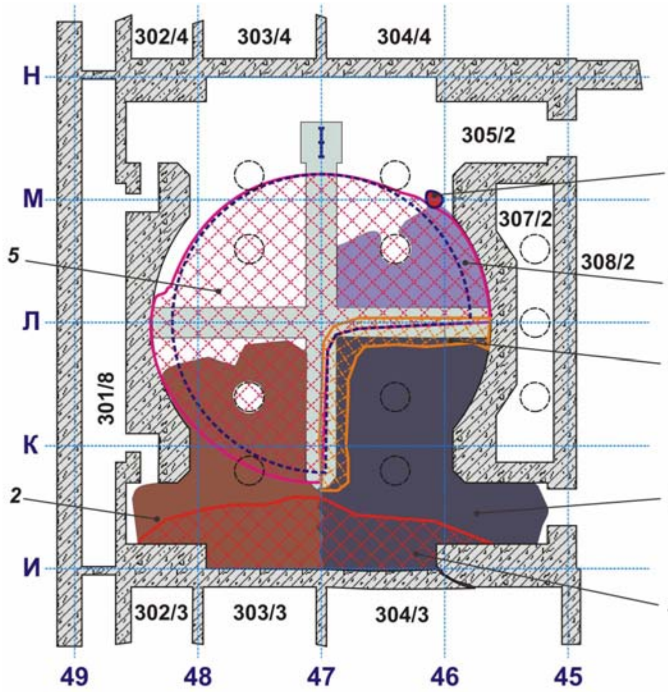


Figure 7. Scheme of FCM congestions location in room 305/2.

In this report a generalized table taken from Reference [1] is used (Table 1).

Table 1. Expert assessments of FCM distribution over room 305/2.

Room	Accumulation, level marks	Brief characteristic of FCM in accumulation	FCM volume, m^3	Fuel amount (U), t
305/2	**#1,** Level mark +9.000 – +11.500	Black and brown ceramics, possibly core fragments	150 ÷ 190	20 ± 3
	#2, Level mark +9.000 – +12.000	Brown ceramics, possibly core fragments	100 ÷ 180	33 ± 8
	#3, Level mark +11.000 – +14.000	LFCM, initial lava components, core fragments	9 ÷ 26	6 ± 4
305/2 and 504/2	**#4,** Level mark +11.000 – +16.500	Loose FCM	50 ÷ 60	5 ± 2
	#5, Level mark +12.000 – +24.000	LFCM, initial lava components, core fragments	70 ÷ 110	19 ± 7
	#6, Level mark +16.000 – +24.000	Stalagmite - LFCM	~ 0.7	0.12
305/2	**#7,** Level mark +9.700	LFCM ?	up to 20 (?)	up to 1.5 (?)

Thus the total FCM volume makes up 380 - 580 m^3.
Fuel amount contained in FCM is estimated at (85 ± 25) t (U).

4. Half an Hour after the Accident

4.1. Status of Constructions

A reconstruction of the view of destructions in the reactor vault and the under-reactor room by the beginning of the second accident phase is demonstrated in Fig. 8. Our subsequent analysis will be based on this figure.

In addition, two viewed-from-above fragments of the reactor vault at +27.000 level mark (Fig. 9) and at +16.000 level mark (Fig. 10) are presented.

Component “OR” descended by ~ 3.8 m. Its southeastern quadrant - ¼ OR (point *12* at Fig. 8) broke off and lowered below the rest of the component - ¾ OR (point *4* at Fig. 8). The latter assumption follows from the fact that at a later time the quadrant in question was entirely melt, and the materials of ¼ OR became lava components. At the same time, despite appreciable damages visible in the break zone, the constructions of ¾ OR were destroyed considerably less

The constructions of “C” component (point *2* at Fig. 8) were crushed by the descended “OR”.

Many BWC tubes were also crushed and pressed to the concrete plate of Room #305/2’s floor (point *5* at Fig. 8).

The major portion of serpentinite of the inter-compensatory gap spilled into the annular gap between the descended “OR” component and semicircular western and eastern walls of Room #305/2 or was thrown by the explosion to the northern and the southern areas of that room.

Sand from the area between “L” tank (point *14* at Fig. 8) and the reactor vault walls spilled to the southern part of Room #305/2.

The area above “OR” component was filled with graphite blocks, damaged fuel assemblies & fuel elements and fragments of process channels up to about +17.000 - +18.000 level marks (point *3* at Fig. 8).

On “OR” top large amounts of debris of building constructions are found above core fragments (point *15* at Fig.8).

The explosion threw fragments of constructions to the southern part of the room, and they now lie on core fragments and BWC tubes.

The reactor shell (“KZh” component) is destroyed. The bottom fragment of reactor shell - “KZh” crimp of about 1.5 m in height still remains in the northern part on “OR” component. There is a probability that in the southwestern section the bottom fragment of “KZh” crimp was attached to the inner surface of “L” tank.

BWC tube bends issuing from OR bottom are fully crushed. The upper ends of two steam bleeder valves are virtually choked up with the above BWC elements. Diaphragms of all steam bleeder valves under Room #305/2 are plucked.

Rolling gates are torn out from their standard place.

The wall separating Rooms #304/3 and #305/2 is arched towards Room #304/3 and cracked; at some spots in Room #304/2 the outer layer of concrete was spilled, and the reinforcement is bared. The upper wall fragment is destroyed and inclined towards Room #305/2, the maximum inclination being about 5°. Concrete of the bottom part of wall is shattered.

The northern (point *6* at Fig. 8) and the southern additional supports still remain in normal vertical position.

The biological shield tank ("L" component) has no considerable damages (there are, possibly, dents and a crack in the bottom southeastern part on the inner surface of "L" component). The bottom part of "L" component's compartments is still filled with water.

4.2. Types and Amounts of Materials Involved into Lava-generation Processes

Fuel Involved into Lava Generation

As indicated above, (85 ± 25) t of fuel (U) remained in Room #305/2 after the second accident phase completion.

However far of the whole of that fuel was incorporated into LFCM. Such a fact is deduced from description of individual accumulations. A considerable portion of fuel remained in the room in the core fragment's form.

On the other hand, during the second accident phase a portion of fuel (as a lava component) moved from Room #305/2 to lower level marks of the Unit (Fig. 11).

For the second phase reconstruction purposes we are mostly **interested in the fuel involved into lava-generation processes** in Room #305/2 and in the reactor vault, i.e. full amount of uranium contained currently **in lava** of the under-reactor rooms.

Such-type estimates were performed using several methods and then generalized in References [1 – 3] and [6].

According to those estimates, the unified space of rooms #305/2 and #504/2 housed (120 ± 45) t of fuel (U), and **the integral fuel amount in LFCM of all under-reactor room makes up (90 ± 30) t.**

In our subsequent analysis the following average data will be used: 120 t and 90 t.

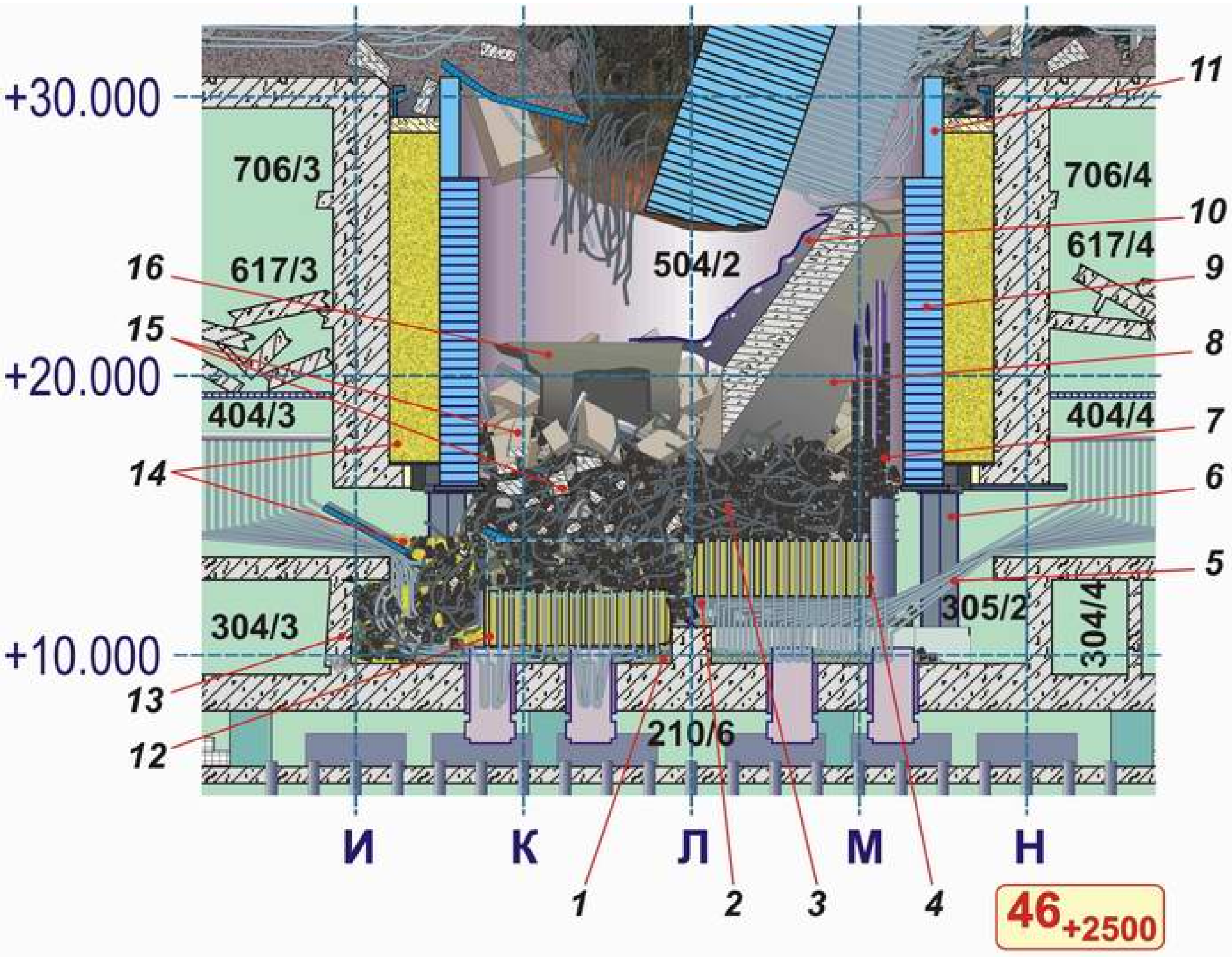
Zirconium Involved into Lava Generation

As a constructional material, RBMK had 103 t of Zr (admixture of Nb up to 2.5%) used in channels and 74 t of Zr (admixture of Nb up to 1 %) used in fuel elements. According to chemical analysis data, LFCM contains 45 t of zirconium [1 – 3].

Graphite Located on "OR" Component and Burnt during Lava Generation

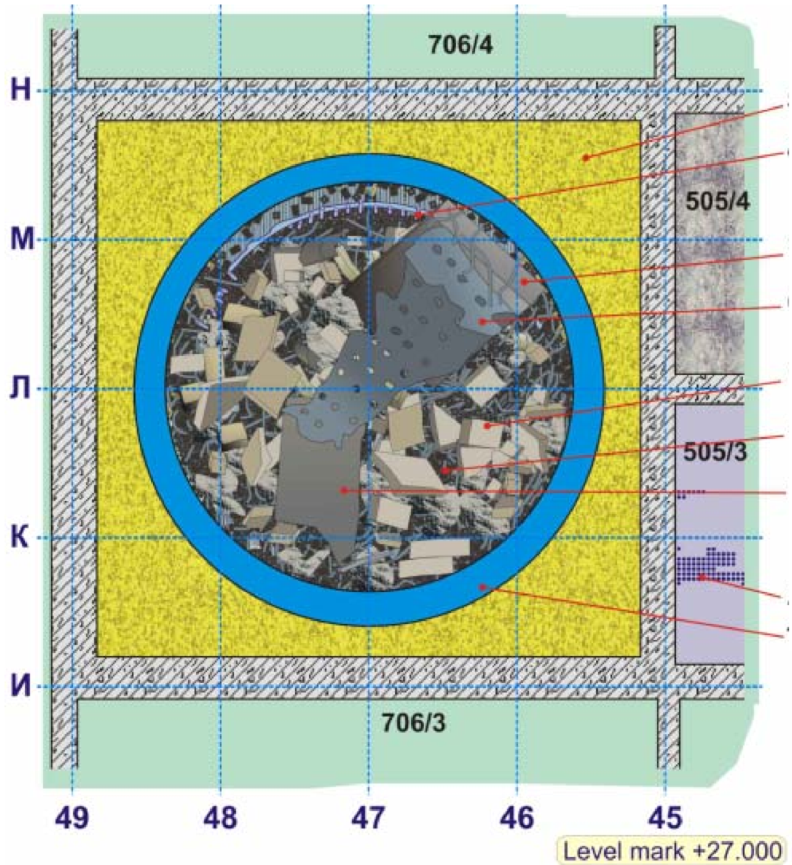
The graphite stack consisted of 2488 vertical columns assembled of 250×250 mm blocks of 1.65 g/cm^3 density. The integral stack mass equaled 1500 t.

Note that, if steel blocks are visually observed on 30% of the survived channels located on "E" component, virtually no graphite blocks are found on the channels. To a first approximation, one can expect that at least 30% of the graphite stack were ejected into the under-roof area. The rest of graphite blocks in the reactor area was partly broken to pieces by the explosion and ejected to the central hall. Small-size fragments and dust could have burnt during early minutes of the accident in the very reactor vault. Thus the amount of graphite remaining within the unified area of rooms #504/2 and #305/2 half an hour after the accident onset could be estimated at about **750 t** (50% of the graphite stack mass).



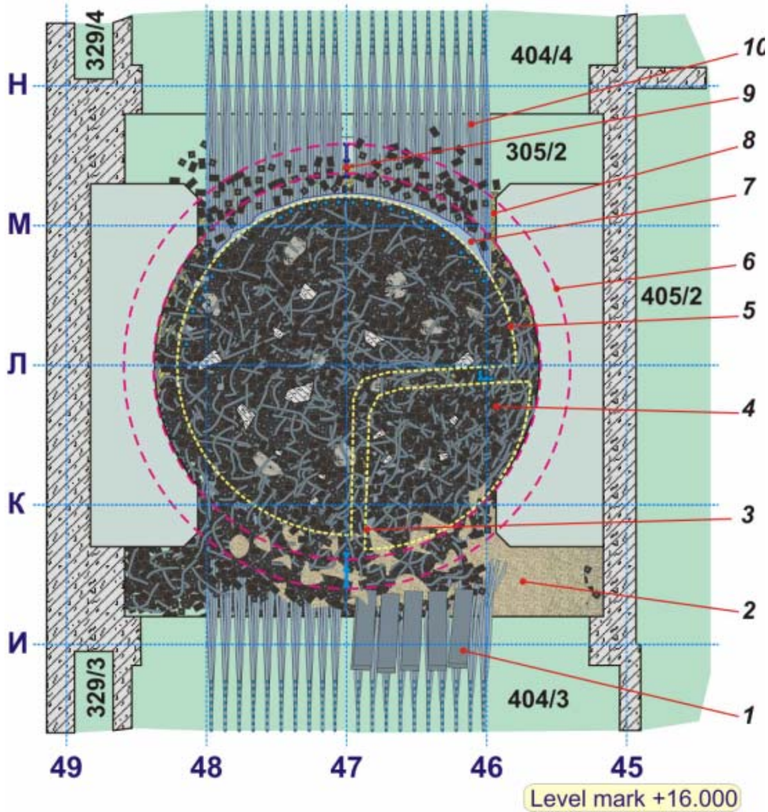
1 - Serpentinite of both “OR” component and the inter-compensatory gap
2 - Crushed “C” component (“Cross”)
3 - Fuel, fuel assemblies, fuel elements, process channels, graphite blocks, fragmented concrete
4 - ¾ OR
5 - BWC tubes
6 - Additional support
7 - Reflector (channels and graphite blocks)
8 - Reinforced-concrete plate (fragments of wall of separator box)
9 - “L” tank
10 - Heat shielding lining of separator box’s wall
11 - “D” tank
12 - ¼ OR
13 - Damaged wall
14 - Vault’s filling-up-origin sand
15 - Debris of reinforced-concrete constructions
16 - Fragment of reinforced-concrete construction

Figure 8. Sectional view of reactor vault and room #305/2 half an hour after the explosion.



1- "Л" tank
2 – Fuel assemblies in the southern cooling pond
3 – Fragment of reinforced-concrete construction
4 - Fuel, fuel assemblies, fuel elements, process channels, graphite blocks, fragmented concrete
5 - Debris of reinforced-concrete constructions
6 - Heat shielding lining of separator box's wall
7 - Reinforced-concrete plate (fragments of wall of separator box)
8 – Reflector's channels
9 – Sandy-gravel filling up material

Figure 9. Fragment of Chernobyl NPP Unit 4: view from above at +27.000 level mark (reactor vault) 30 minutes after the explosion.



1 - panels (BWC attachment points)
2 - Vault's filling-up-origin sand
3 - ¼ OP
4 - Fuel, fuel assemblies, fuel elements, process channels, graphite blocks, fragmented concrete
5 - ¾ OP.
6 – "Л" tank projection
7 – Survived fragment of "КЖ" component on "OP" component
8 - Serpentinite from the inter-compensatory gap
9 – Additional support of BWC tube

Figure 10. Fragment of Chernobyl NPP Unit 4: view from above at +16.000 level mark (reactor vault) 30 minutes after the explosion (a section over the bottom edge of "Л" tank, level mark +15.950).

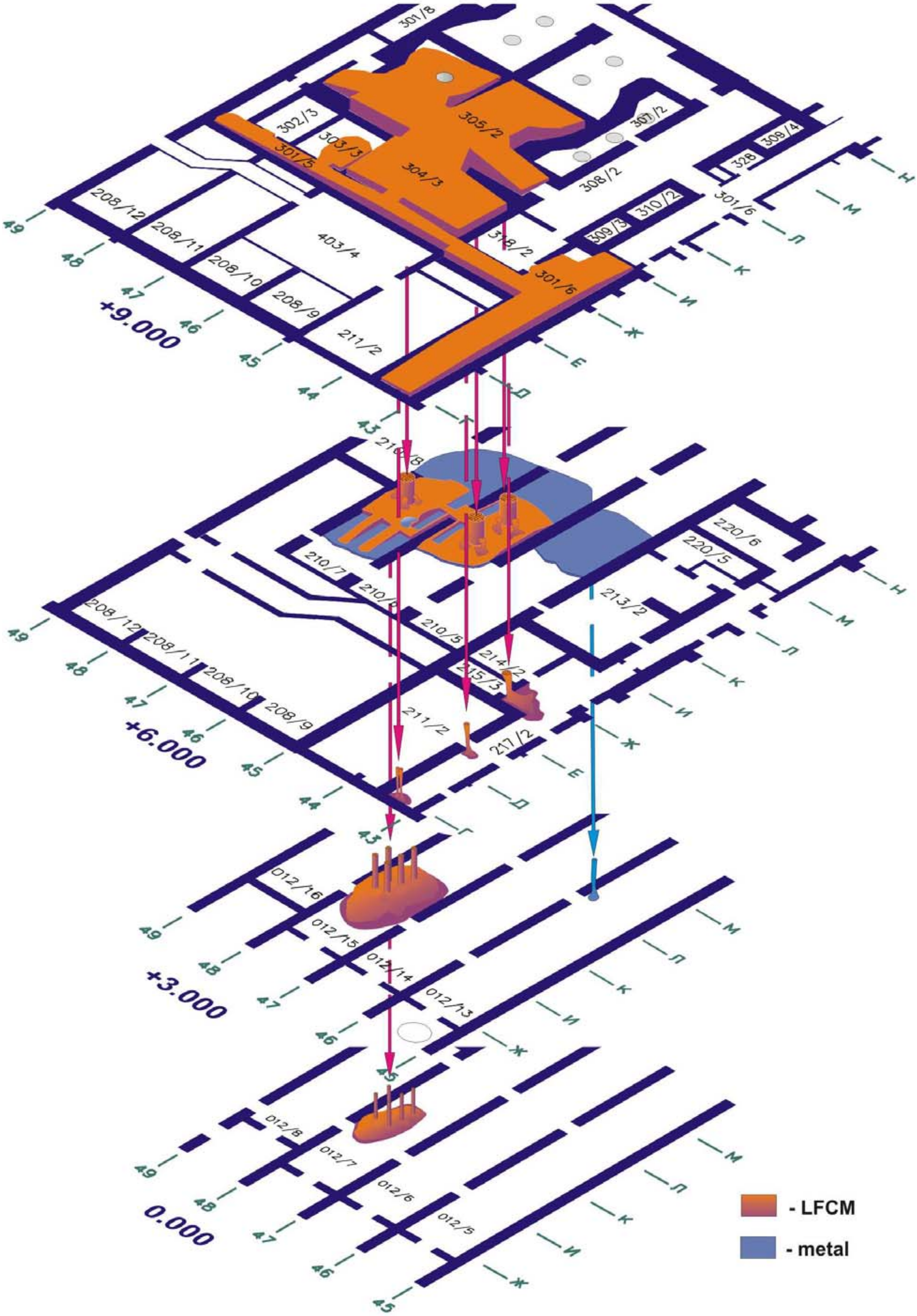


Figure 11. Spreading of LFCM flows over Unit 4 under-reactor rooms.

Materials of "OR" Component Incorporated into LFCM

"OR" component (more precisely, its south-eastern quadrant) was the main "building material" during lava generation, and thus its constituting materials merit a special consideration. Before the accident "OR" component represented a wide cylinder 14500 mm in diameter and 2000 mm in height with two lids (the upper lid and the bottom lid) connected in between by stiffening ribs and BWC tubes. The area between the lids was filled with serpentinite mixture (waste of asbestos-concentration plants) - Fig. 12.

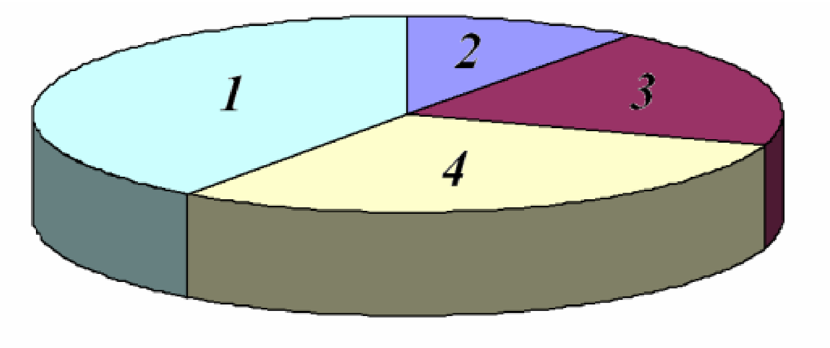


Figure 12. Materials of "OR" component.

1 - Steel 10XH1M – 500 t
2 - Steel OX18H10T – 200 t
3 – Black steel – 230 t
4 - Serpentinite mixture – 410 t

In total: 1340 t

Serpentinite is a water silicate of magnesium of the following composition (Mg_6 Si_4 O_{10}) $(OH)_8$. According to the design documentation, the filling-up serpentinite has the following element composition:

SiO_2 – (32 – 40) %	Fe_2O_3 – (3 – 8,5) %	CrO_3 – (0,3 – 2,4) %
MgO – (43 – 45) %	FeO – (0,2 – 2,0) %	Al_2O_3 – (0,6 – 3,5) %

Serpentinite mixture is a mixture consisting of serpentinite broken stones and sand (fraction sizes are 20 mm and up to 3 mm, accordingly) at mass ration 1 : 2 at maximum density 1.7 t/m^3. [8].

As indicated above, lava incorporated only "OR" materials located within the melted sector, i.e., 1/4 part of materials of "OR" component including:

- steel 10XH1M – **125 t**;
- steel OX18H10T – **50 t**;
- black steel – **57 t**;
- serpentinite mixture – **103 t**.

Serpentinite Mixture of the Compensatory Gap

The compensatory gap between the outer generatrix of "OR" component and "L" tank was filed with a serpentinite mixture of the same composition as "OR" itself. Because the compensatory gap was about 75 m^3 in volume, it contained ~ 130 t of serpentinite mixture. About one half of that amount – i.e. **60 t** - could have been incorporated into LFCM.

Steel Blocks

Steel blocks confined the graphite stack from above and from below. The bottom blocks (above "OR") were 250×250 in size and 100-250 mm in width [8]. According to [9], the mean width of the block's layer equaled 200 mm. The integral mass of the blocks was about 200 t.

From above, under "E" component, steel blocks of 250×250×250 mm were arranged. The integral mass of those blocks was ~260 t.

About 25% of the bottom block layer (bearings), i.e. **50 tons,** were involved into the lava-generation process.

Most of the upper-layer steel blocks must have dropped into the reactor vault, because the destruction of the major portion of process channels occurred in the area of their connection with the reactor upper head. According to the results of visual observations, about 70% of process channels and cooling channels are currently missing in “E” component. Taking into account those data, one may assume that at the thirtieth minute of the accident ~ 60% of blocks (~160 t) located in the reactor vault above “OR”component. About 1/4 of that amount, i. e. ~**40 t,** were involved into the lava-generation process.

BWC Tubes and Other Communications of the Reactor Bottom

BWC tubes (∅57×3.5 mm) and u-bends - steeply curved bends that issued from “OR” bottom (∅60×5 mm) – were made of OX18H10T-grade steel.

There were 1693 working channels, i.e., about 423 channels per ¼ OR. The mean u-bend length was ~4 m. The mean length of BWC tubes located in the immediate vicinity of the room’s floor and melted during the accident (the south-eastern sector) equaled ~ 6 m.

Obviously, in the southeastern sector those constructions were melted, their materials being partly incorporated into LFCM.

Thus in the southeastern quadrant of Room #305 ~12 t of BWC tubes were melted in the course of the accident.

Taking into account the available data [1-3, 6], about 6 t of BWC tubes could have melted in the southwestern quadrant.

The integral amount of materials of reactor bottom communications (including supply manifolds, drainages, etc.) melted during the accident can be estimated at **20 t** (OX18H10T-grade steel).

Materials of “C” Component

“C” component served as a support for “OR” component.

The bottom part of “C” component bore on embedded items of the building basement at +11.000 level mark. It was assembled of beams – rests ~5000 mm in height – arranged over two reciprocally perpendicular planes in the shape of a cross. The upper end of “C” component had lugs and was adjusted to the bottom plate of "OR” component over the contact area.

All details of “C” component were made of 10ХСНД-grade steel.

According to visual observations, “C” component was crushed but its elements were not melted.

Heat Shielding and Cooling System of Building Constructions

The walls and the floor of Room #305/2 were provided with a heat shielding ~300 mm in width – heat-insulating plates “ПП” of spinneret synthetic wadding. Heat insulation was lined with 12X21H5T-grade steel 10 mm in width. There was a reinforced cement belt 45 mm in width under the heat-insulating layer wherein cooling system’s tubes of building structures (Steel #20, ∅34×4 mm) were arranged with 250-700 mm spacing.

The integral area of melted metal liner can be estimated at ~140 м^2, whereas the tube melting area at ~100 m^2.

Thus, the mass of melted liner is equal to ~**10 t** and that of tubes of building constructions’ cooling system to ~**0.5 t**.

Concrete of the Under-reactor Plate and Walls of Room #305/2

Rather roughly, the amount of destroyed and melted concrete can be estimated using, mainly, the results of drilling operations [1, 2].

The area of FCM spreading in the southeastern room’s sector makes up 80-96 m^2, the bottom boundary of FCM location being recorded at +9.000 – +9.100 level marks.

The estimates of References [1, 2] allow suggesting that the area of intense destruction and melting of concrete for ~0.5 m depth makes up 80 m^2.

Thus, at a density of 2.2 t/m^3, the mass of destroyed and next melted concrete equals 90 t.

The area of FCM spreading in the southwestern room's sector equals 60-92 m^2, the bottom boundary of FCM location being recorded at +9.000 – +9.200 level marks.

The area of intense concrete melting for ~0.5 m depth equals 40 m^2.

Thus the mass of destroyed and subsequently melted concrete equals 40 t.

Obviously, under LFCM layer destroyed concrete is located which width can be estimated at ~0.3 m. Thus the mass of this layer is about 80 t.

Therefore, according to our estimates, the mass of destroyed concrete made up 210 t, of which **130 t** were involved into lava generation processes.

Sand from the Area between "L" Tank and Reactor Vault Walls

According to visual observations, a "gravel" pile is found in Room #305/2 just opposite the southern rolling gate originated, most likely, from filling material spilled from the area between "L" tank and reactor vault walls (vault's filling material). According to References [8, 9], such an area is normally filled with mortar sand 1.3 t/m^3 in density.

We assume that that sand could have formed a pile of 40-60 m^3 in Room #305/2 opposite to southern rolling gate in the area of axes 45 – 46_{+3000}. It is also expected that most of the pile's materials - about **30 t** of sand – was melted and incorporated into LFCM.

Plate Floor

Elements of the central part of the plate floor were filled with Iron-Baric-Serpentinite Cement Stones (IBSCS). The peripheral area of the plate floor represented boxes filled with a serpentinite mixture [9] or with IBSCS [8]. Almost the whole of peripheral area of the plate floor is beyond the reactor space projection. Most likely, the central area's blocks were not involved into lava-generation processes; however, a portion of them could have "spilled" into the northwestern reactor space area. Thus the probability of involvement of the considered materials into the lava-generation process is rather low.

Based on the above data, a preliminary estimate of the amount of materials involved into lava generation and located in the reactor vault and Room #305/2 by the second accident phase beginning can be made (Table 2).

Table 2. Materials involved into lava formation processes (preliminary estimate).

Material	Total mass, t	Mass of contained silicon, t
Fuel (U)	90	-
Steel	350*	-
Serpentinite mixture	160	53
Concrete of under-reactor plate	130	48
Reactor vault filling sand	30	12

* In total LFCM can contain 20 t of iron at the most

From Table 2 it follows that there was an excess of steel for generation of the whole of LFCM [3].

According to data of Reference [3] the whole of LFCM of Unit 4 contains ~ 390 t of silicon[1].

Silicon concentration in serpentinite mixture is about 33%, in sand – 40% and in concrete – 37%. There are 113 t of silicon in the materials listed in Table 2.

Thus, to observe the balance on silicon, one additionally needs 750 t of concrete (that could have only come there from CH) or 690 t of the vault's filling sand, i.e., the integral mass of sand of the vault filling material that reached Room 305/2 must have been 720 t.

It is obvious that LFCM incorporated both concrete of constructions dropped into reactor vault from CH and sand of the vault filling-origin.

Let us assume that debris of building constructions and concrete fragments attained the reactor vault in a quantity equaling 4 fragments of box-separator's walls 9×6×2 in size (point *8* at Fig. 8). In such a case that concrete 430 m^3 in volume and 950 t in mass could have taken (with 50% fill factor) an area above "OR" of about 5 m in height (Fig. 8).

Let us consider that one half of the whole mass of concrete was involved into lava generation providing the lava with ~180 t of silicon. Only sand of the vault's filling material (about 280 t) could have been a source of the rest of silicon (110 t), i.e. ~10% of the whole sand mass in the vault's filing material. Thus the presence of ~300 t of sand in the southern part of Room #305/2 at the second accident phase beginning could have been a quite probable event.

A summary estimate is demonstrated in Table 3.

Table 3. Materials presented in the reactor vault and in room #305/2 at the beginning of the second accident phase.

Material	Amount in rooms #504/2* and #305/2, t	Incorporated into LFCM, t
Fuel (U)	120	90
Steel	1300**	< 20***
Serpentinite mixture	580	160
Concrete of the under-reactor plate	-	130
Concrete of building constructions dropped into the vault from upper level marks	950	480
Sand of the vault's filling material	300	280
Zirconium	?	45
Graphite	750	?****

* within the reactor space boundaries;
** excepting materials of "C" component and non-melted communications of the reactor bottom;
*** 330 t melt and spread over the under-reactor rooms;
**** an insignificant admixture was discovered.

[1] LFCM-generation scenario and silicon balance are considered in detail in Reference [3].

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