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ANALYSIS OF THE THERMAL METHODS USED TO DETERMINE THE AMOUNT OF NUCLEAR FUEL IN THE SARCOPHAGUS

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The heat sources in the unit 4 of the Chernobyl NPP are shown not to be merely accumulations of fuel-containing materials (FCM), but also to include electrical equipment, heating and hot water supply and other sources; it is further shown that, by comparison with non-nuclear sources of energy, they are a small or insignificant part of the energy releases within the Sarcophagus. Comparison of the various sources of energy release has revealed a number of characteristic features of the thermal status of the Sarcophagus:

1. in connection with the scaling down of operations in the period 1988-1992, the internal (non-nuclear) heat sources are clearly decreasing with time;
2. technogenic factors connected with switching the heating on and off are superimposed on the seasonal fluctuations in the thermal state of the Sarcophagus;
3. convective heat exchange between the Sarcophagus and the environment creates a thermal background on such a scale that switching on the equipment with a rating of approx. 100 kW (or an input of other sources at the same time) has a negligible effect on the thermal state of the Sarcophagus;
4. the task of accurate determining the amount of nuclear fuel, which is not the only or the main source of heat, and is in general a minor source, is extremely difficult.

An analysis has been made of the estimates of the amount of nuclear fuel within the Sarcophagus based on heat measurements. Error sources in these estimates are demonstrated. A definition is given of the conditions that must be satisfied for the adequate determination of the amount of nuclear fuel from the measurements [1].

1. The heat sources of the Sarcophagus

The thermolocation studies conducted on Unit 4 in 1986 and later on with the object of detecting the nuclear fuel were implicitly based on the assumptions that,

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firstly, the fuel array was not modified at the time of the accident and that, consequently, the afterheat of the damaged fuel was equivalent to the afterheat from the fuel of the shut-down reactor; secondly, that the source of the heat in the Unit was exclusively nuclear fuel [2].

Both these assumptions simplified the analysis of the information obtained by researches and may have led to mistakes when interpreting the results of the heat measurements.

Let us consider the main heat sources in the Unit.

2. Nuclear fuel

If 96% of the initial fuel load remained in the Unit, it follows that, given the afterheat release rate was 1.1 kW/t in 1989 and 0.42 kW/t in 1992, the total release would have been 200 kW in 1989 and 77 kW in 1992. If less nuclear fuel had remained in Unit 4, the total heat release would have been correspondingly less.

Table 1. Afterheat release, kW, as a function of the amount of fuel remaining in Unit 4, % of the initial load.

Amount of fuel remaining in Unit 4,% of the initial load		10	20	30	40	50	60	70	80	90	96
Afterheat from fuel, kW	1989	20,9	41.8	62.7	83.6	104	125	146	167	188	200
	1992	8.0	16	24	32	40	48	56	64	72	77

3. Electric power

In the final analysis almost all the electric power used in Unit 4 is converted into heat. In 1991 the installed power of electric lighting was 96 kW. To that must be added the unrecorded power of searchlights and suspended lights installed in 1988-1989 and still in operation in the rooms of Unit 4 to which an access is difficult. Thus, for example, one searchlight having a power of 1.5 kW and several of the suspended lights are still burning on level 1 of the bubbler pond. This is significant because the afterheat from the FCM in the bubbler pond was estimated as 0.4 W/kg in 1989-1990, and with 1.5 (tons) of uranium, the FCM 'heap' is heating level 1 of Unit 4 to only three-quarters of the heating effect of the lights.

An exploratory analysis of the heat sources in the Sarcophagus in 1988-1991 was made in 1992-1993. When an inventory was made of the lighting as a heat source, it was concluded that, according to the estimates, 40·1.5 kW searchlights (i.e. 60 kW) were continuosly on in 1988 and early 1989 below 27.0

m level, in addition to 1 200·40 W electric lights (i.e. 50 kW), and also 10 lights and searchlights of 5 kW each used in carrying out investigations in the vault of the reactor and in other places where there are accumulations of FCM.

The power of the heat absorbers of the power facilities in Unit 4, defined in terms of the number of units of equipment - electric drives for machine tools, fans, power tools, welding equipment etc. - was more than 5000 kW in 1989, although, naturally, not all of this equipment was in operation at the same time or round the clock. In 1988, for example, there were 6 drilling rigs, each consuming 36 kW. Drilling was then in progress round the clock, without rest days, but only, as a rule, using 2-4 rigs, while the others were halted and in the course of erection. At the same time metal structures of staircases and corridors were being erected round the clock (e.g. from level 24.0 m to level 12.5 m and room 406/2), as were passages and equipment (including metal cladding) for workrooms; 20 or more welding plants, each consuming 6 kW, were simultaneously in use in assembly areas of the IAE`s visiting team of experts in Unit 4. Even on the assumption that only 2-3 of the plants were in constant operation, that amounts to 12-18 kW.

4. Electric heaters

Roughly 30 of the constantly staffed rooms of the non-functioning reactor were fitted with 1 kW electric heaters of the tramway type, 2-3 per room, with a total power consumption of 60-90 kW, so as to make working temperatures a little more congenial in autumn, winter and early spring.

5. Overview of heat release from electric power sources in Unit 4

On totalling the above data we find an input of 410-470 kW into Unit 4 from the electricity-consuming plant and equipment in 1988 and early 1989. Moreover, it should be noted that power is supplied to Unit 4 by four transformer substations with a total power of 2060 kW.

When the reserve regiment of the army unit 55237 had ceased all the operations in Unit 4, all work was taken over by the staff of the visiting team of experts, with rest days, and gradual switching from the previous four shifts to single-shift working. The volume of operations was reduced by approximately three-quarters. An analysis of the status of electric power for 01.09.1989 shows that by that time the power consumption in Unit 4 was already at the daily level.

5.1. 145,000 kW/month = 145,000 kW/24 (h) : 30 (days) = 200 kW.

In 1991 the power of the utilized equipment in Unit 4 (47 electric drives = 410 kW; 11 welding plants = 60 kW; lighting = 96 kW) was 575 kW with a simultaneity factor of 0.25 .

Consequently, the dependence of electric power consumption in Unit 4 on time (disregarding seasonal, daily and technogenic fluctuations) may be conventionally represented as an exponential graph.

5.2. Heating and hot water supply

In accordance with the situation in 1991, heating and hot water supply is in operation for six months of the year from 15 October to 15 April, with a heat consumption of (12-17)* 1,000 kW.

Consumer heat loads have been altered with time in connection with the sharp reduction in the volume of operations in Unit 4 and the corresponding reduction in the number of workers, the closing of the decontamination post and the change in the pattern of hot water supply to Unit 4.

Thermal calculations of the internal heat-supply system of the Sarcophagus were done in May 1992 to ensure the operation of the heat-supply system in accordance with the heating temperature graph of 70-130 °C, with the pressure difference between the incoming and outgoing pipelines of 6.5 kg/cm^2.

Heat consumption on heating is determined from the surface of the actually installed heaters (including smooth-tube storage devices, cast-iron radiators, convectors and blow- heaters). The total heat consumption on heating was Q = 279 kW for a total flow rate of the heat-carrier G = 3.96 t/h.

5.3. Other sources

Other heat sources in the Sarcophagus were considered for the sake of the completeness.

Daily engagement of 350-500 people (round the clock) in the block made a contribution of approx. 30-75 kW to the heat status of the Sarcophagus, equivalent in terms of heat emission to 50-100 t of fuel. Heating the Sarcophagus by the solar energy is not, of course, a dominant factor: approx. 2-7 kW.

6. Convective heat exchange between the Sarcophagus and the environment

Long-term measurements inside Unit 4 show that the temperature difference between the surfaces of the walls (coatings) and air temperature outside varies in the course of a year in the range between approx. - 15 °C and + 15 °C.

Taking the total area of cracks in the Sarcophagus to be approx. 1,500 m^2 and the rate of air flow through them to be (0-4) m/s (on either side), under the condition that one half of the slits let air into the Sarcophagus and the other half let air out, the outgoing (or incoming) thermal power may be estimated as (1,440 - 14,000) kW.

It is, therefore, evident that the incoming or outgoing thermal power varies widely at different times of the year and of the day.

7. Generalized picture of the thermal status of the Sarcophagus and thermolocation of nuclear fuel

The recorded heat income from constant or non-nuclear sources into Unit 4 amounts to 500-700 kW. Convective heat exchange is obviously more than capable of removing all the heat, but in summer it may also bring in heat greater by one or more orders than the heat from internal sources.

At the time being the Sarcophagus, by the very nature of its construction, possesses a large reserve of heat, and a change in the temperature of the building by 1°C (such variations have, in fact, been recorded) during 6 hours, for example, is equivalent to a thermal power of approx. 7,750 kW.

That is tantamount to saying that with such a thermal background anthropogenic variations of heat flows become negligible. This can especially be referred to the nuclear fuel, since even if 100% of the nuclear fuel were in Unit 4, its total afterheat release would be 160-80 kW (in different years) against a thermal background of approx. 80,000 kW, i.e. 1% of the thermal 'breathing' of the building.

The building does, of course, have a thermal life of its own, and the heat flows differ both in direction and in their pulsation. Without the knowledge of the real thermal architecture of the building it is very difficult to give a correct interpretation of individual changes at individual points.

To sum up, it may be concluded that the thermal status of the Sarcophagus has several characteristic features:

1. The internal heat sources are clearly declining with time (in connection with the curtailment of operations in the period 1988-1989)
2. Seasonal fluctuations, including those connected with switching on and off the heating, are superimposed on the thermal pattern.
3. Convective heat exchange between the Sarcophagus and the environment creates a thermal background of such a scale that the use of a few drilling rigs and several dozens of searchlights has a negligible effect on the heat status of the Sarcophagus, and in particular on the remains of nuclear fuel in Unit 4.
4. The nuclear fuel, while not being the only or the main source of heat in Unit 4, does, by virtue of its presence in the accumulations of FCM in which the radionuclide composition differs, make its own contribution to the thermal power of the FCM, but the converse problem of determining the amount of fuel from the heat radiation becomes ambiguous.

It is natural to query whether it is, in general, possible to use heat measurements for a subsequent estimate of the amount of fuel. The answer is definitely in the affirmative, under the following conditions:

1. when information about the value of heat emission can be obtained from the experiment simultaneously throughout the entire volume of the FCM for the integral of heat release;
2. when clear discrimination between nuclear and non-nuclear heat sources is possible;
3. when it is possible to establish for the nuclear sources what percentage of the thermal energy comes from the fuel, and what from other radionuclides.

Such work has not been carried out yet.

8. Heat measurements and estimates of nuclear fuel amount

Calculation of the strength of FCM afterheat sources was done with the use of Ostrogradsky-Gauss theorem and the corresponding heat-flow measurements - ideally over the whole closed surface bounding the FCM volume.

In practice, the scope for measurement was, of course, extremely limited for a number of reasons:

1. the number of probes was invariably considerably less than the number of rooms assumed to contain the main accumulations of fuel;
2. measurements on the surfaces closest to the accumulations of fuel were made difficult by strong radiation fields (approx. 1,000-2,000 r/h), which made it necessary to move back to more remote flows;
3. the unknown 'architecture' of the destroyed paths of the reactor precluded adequate allowance for the heat flows.

Nevertheless, a great many of nearly impossible heat-flow measurements were made inside Unit 4, namely beneath the SDC and the service passage beneath the equipment.

Below is the listing of the measurement points and the results of the measurements of heat flow densities (W/m) in the ceiling of the upper level of the bubbler pond beneath the SDC. These measurement results were numerically integrated over the following square sectors for which there were sufficient experimental points:

- on axes 45 - 46 between rows:

N-M: W1 = 61 W; q1 = 2 W/m^2
M-L: W2 = 214 W; q2 = 7 W/m^2
L-K: W3 = 459 W; q3 =15 W/m^2
K-I: W4 = 306 W; q4 = 10 W/m^2
I-Zh: W5 = 241 W; q5 = 7 W/m^2

- on axes 45 - 47 between rows:

N-M: W6 = 107 W; q6 = 3.5W/m^2
M-L: W7 = 520 W; q7 = 17 W/m^2

- on axes 47 - 48 between rows:

N-M: W8 = 0; q8 = 0
M-L: W9 = 153; q9 = 5 W/m^2

- on axes 48 - 49 between rows:

N-M: W10 = 0; q10 = 0
M-L: W11 = 138; q11 = 4.5 W/m^2
L-K: W12 = 184; q12 = 6 W/m^2
K-I: W13 = 122W; q13 = 4 W/m^2
I-Zh: W14 = 613W; q14 = 2 W/m^2.

Heat emission in the experimentally investigated sectors of the ceiling surface of the bubbler pond was approx. 2,539 W.

Graphic interpolation was carried out on the basis of the above values to arrive at the mean values of heat-flow densities on the surfaces of the following square sectors (in the calculation order):

-between rows I-Zh on axes :
46-47: W15 = 245 W; q15 = 8 W/m^2
47-48: W16 = 122 W; q16 = 4 W/m^2
-on axes 46-47 between rows:
L-K: W17 = 612 W; q17 = 20 W/m^2
K-I: W18 = 459 W; q18 = 15 W/m^2
-between rows K-I on axes:
47-48: W19 = 367 W; q19 = 12 W/m^2
-between rows L-K on axes:
47-48: W20 = 490 W; q20 = 16 W/m^2.

The total heat emission on the surface of these sectors estimated by the interpolation method described above was approx. 2,295 W. The total heat emission from the free surface of the ceiling of the bubbler pond (i.e. the surface not subject to partition) into the air was estimated from the results of the heat-measurement studies to be approx. 4.8 kW.

It was also assumed that the presence of concrete partitions (0,9 m thick) had a negligible effect on the heat-flow density distribution in the ceiling of the bubbler pond, and a correction was declared in proportion to the cross-sectional area of the bubbler pond partition to arrive at a new value of approx. 5,7 kW.

The main values of heat-flow densities were also estimated in the lateral sector of the surface bounding the accumulation of FCM in the SDC from the results yielded by graphic interpolation:

-along axis 45 between rows:
N-M: W21 = 0; q21 = 0
M-L: W22 = 4 W/m^2; q22 = 14W
L-K: W23 = 10 W/m^2; q23 = 36W
K-I: W24=6 W/m^2; q24=22W
I-Zh: W25=5 W/m^2; q25=18W
-along row Zh between axes:
45-46: W26=6 W/m^2; q26=22W

46-47: W27 = 6,5 W/m^2; q27 = 23 W
47-48: W28 = 2 W/m^2; q28=7 W
48-49: W29 = 1 W/m^2; q29 = 4 W

-along the axis between rows:
Zh-I: W30 = 1 W/m^2; q30 = 4 W
I-K: W31 = 2.5 W/m^2; q31 = 9 W
K-L: W32 = 4 W/m^2; q32 = 14 W
L-M: W33 = 3.5 W/m^2; q33 = 13 W
M-N: W34 = 0; q34 = 0.

As a result of interpolation, the total heat removal through the ends of a concrete 600 mm thick slab that forms the partition between the SDC and the bubbler pond was taken to be approx. 0.2 kW.

It was assumed in the calculations that the thermal power lost by FCM accumulations through the surface of the bubbler pond was carried down by the thermal radiation to the floor and cold walls of the bubbler pond, and was also carried by free convection into the air on the premises of the bubbler pond, and it was further assumed that the surface temperature of the ceiling of the bubbler pond in 1989 fluctuated around the mean value of 20 °C, rising to 23 °C in June and falling to 17 °C in December. It was noted that «there had not been regular measurements of the temperature of the floor and the walls in the bubbler pond», and it was assumed that their temperature and air temperature on the premises of the bubbler pond was below the temperature of the pond ceiling. No direct temperature measurements were made, and by varying the mean temperature values of the «hot» and «cold» spots a thermal balance was achieved with the total heat emission of approx. 17 kW.

It was assumed that the nuclear fuel, along with the fission products (FP), was the only source of heat emission and that the energy release of the FP was 0.265 kW/t UO_2 (which was postulated without any argument), and that the heat emission of the uranium dioxide itself was 0.735 kW/t UO_2.

This caused an error in the measurement results that led to the estimate that the amount of fuel in the SDC was 23 t of UO_2. This estimate was not subjected to any analysis and was reproduced in many publications and official documents, although it was known even then that there were no accumulations of FCM in the SDC between axes 45-46 and 48-49, and that with the then-known density values of the lava-like fuel-containing materials (LFCM) and the UO_2 concentrations in them, such an amount of lava was physically impossibile at the points in the SDC where LFCM were accumulated, even if they had been filled up to the ceiling (in reality they were only a few centimetres thick) [3].

A similar approach was used in estimating the amount of fuel in the space under the equipment, with allowance for the heat taken up by the air in the reactor space (RS).

The results of a series of experiments to determine the airflow in the reactor space (table 2) were used in the heat abstraction from the upper surface of the FCM accumulation in room 305/2.

Table 2. Airflow in the reactor space determined by various methods.

Serial number	Method	Airflow, m^3/s
1	Gas tag	10-28
2	Mean helium concentration in an air-gas mixture	20-70
3	Abrupt injection of an indicator	2-130
4	Tritium marker	24-100

N.B. The cross section of the airflow in the reactor space was taken to be 200 m^3, i.e., it was considered that the airflow through the RS was unidirectional.

When determining the uptake of heat by the air in the RS, it was considered that «the measured airflow through the vault of the reactor was 8.15 m^3/s» - no longer the mean value of 16 m^3/s or 7 m^3/s - but when inserting numerical values in the formula, the figure taken for the airflow was 10.62 m^3/s. The spread 2-130 m^3/s clearly gives a considerable scope for the selection of a highly accurate airflow figure, e.g. 10.62 m^3/s, and it is possible to vary the airflow cross-section within the RS: it was taken to be half the flow area through the reactor vault, proceeding from the assumption that the heating of the air is slight (approx. 3 degrees) and there is no inflow of air into room 305/2 from the adjacent rooms.

The mean heating of the air was taken as the mean of 10 single measurements at different times over 10 days of measurements.

It was, therefore, determined that the total afterheat from the space under the equipment was 35 kW (convective in the RS) + 25 kW (down into the SDC) = 60 kW.

Again, with allowance for UO^2 emission of 0.78 kW/t, it was established that the amount of UO^2 in the space under the equipment is approx. 77 t.

9. Analysis of the estimated amount of the fuel based on the heat measurement procedure

The measurements of heat flows from the SDC side were made in the bubbler pond where the radiation situation permitted and not everywhere where it was desired to make measurements. Now that we know where the FCM are located in the SDC, it may be asserted that no direct measurements of the heat flow were made in places where there are accumulations of FCM in the SDC (neither above nor below the FCM layer).

The task of a direct measurement of heat flows was replaced by a scarcely arguable extrapolation of values from the measurement ranges where there was no fuel to the ranges where it was.

Thus, for example, there is no fuel in the SDC sector on axes 45-46 between rows I-N (the heat output of which is 1, 254 W): in room 210/5 a highly active metallic melt (the activity of which is most probably accounted for by ^{106}Ru and ^{125}Sb), not containing fuel, has poured onto the floor. Consequently, there has been an involuntary substitution of the heat source: what was considered to be the heat source was not ^{106}Ru, but nuclear fuel, which was assumed to be present in the metallic melt because of the high exposure dose rate in room 210/5. Investigations in rooms 210/6 and 210/7 revealed that there was a layer of remelted metal exhibiting the same characteristics (no fuel, but presence of ^{106}Ru) beneath a thin FCM layer (the actual thickness of the LFCM beneath a blister approx. 0.3-0.4 m high is approx. 1-2 cm), and that in room 210/7 the layer of metal is thicker and ^{106}Ru is there apparently more important as a heat source than fuel. When inclined boreholes were drilled into the SDC (through a layer of the 1986 concrete) melted metal was found on the floor of rooms 210/6 and 210/7 north of the L axis, but no FCM were found there.

Consequently, the source of the heat output on axes 46-48 between rows L-N (680 W) is apparently not fuel, but most probably ^{106}Ru. As regards the sector on axes 48-29 between rows Zh-K (183 W), neither fuel nor concrete were found in the rooms, which were completely empty. If there were heat sources there, they were most probably the suspended lighting and searchlights installed in the southern part of the SDC in November-December 1988, which remained alight until they burnt out in 1990. The same applies to the sources of 367 W between rows I-Zh on axes 46-48.

Therefore, there are real grounds for doubting that fuel is the source of the heat output in the SDC. Other heat sources are an experimentally established fact.

At the same time, there are also doubts concerning the quantitative aspect of the estimates of the heat output of the sources. It is apparent from the data of the «Finish» system that heat flow and temperature values change not only in absolute magnitude but also in sign at different times of the day, and even more so at different times of the year. It was physically impossible in the conditions of Unit 4 to measure simultaneously heat flows on all sides of the assumed heat sources, the nature and the spatial and temporal characteristics of which were known in advance. However, when these characteristics are not known, extrapolation becomes a hit and miss process: it is possible to select a time interval for measurements randomly, or at will, during which the heat flow will be zero (i.e. the heat source will appear to be non-existent) or even negative (i.e. the FCM or metal in the SDC appears to be not a heat source but a heat sink).

At the same time, the processing of the daily readings of heat-flow probes shows that the fluctuations in the readings (sometimes approaching 100%) are not strictly seasonal and, moreover, are not due exclusively to radionuclide decay, but are also due to climatic and anthropogenic factors that were not considered in the thermal estimates of the amount of fuel. Besides, as it is evident from the nature of the decrease of heat output in the SDC, the rate of decline corresponds to a half -life of ^{106}Ru (approximately 1 year). Consequently, an analysis of heat

measurements covering a long period (2-3 years) should suggest that the heat sources in the specific locality are ^{106}Ru and ^{137}Sb and FCM with a decreased or increased content of these or other nuclides, or combinations of them, or some other source. For example, where fuel is added to ^{106}Ru, the curve of the decrease in heat emission is less steep.

Consequently, for the comparison of the measured values of heat flows and the thermal radiation of fuel we need the values for partial contributions of various sources and also for various compositions of lava-like FCM (LFCM), rather than the average values that were used.

Values at points 1 - 2 metres apart sometimes differ by several orders of magnitude, and sometimes even in sign. It may be assumed that this spread of heat flow values over short distances is connected with the difficulty of a rapid achievement of thermodynamic equilibrium between the ceiling (concrete wall) and the metal disc contact of the probe.

The function of the strength of thermal radiation (approx. T to the fourth power) is highly sensitive to temperature changes. As it has been noted above, no direct measurements were made of temperature changes.

Table 3 shows the results of calculations that demonstrate sensitivity to the choice of T1 and T2 (temperature variation).

Table 3. Results of calculations demonstrating sensitivity to the choice of T1, T2.

Number	T1 (K)	T2 (K)	T1 - T2, K4		
1	295	295	101	212	031
2	296	294	205	381	360
3	296	293	306	512	655
4	290	289	97	052	559
5	290	288	193	102	864
6	290	287	288	157	839
7	298	297	105	322	735
8	298	296	209	586	960
9	298	295	312	799	791
10	319	306	1587	600	625
11	319	290	3282	491	121
12	316	310	736	010	736
13	316	293	260	116	9935

As it is evident from table 3, a variation of T by 1 leads to a variation of f(T) by a factor of 2-3 times. When allowance is made for arbitrariness in the choice of the area of the radiating surface and the degree of blackness, it further becomes possible to vary the order of strength of the thermal radiation. However, in the absence of direct measurements, it is possible, by varying «mean temperature values» «in the range of really observable values», to increase or decrease the strength of thermal radiation by 4-5 times. As it is evident from table 3, the strength of thermal radiation is altered by roughly the same number of times as the number of degrees by which T is altered, which in its turn implies an increase or decrease by the same number of times in the amount of heat in the

SDC. It is, therefore, possible at will to arrive at any pre-assigned amount of fuel. Determination of the amount of fuel in the space under the equipment is based, in particular, on two key points: the flow of air through the reactor space and its heating in the «input-output» sector.

As it has already been noted, when the spread of the experimentally determined flow of air through the reactor space is from 2 to 130 m^3/s, there is nothing to support the choice of the value of 8.15 m^3 or 10.62 m^3 other than whim. The same applies to the selection of the airflow cross-section which has not been experimentally determined.

As regards the «mean heating of the air» (average for 10 days, with measurements once a day, every other day, and with differences from 0 °C to 6°C - the fact of having randomly excluded one measurement or of making an additional measurement may cause, for example, a two-fold variation and lead, correspondingly, to a two-fold change in the heat output and the amount of fuel), this non-physical quantity must be proportionally linked to the flow of the heat-carrier through the reactor space, but no such dependence has been experimentally established.

The foregoing casts doubt on the reliability of the estimates of the amount of heat removed by free convection through the reactor space.

Finally, the thermal physical model used for the space under the equipment and the SDC itself lacks any backing by measurements and does not allow for the actual airflows in rooms 305/2, 504/2, 404/5, 404/4, 706/3, 308/2, 318/2, 317/2, 405/2, 207/5, 427/2, 502/7, 605/2, 208/9, 208/10 and other air pathways, nor does it allow for (or even assume) other heat sources (apart from fuel), whereas their total strength is roughly by two orders greater than the afterheat release of 100% of the fuel.

10. Conclusions

The analysis made of the estimates of the amount of fuel based on heat measurements has demonstrated that these estimates were based, firstly, on the assumptions which do not reflect the real heat pattern of Unit 4 and that, secondly, they relied on experiments based not on reliable measurements but on hit and miss assertions concerning the heat and flow parameters, the experimentally recorded variations of which can be as much as two orders. In that context, all the previous estimates of the amount of fuel based on such heat measurements should be acknowledged as unsubstantiated.

It is natural to query whether it is, in general, possible to use heat measurements for a subsequent estimate of the amount of fuel. The answer is definitely in the affirmative, under the following conditions:

1. when reliable information about the value of heat emission can be obtained from the experiment simultaneously throughout the entire volume of the FCM for the integral of the heat release;

2. when clear discrimination between nuclear and non-nuclear heat sources is possible;
3. when it is possible to establish for the nuclear sources what percentage of the thermal energy comes from the nuclear fuel, and what from other radionuclides.

Such work has not been carried out yet.

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АНАЛІЗ ТЕРМІЧНИХ МЕТОДІВ, ВИКОРИСТАНИХ ДЛЯ ВИЗНАЧЕННЯ КІЛЬКОСТІ ЯДЕРНОГО ПАЛИВА ВСЕРЕДИНІ САРКОФАГУ

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Показано, що теплові джерела в 4-му енергоблоці Чорнобильської АЕС є не просто скупченнями паливомісних мас (ПММ), а включають також електричне обладнання, засоби нагрівання і тепло-водо-забезпечення та інші джерела; встановлено, що порівняно з неядерними джерелами енергії вони складають малу або несуттєву частину всієї енергії, що виділяється всередині саркофагу. Порівняння різних джерел виділення енергії виявило низку характерних рис теплового стану саркофагу:

1. у зв'язку зі згортанням діяльності протягом 1988-1992 років внутрішні (неядерні) теплові джерела з часом явно загасають;
2. техногенні фактори, пов'язані з включенням та виключенням тепла, накладаються на сезонні флуктуації теплового стану "Укриття";
3. конвективний теплообмін між саркофагом та навколишнім середовищем створює тепловий фон такого рівня, що ввімкнення обладнання потужністю приблизно 100 кВт (або запуск інших джерел у цей самий час) має незначний вплив на тепловий стан "Укриття";

4. завдання точного визначення кількості ядерного палива, яке є неєдиним чи головним джерелом тепла, є надзвичайно важким.

   Проведено аналіз оцінок кількості ядерного палива в саркофазі на основі теплових вимірювань. Вказано на джерела похибок у цих оцінках. Сформульовано умови, які повинні задовільнятися для адекватного визначення кількості ядерного палива за даними вимірів [1].