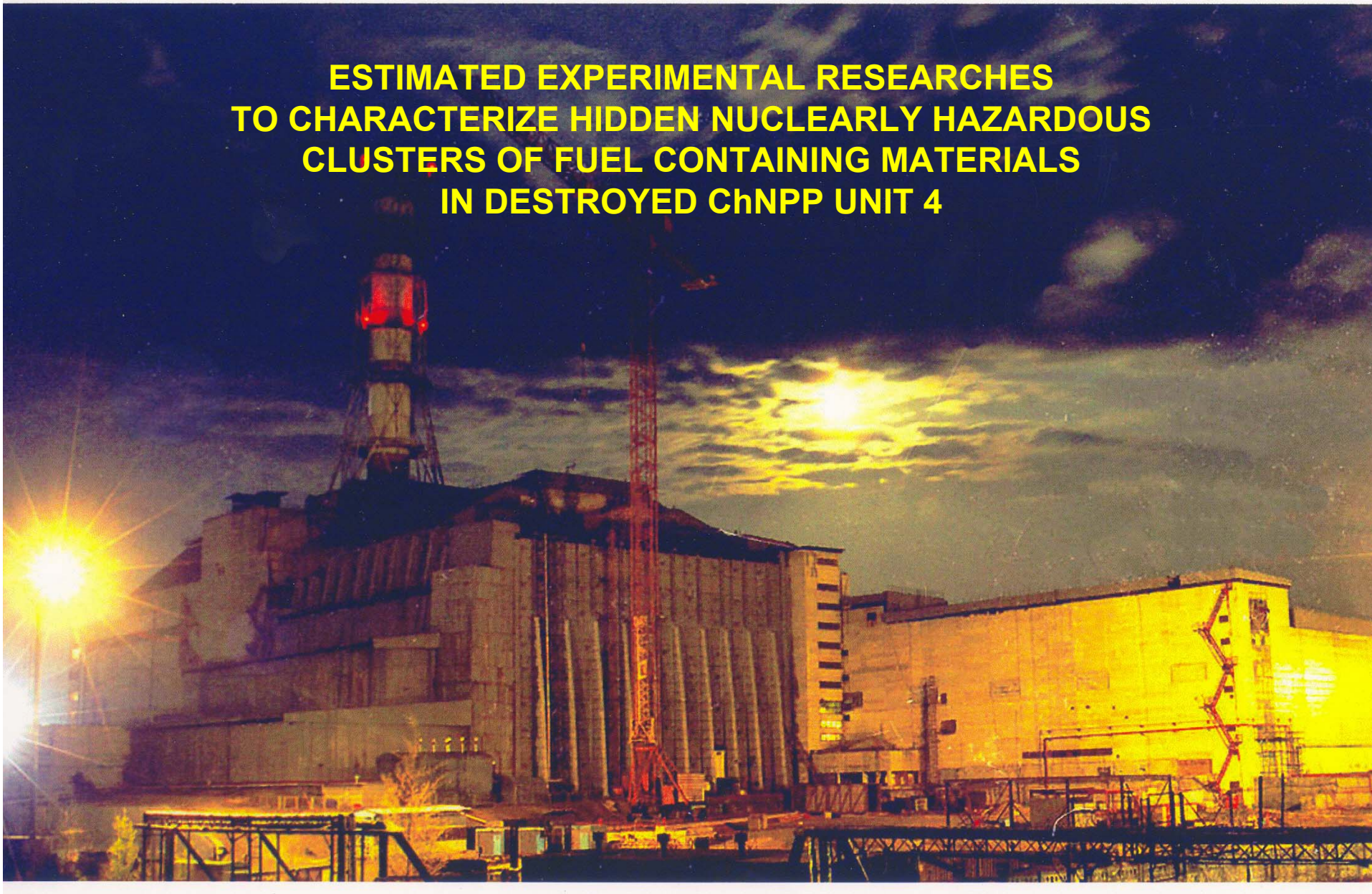
ESTIMATED EXPERIMENTAL RESEARCHES TO CHARACTERIZE HIDDEN NUCLEARLY HAZARDOUS CLUSTERS OF FUEL CONTAINING MATERIALS IN DESTROYED ChNPP UNIT 4



UNAS Cor. Memb. TSD Klyuchnykov O.O., PMSC- Shcherbin V.M.,
TSD - E.M. Pazukhin, TSC - Vysotskiy E.D, V.O. Krasnov

Institute for safety problems of NPPs
National Academy of sciences of Ukraine
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Institute for safety problems of nuclear power plants of Ukraine's NAS (ISP NPP) carries out fundamental and applied researches in area of nuclear and radiation safety of "Shelter" Object since year of 1986, as well as of operating Ukrainian NPPs.

Institute incorporates seven divisions as regards:

- division of nuclear and radiation safety;

- division of measuring and diagnostic systems;

- division of radiation technologies, material sciences and ecological researches;

- division for designing objects with radiation and nuclear technologies;

- division of atomic power engineering;

- division of NPP decommission;

- division of safe NPP operation.

Three divisions are incorporated in Interdisciplinary Scientific and Technical Center – ISTC "Shelter" and located in town of Chornobyl.

PREFACE

On April 26, 1986, a most global technogenic accident occurred at RBMK-1000 reactor of Chornobyl Nuclear Power Plant Unit 4.

As result of reactor core destruction around (25-50) · 106 Ki activity was fallen out into atmosphere.

Approximately 180 t nuclear fuel being in form of reactor core fragments, diverse types of fuel containing materials, radioactive fuel dust (Table 1), remained inside the destroyed Unit.

Unit building structures ((a), (b), Fig. 1, 2) were subject to a significant destruction.

Protective structure (Fig. 3) called as “Shelter” Object (“Sarcophagus”) was erected on building structures, which remained intact after destruction.

a)

b)

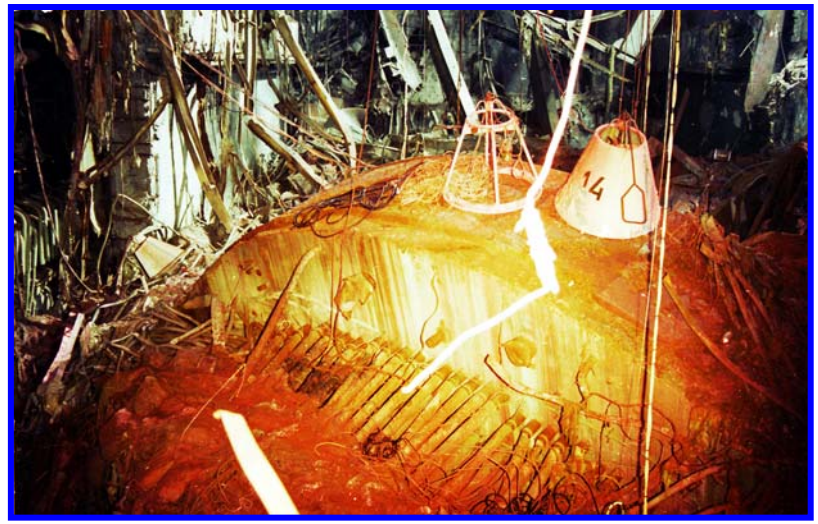


Table 1 – Fuel amount estimate in "Shelter" Object premises

Title (number) of premises	LTCM modifications	Fuel amount, t (U) (2006 y. estimates)	Notes
CH (914/2)	ACF	more 21	Considering 48 fresh fuel assemblies – - around (5,5 t). LTCM presence is probable
Southern cooling pond (505/3)	ACF	14,8	129 OFA. LTCM presence is probable
All upper premises, including CH (mark +24.00 and above)	Fuel dust	~5 on obstruction surface in CH, All ~ 30	Estimate of 30 t considers surface pollution inside obstruction in CH and in all other premises
304/3	LTCM	6 ± 2	«Horizontal lava flow». Considering LTCM in breach between premises 304/3 and 305/2
301/5+301/6+303/3	LTCM	4,5 ± 2,5	«Horizontal lava flow»
217/2	LTCM	0,4 ± 0,2	«Elephant foot», «stalactite». LTCM came from horizontal flow»
Subapparatus premises 305/2 and 504/2 on mark +24.00 m	ACF, LTCM, fuel dust	85 ± 25	Estimates are made on six LTCM clusters
SDC (210/5+210/6+210/7)	LTCM	12 ± 6	«Big vertical flow» and «small vertical flow»
PSP-2 (012/14+012/15+012/16)	LTCM	Minimum – 3 maximum - 14	
PSP-1 (012/5+012/6+012/7)	LTCM	1,0 (+1,0; -0,5)	

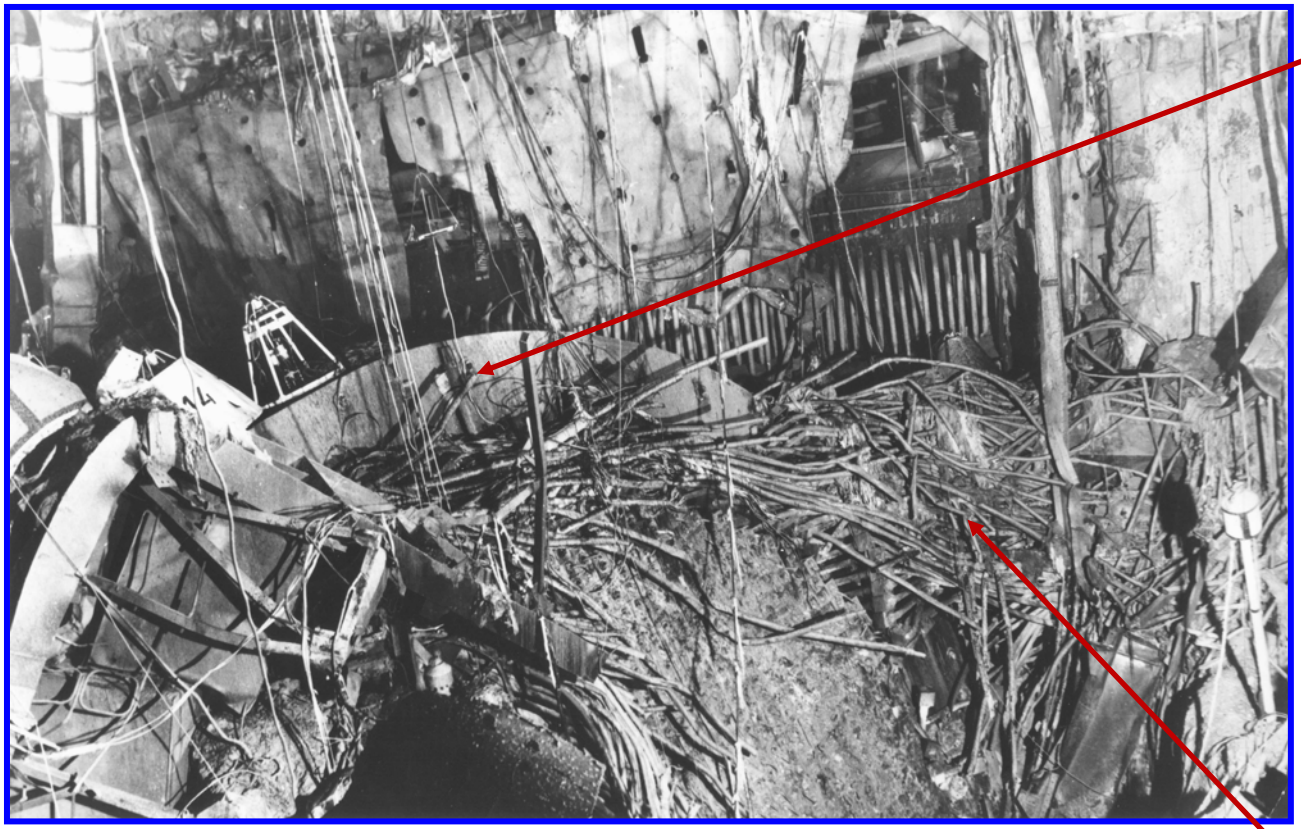
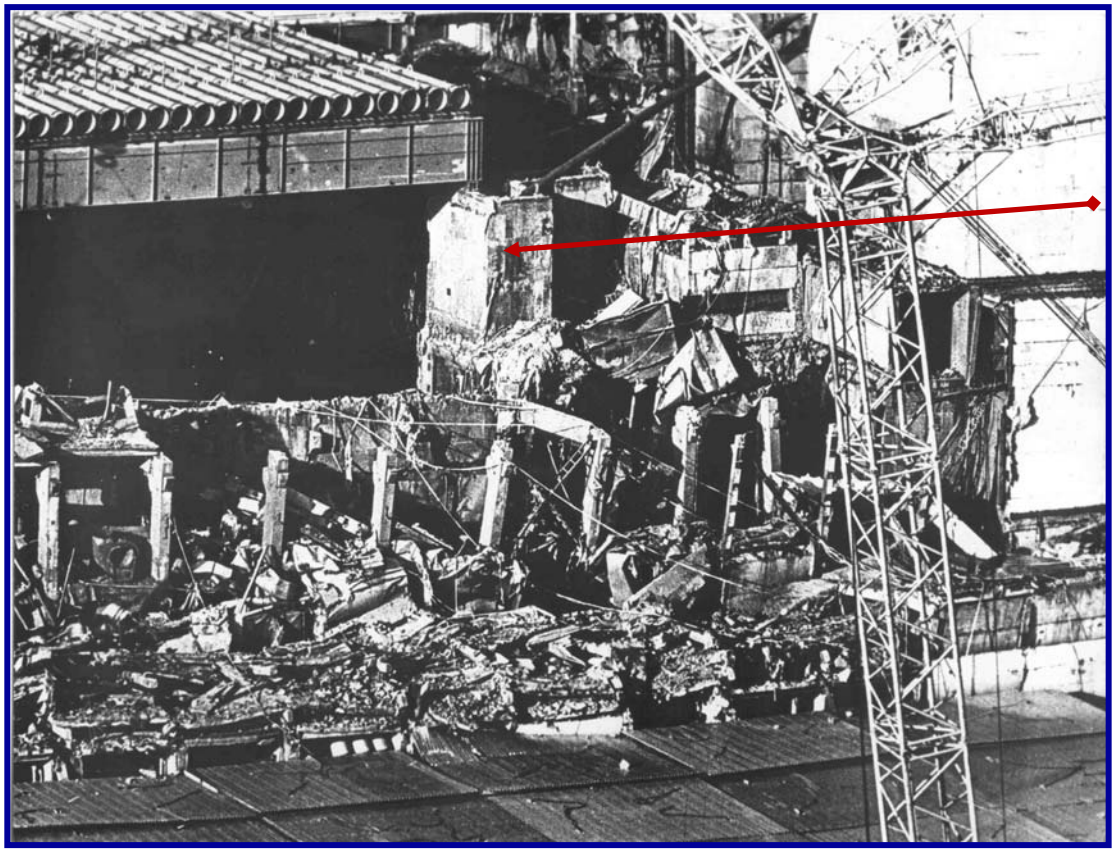


Figure 1- Destructions in ChNPP Unit 4 Central Hall.



Remained intact building structure fragments, on which protective edifice «Shelter» object («Sarcophagus») was erected

Figure 2 - Destructions in ChNPP Unit 4 southern part

Figure 3 - Actual view of protective edifice - «Shelter» object after performed works for western fragment stabilization

Producing lava-like fuel containing materials.

Origination of Chornobyl lava-like fuel containing materials (LTCM) can be split into two main stages:

First stage - Reactor core is still hermetic.

1. Abrupt and very big splash of neutron flow value bringing to abrupt increase of steam content in coolant, which is located in zirconium fuel channels (FC) of graphite cladding of reactor core (RC).

2. Steam content increase in FC leads to change of cooling regime of fuel assemblies.

3. Abrupt (during some seconds) temperature increase of FR (fuel rod) walls from normal value 295/325 ^{0}C (inside/outside) to maximum temperature in fuel pellet center (2100 ^{0}C).

4. Destruction of fuel rods, start of steam zirconium reaction with emanation of big heat amount:

$Zr + 2\ H_2O \rightarrow ZrO_2 + 2\ H_2 \uparrow + [\ 7760 + 1{,}15 \cdot (To - 2000\ ^0C)]$ J/g Zr.

5. Active solution of nuclear fuel in zirconium melt of FR pipes.

6. Breaking of big part of fuel channels with total pressure increase in AC and throw out of reactor upper lid (sch. E) to Central Hall.

Second stage – Total depressurization of active core.

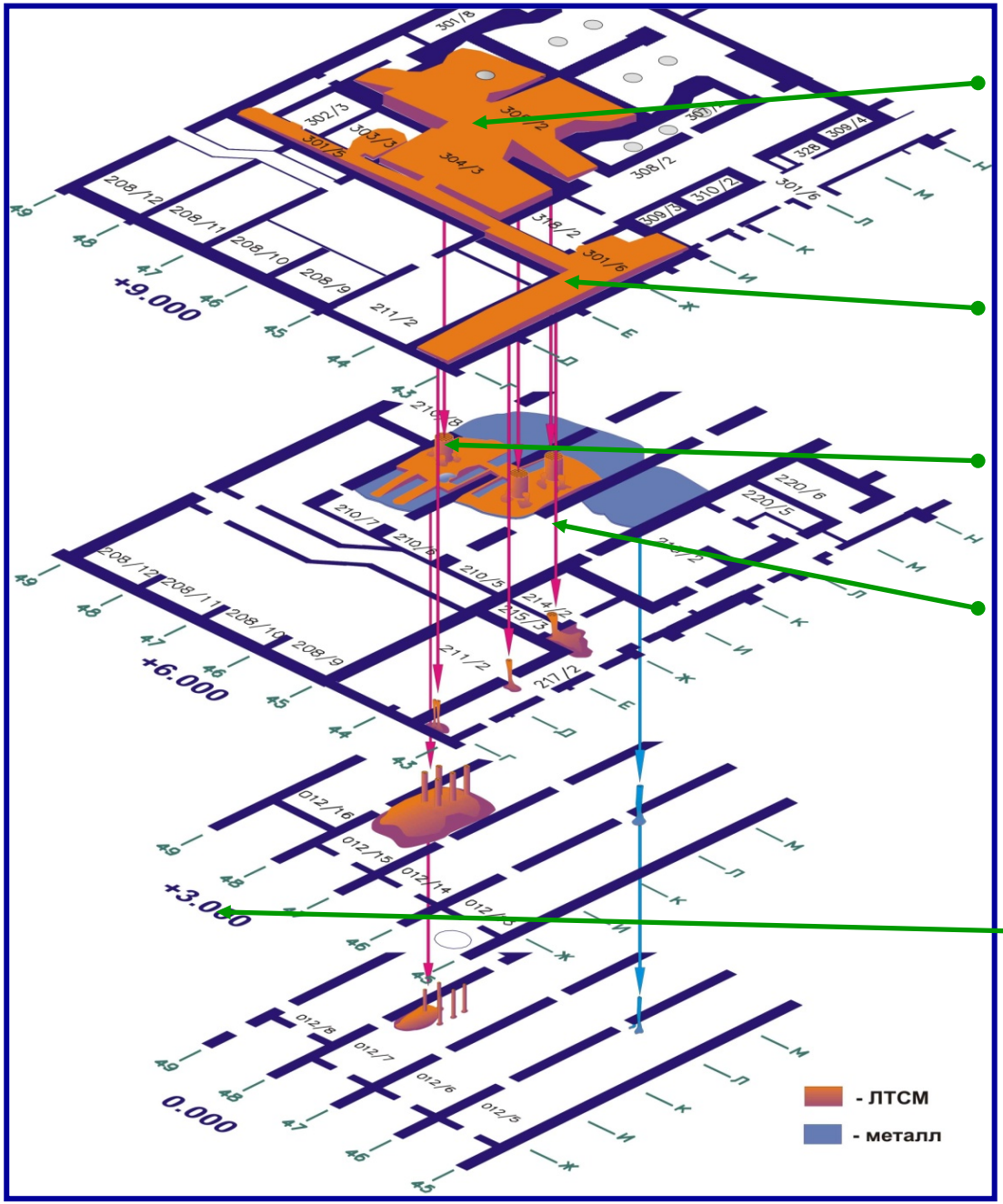
From premises 305/2 – LTCM spread by three flows (Fig .3):

1-st–big vertical – via steam discharging valves and steam discharging pipes passed from premises 305/2 via steam distributing corridor to first floor of pressure suppression pool, with producing there two clusters – on first and second floors.

2-nd–small vertical flow – reaches only premises of steam distributing corridor 210/6.

3-rd – big horizontal flow – via wall breach flew out from premises 305/2, passed along premises 304/3 floor, came to corridor 301/5 and turned first eastward – to corridor 301/6, and then – southward, producing in underlaying premises 217/2 a LTCM cluster (s.c. «elephant foot »).

Currently, element and radiochemical content of diverse Chornobyl lava modifications, (Table 2) different options their origination scenarios is seen.



Main process of lava-like fuel containing materials (LTCM) origination occurred in premises 305/2.
Further, LTCM spread by three basic flows

Horizontal LTCM flow

Big vertical LTCM flow

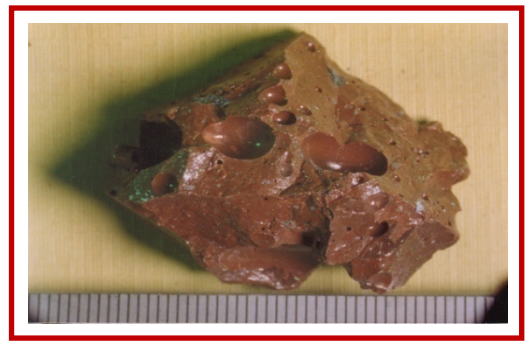
Small vertical LTCM flow

Height building marks (in meters)

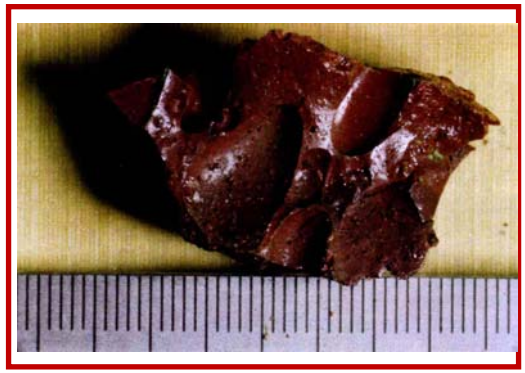
Figure 3 - Scheme of LTCM clusters production

Big vertical LTCM flow – via steam discharging valves and steam discharging pipes passed from premises 305/2 via steam distributing corridor to first floor of pressure suppression pool, with producing there two clusters: on first and second floors

LTCM cluster on first floor of pressure suppression pool (porous ceramics)

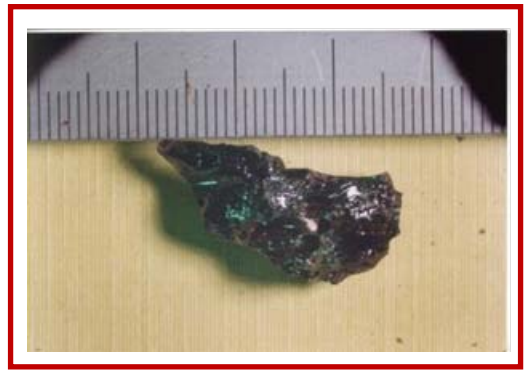


LTCM cluster on second floor of pressure suppression pool (brown ceramics)



LTCM cluster in premises 210/7 – steam distributing corridor (brown ceramics)

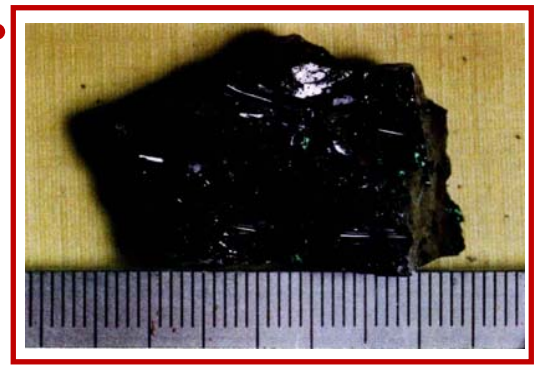
Small vertical LTCM flow –reached only steam distributing corridor premises and stiffened as a waterfall flowing out of steam discharging valve in premises 210/6



LTCM cluster in premises 210/6 – steam distributing corridor (black ceramics)

Horizontal LTCM flow – via a wall breach flew out of premises 305/2, spread along premises 304/3 floor, came out via torn off door hinge to corridor 301/5 and turned first eastward – to corridor 301/6, and thereafter – southward, with producing a cluster in premises 217/2, so called «elephant foot»

LTCM cluster (black ceramics) in premises 304/3



LTCM cluster in premises 217/2 - «elephant foot» (black ceramics)

Table 2 – Composition of diverse Chornobyl lava modifications

LTCM type	Main oxides, mass. %												
	SiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	CaO	Na_2O	TiO_2	ZrO_2	BaO	UO_2	MnO	Cr_2O_3	NiO
Black ceramics 304/3	70,6	7,4	0,25	0,23	3,9	6,7	6,2	0,21	5,8	0,13	4,3	1,9	0,30	$1,2 \cdot 10^{-3}$
Black ceramics 217/2	66,6	8,7	0,40	0,36	3,8	8,5	5,6	0,27	5,8	0,15	5,0	3,8	0,33	0,19
Black ceramics 210/6	62,1	7,2	2,91	2,63	5,1	6,0	5,2	0,19	5,5	0,18	5,8	0,40	0,40	0,39
Brown ceramics 210/7	64,0	6,8	0,64	0,57	7,0	6,7	5,4	0,24	6,6	0,19	9,4	0,53	0,39	0,36

Brief findings to introduction

1. As result of ChNPP Unit 4 accident, reactor RBMK-100 core was destroyed.

2. Availability of high temperatures brought to meltdown of reactor core fragments, debris of building structure, metal, reactor filling products and production of lava-like fuel containing materials – LTCM.

3. Melted LTCM, when spreading along destroyed ChNPP Unit 4 premises and when stiffening, produced the clusters of diverse content, volume and configuration.

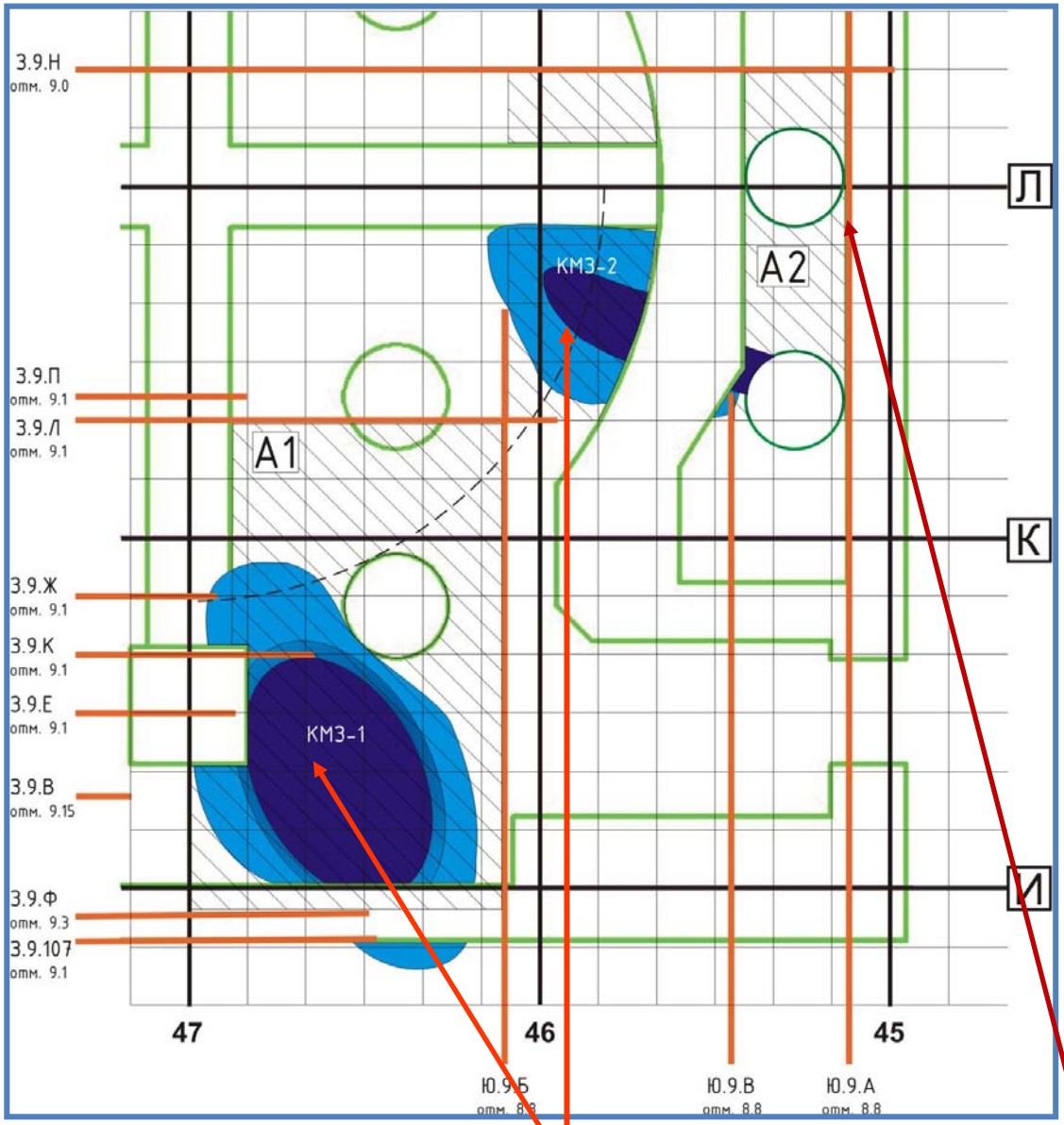
4. Major part of LTCM – open laying cluster are sufficiently well studied. Though, currently that clusters are considered as nuclearly and radiation hazardous, however, a possibility (being complicated enough) of access to them permits developing and realizing some preventive and shielding activities.

5. Another part of LTCM remained under obstructions destroyed Unit structures and «fresh» concrete during erection of new structures, is unreachable for direct researches and, therefore, is the most dangerous.

The last time, we succeeded in detecting such hidden LTCM clusters, to which ones will be dedicated this presentation.

ESTIMATED AND EXPERIMENTAL RESEARCHES TO CHARACTERIZE HIDDEN NUCLEARLY HAZARDOUS CLUSTERS OF FUEL CONTAINING MATERIALS OF DESTROYED ChNPP UNIT 4

1. Drilling works



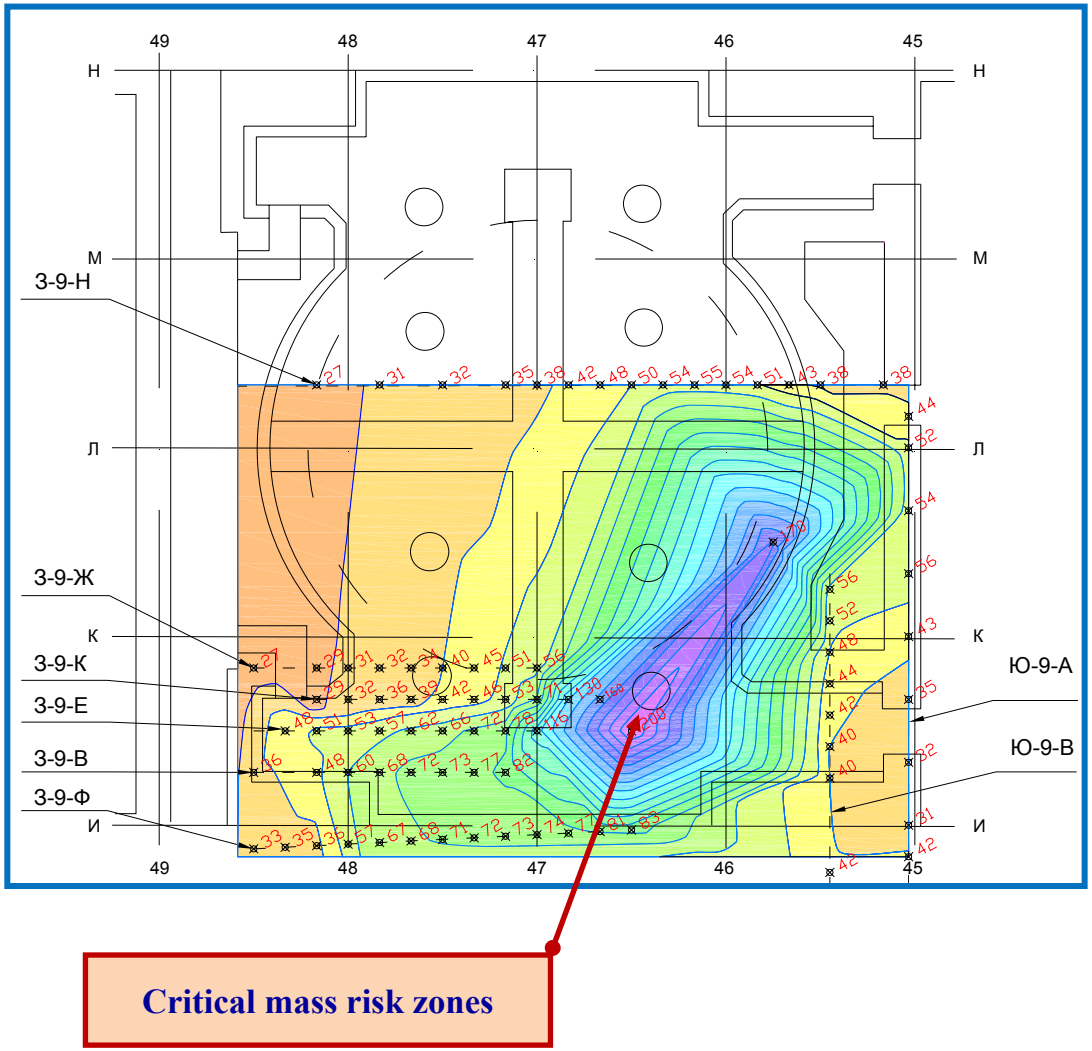
Drilling boreholes in direction to premises 305/2 were carried out in 1987-1990 with the aim to identify LTCN layout boundaries. Drilling process was stopped, when the activity of withdrawn cores testified the fact, that drilling tool entered a LTCM cluster with high fuel content.

Considering the above, one should assume that bottom holes of such boreholes, which were not drilled to the end (З.9.П, З.9.Ж, З.9К, З.9.Е), reached the boundaries of LTCM clusters with high fuel content hidden under the concrete.

Critical mass risk zones

Drill boreholes

2. Heat measurements



Another evidence of existence of critical mass risk zones in premisesи 305/2 became temperature field analysis in this area, measured in the year of 1987.
Temperature fields (Fig. 6) indicated the presence of heat emanation sources in separate parts of subreactor plate.
Measurements of heat flows enabled making approximate evaluation of fuel amount within the area of clusters (around 50 tons uranium).
Currently, temperature within the area of cluster located in south-east part of premises 305/ 2 exceeds the temperature on subreactor plate peripheria at more than 20 °C. Outflow of warm water is periodically observed within the cluster area (Fig.7).

Figure 6 - temperature fields in premises 305/2 (data of 1987)

temperature jump on borehole 3.9.К

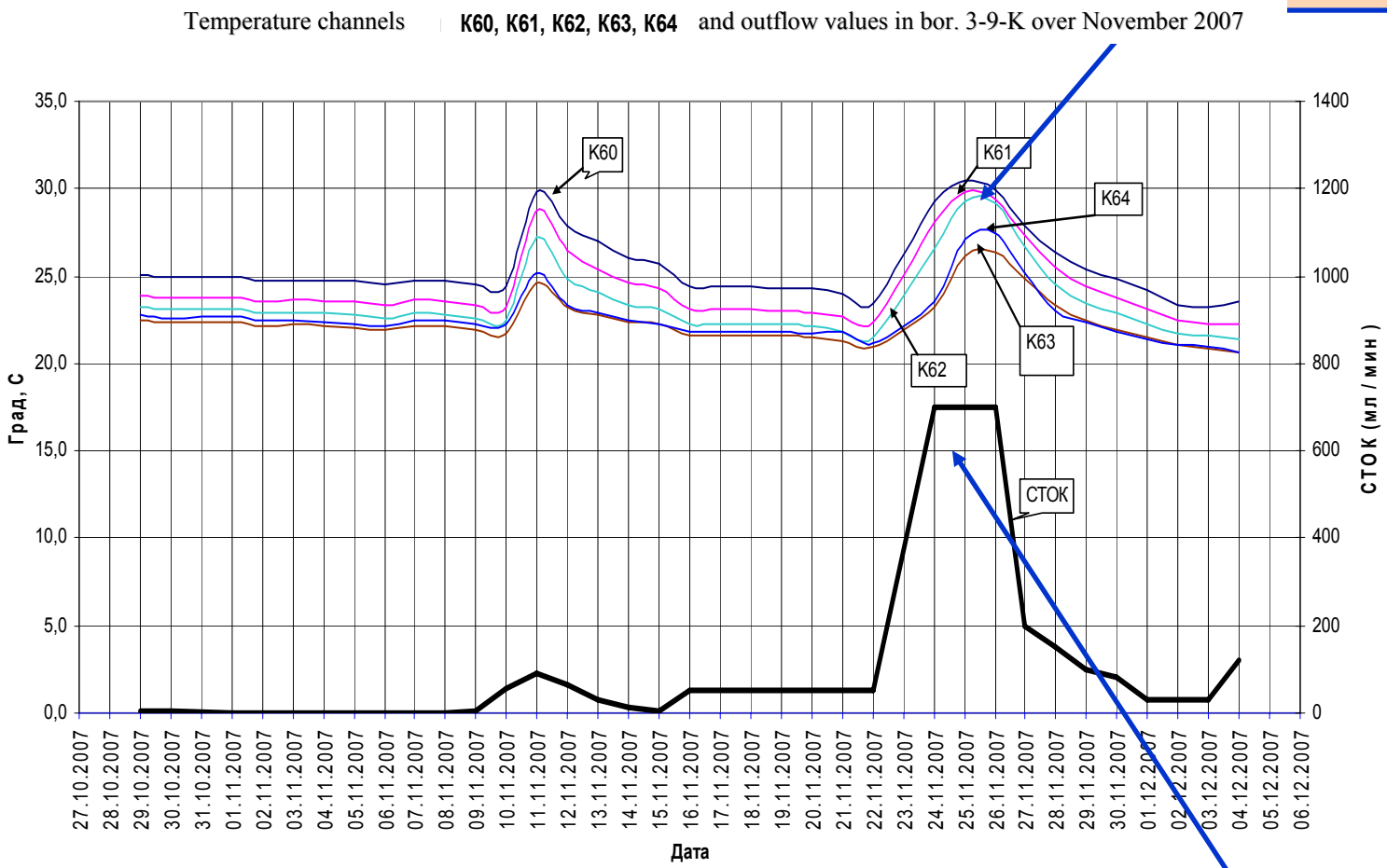
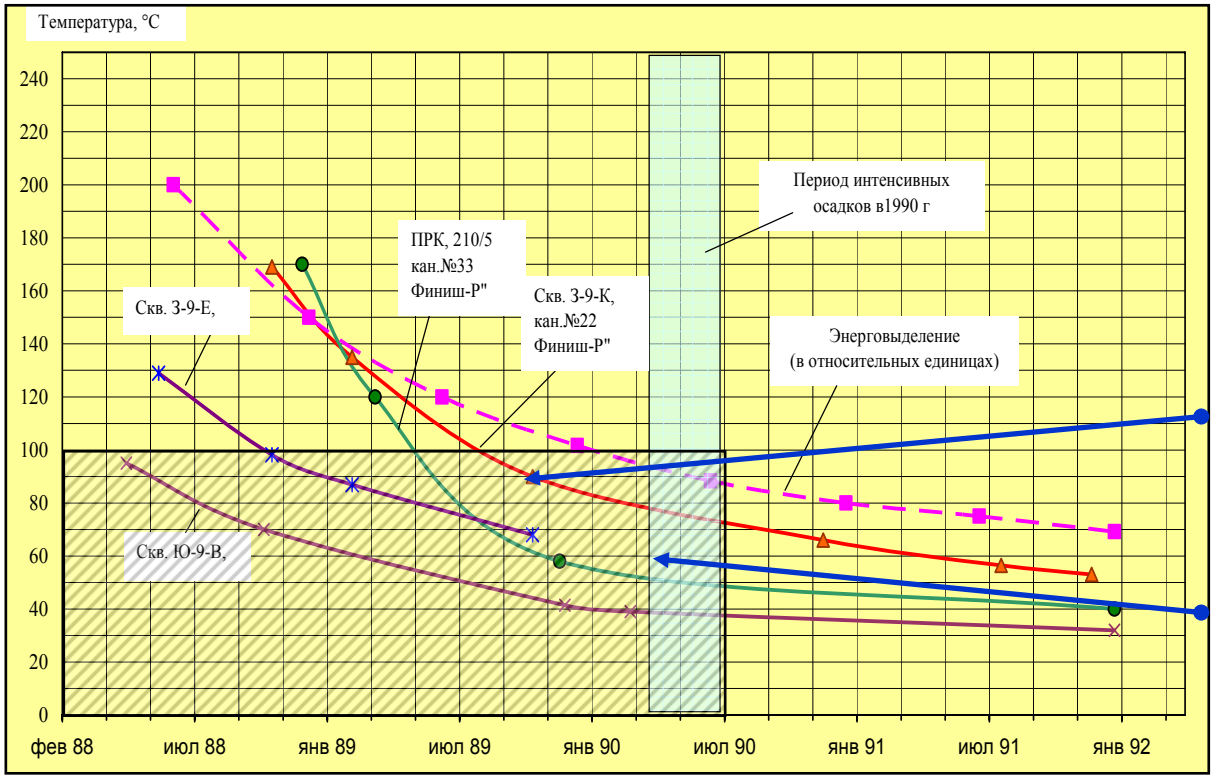


Figure 7 - Graph of temperature change in borehole 3.9.К coming to area of critical mass zones of premises 305/2

Jump of warm water source in borehole 3.9.К

3. Neutron incident in premises 305/2.

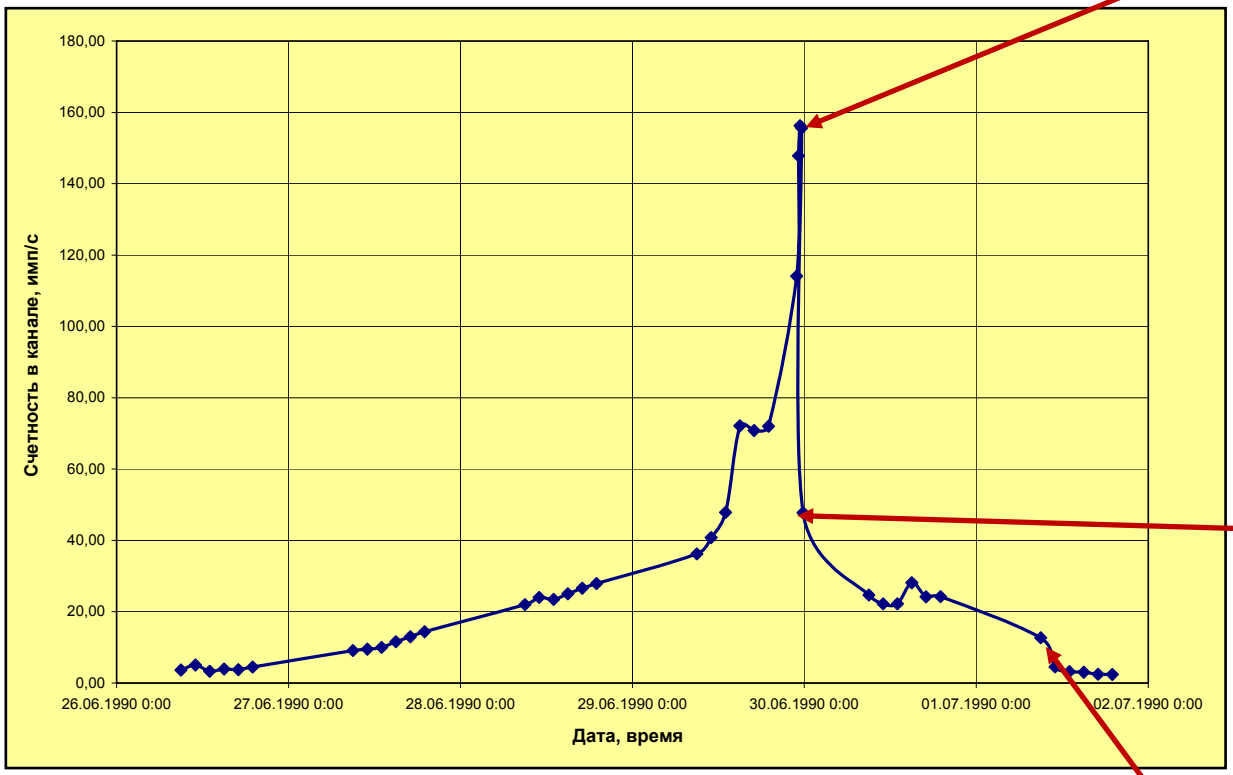


One more fact idicating the existence of critical mass zones became neutron incident (Fig. 8) occurred in premises 305/2 in June 1990. A version of incident reasons was water penetration within clusters area.

a) In early 1990, clusters temperature dropped below 100 °C (Fig.7).

b) Water coming via roofing cracks into «Shelter» object during March – April 1990 and intensive precipitation in June resulted in impregnation of LTCM clusters with water.

Figure 8 - temperature in subreactor plate of premises 305/2



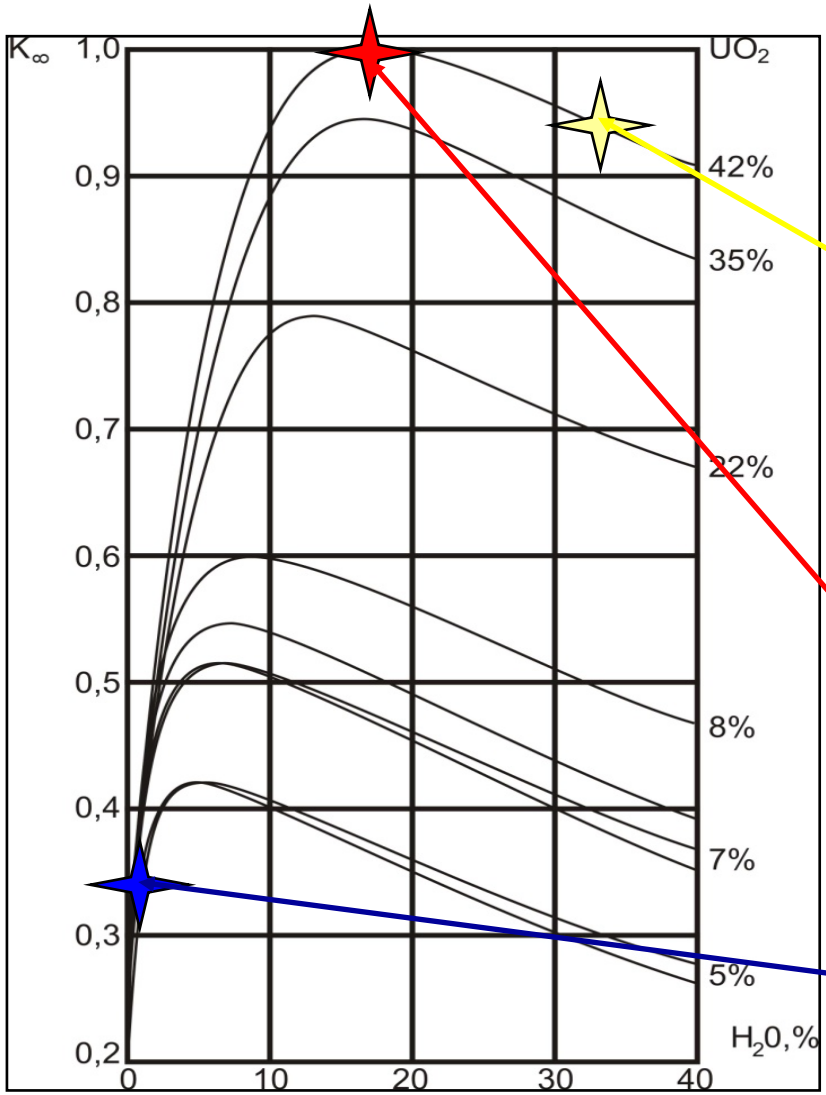
a) Neutron sensors located in neighboring premises 304/3, fixed consequent increase in flux density of neutron leak (via 1-m concrete wall) from premises 305/2 in more than 60 times (Fig. 9) – system took conditions of multiplying medium with positive reactivity.

b) Filling of neutron absorber - gadolinium led to sensors blocking.

c) Self-dumping of incident occurred after 36 hours as result of probable over-wetting of multiplying medium of clusters. Currently, clusters are permanently located in water, whose level does not drop below building mark + 9.10 m. Therefore, these clusters can be nuclearly hazardous ones.

Figure 9 - Neutron incident of 1990 year. Version of speed-up and self-dumping in subcritical abnormality in premises 304/3

Nuclear hazard of hidden LTCM clusters in premises 305/2 of «Shelter» object



Estimates of effective neutron multiplying factor (Fig. 10) for medium with low-enriched uranium in composition $UO_2 + SiO_2 + H_2O$ demonstrated as regards:

c) Currently, LTCM in premisesи 305/2 are strongly wetted and are again in subcritical state. However, when lessening penetrated water volumes in south-east part of subreactor plate the clusters can be again optimally wetted, that does not rule out a reiteration of 1990 incident.

b) Since 1988 to 1990 years, temperature in clusters dropped to t<100 °C and LTCM became being wetted (a moderator appeared). To July 90, the wetting achieved optimal value and the system transferred to condition of multiplying medium with positive reactivity(1990 incident).

a) In 1988, temperature in LTCM clusters of premises 305/2 made more 200 °C. LTCM were dry and that is why they were in subcritical state.

Figure 10 - Dependence of K_∞ of LTCM wetting and fuel concentration.

Conclusions

1. As result of active stage of nuclear accident at ChNPP Unit 4 with RBMK-1000 reactor lava-like fuel containing materials – LTCM produced, which originated in premises 305/2 and spread along Unit premises with forming clusters of diverse configuration and with diverse uranium content. A part of them is in open state and is sufficiently well studied.

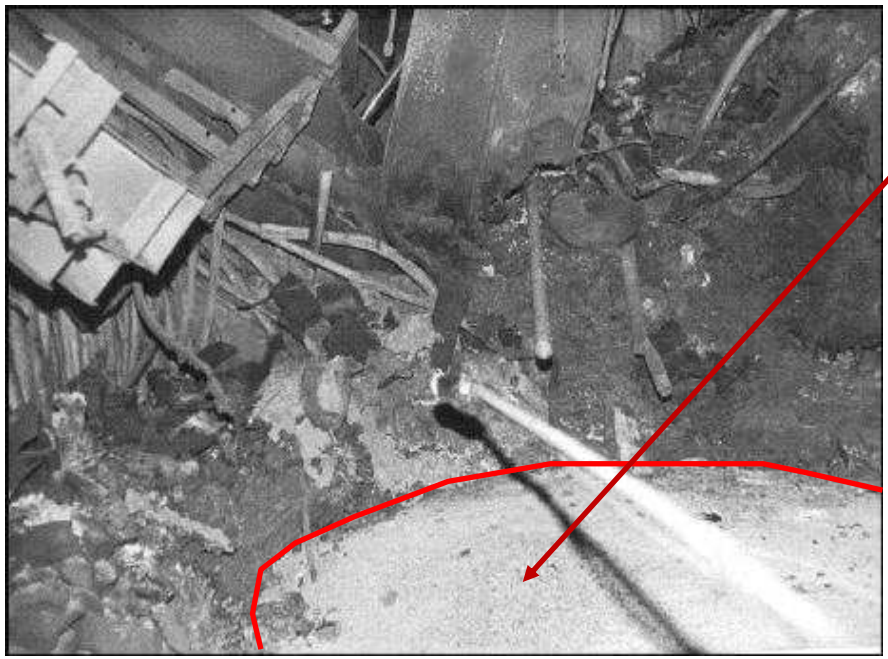
Considerable LTCM part is hidden under destroyed Unit debris and 1986 year concrete, is practically inaccessible and few studied.

2. Such hidden FCM cluster are located also in south-east part of subreactor premises 305/2 of «Shelter» object. They are located in cavities produced as result of concrete melting through by fuel meltdown, which penetrated on subreactor plate after depressurization of active core. Here can be located hidden FCM clusters with high nuclear fuel content. It is testified by:

- **results of core analyses from boreholes drilled in assumed area of hidden fuel clusters;**
- **dynamics of temperature fields and neutron fluxes change;**
- **neutron incident fixed in 1990 Summer.**

3. Due to preliminary estimates, nuclear fuel concentration in that clusters can reach 40 % and more.

Currently, this cluster is filled by water penetrating to premises 305/2 due to precipitation and condensate. From above (Fig. 11), clusters are closed with «fresh» concrete layer, which penetrated to these zones during «Shelter» object erection. Nowadays, temperature on cluster location perypheria exceeds the temperature of foundation plate at more than 20 °C. A discharge of warm water is periodically fixed within the cluster area.



FCM cluster closed by «fresh» concrete layer

Figure 11 – LTCM clusters closed by «fresh» concrete layer.

4. Such fuel compositions are nuclearly hazardous ones. Criticality of such clusters is probable only under the presence of water as moderator. Today – decrease in water penetration into clusters area can lead to optimal wetting and occurrence of nuclear incident.

Such a scenario can reveal as result of change of temperature-moisture regime of these clusters.

Thus, estimated and experimental researches to characterize hidden nuclearly hazardous clusters, as well as to define the ways for preventive subcriticality suppression are nowadays an urgent task during the process of converting «Shelter» object into an ecologically safe system.

5. Researches of characteristics of hidden nuclearly hazardous clusters are an actual task, which can be solved before new confinement is erected. Research results shall provide solution of tasks as regards :

1. **Definition of mass- and geometric parameters of clusters;**
2. **Definition of physicochemical properties of multiplying;**
3. **Assessment of risks and severity of aftermath of probable critical incidentкритического инцидента;**
4. **Development of ways and means of preventive or operative suppression of medium multiplying properties.**

6. In conditions of inaccessibility to clusters, the main research methods will be search and research works in boreholes drilled to area of clusters in premisese 305/2, as well as modeling of clusters media and processes occurring under influence of external factors (humidity, temperature, medium geometry change et al.).

Estimate of totality of data obtained on LTCM state and dynamics of their changes will permit creating a prognosis of LTCM behaviour and in needed time to detect the terms of coming potentially dangerous critical events, that in its turn will enable a possibility for timely taking of measures aimed at restriction of their negative aftermath.

7. Besides, continuation of researches of this topicality will allow obtaining unique data on processes of interaction of fuel meltdown with structural materials and will permit developing proposals to localize out-of-project accidents at NPP.