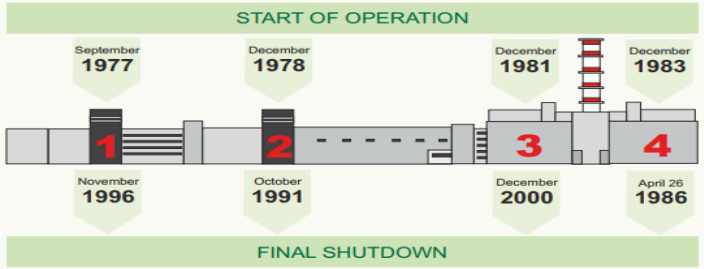
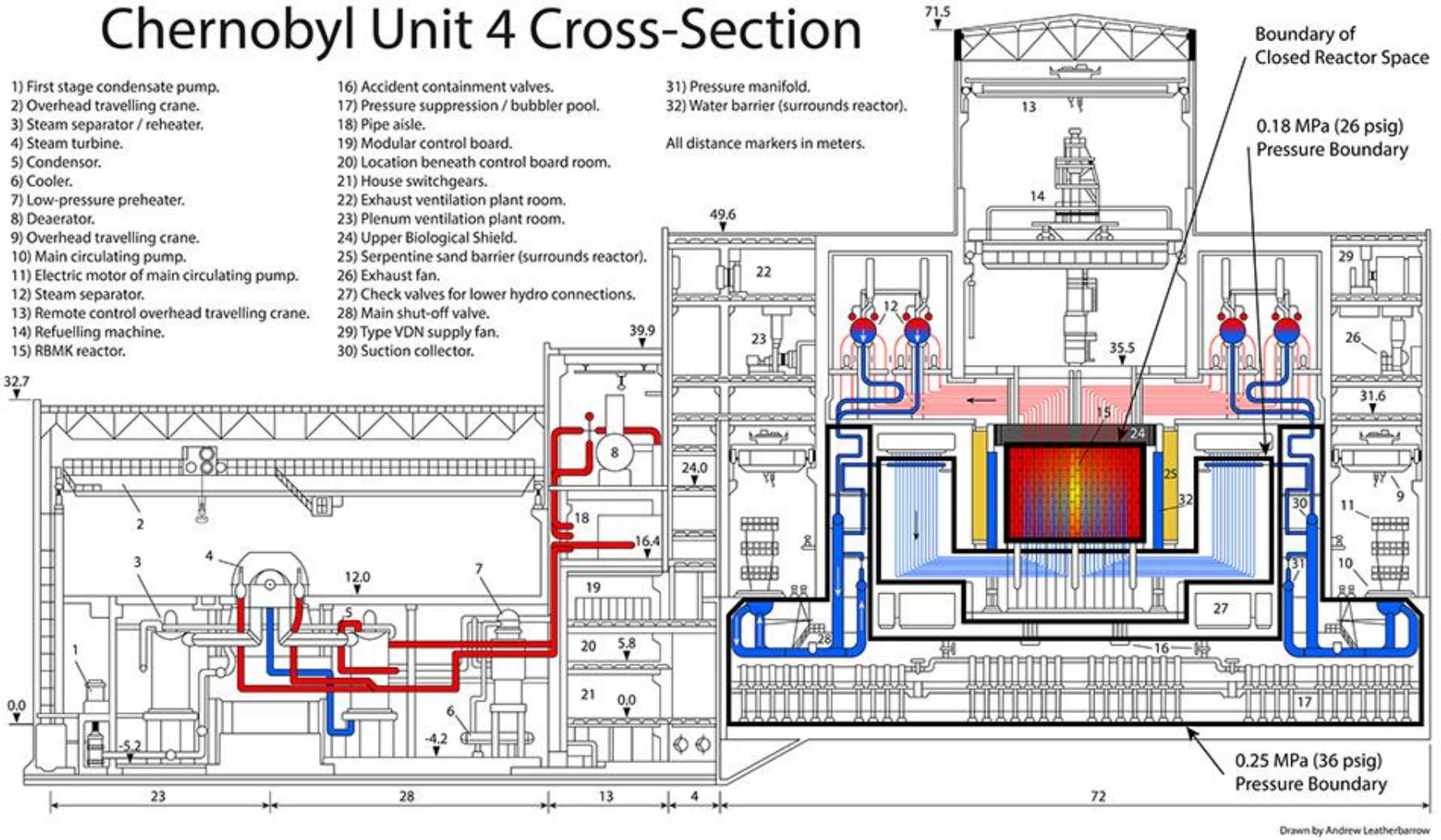
CHERNOBYL

By Martin Malík

mm@hwinfo.com

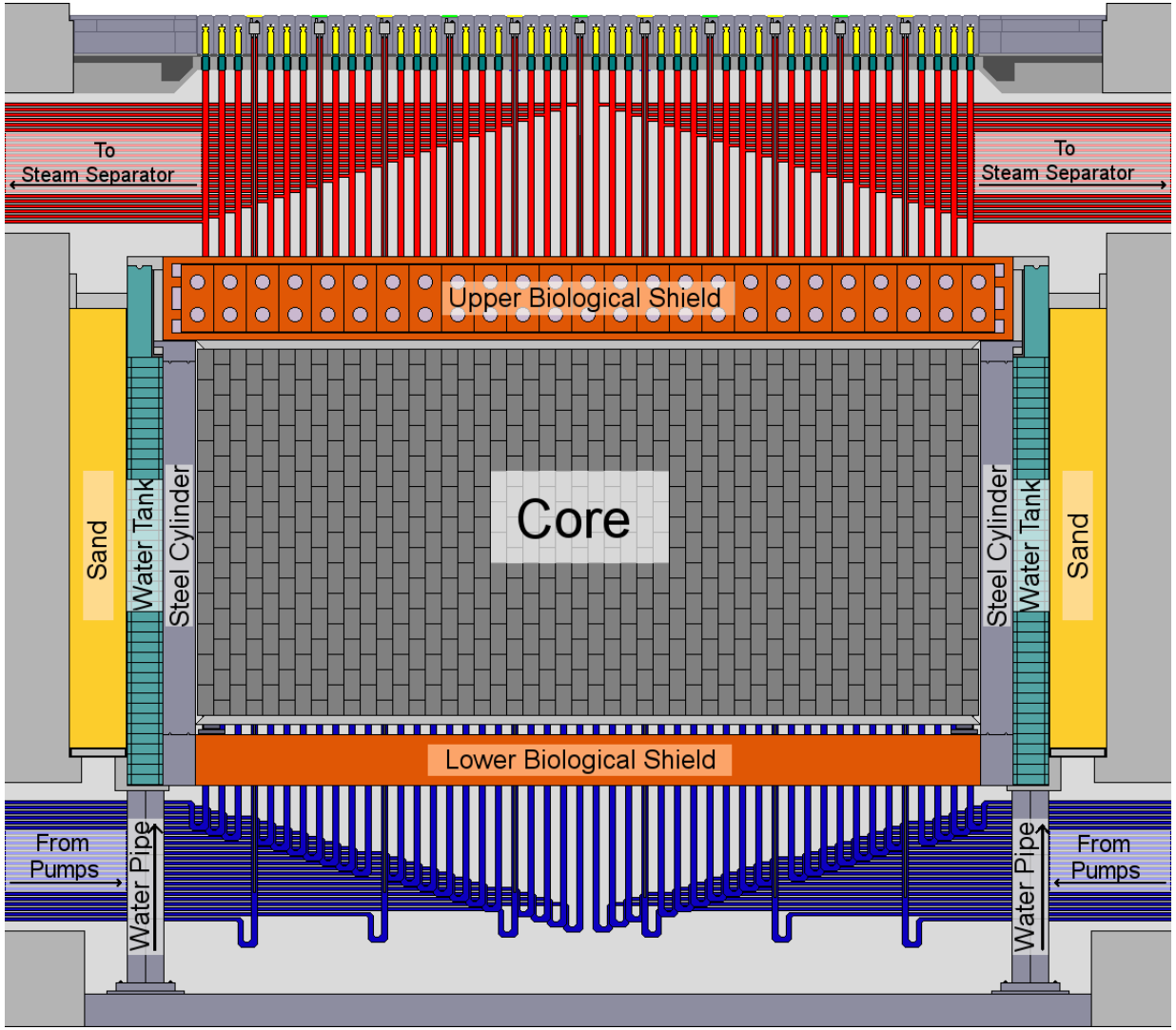
CHERNOBYL NUCLEAR POWER PLANT (ЧАЭС)





РБМК-1000 - РЕАКТОР БОЛЬШОЙ МОЩНОСТИ КАНАЛЬНЫЙ

High Power Channel-type; Graphite moderated, water cooled

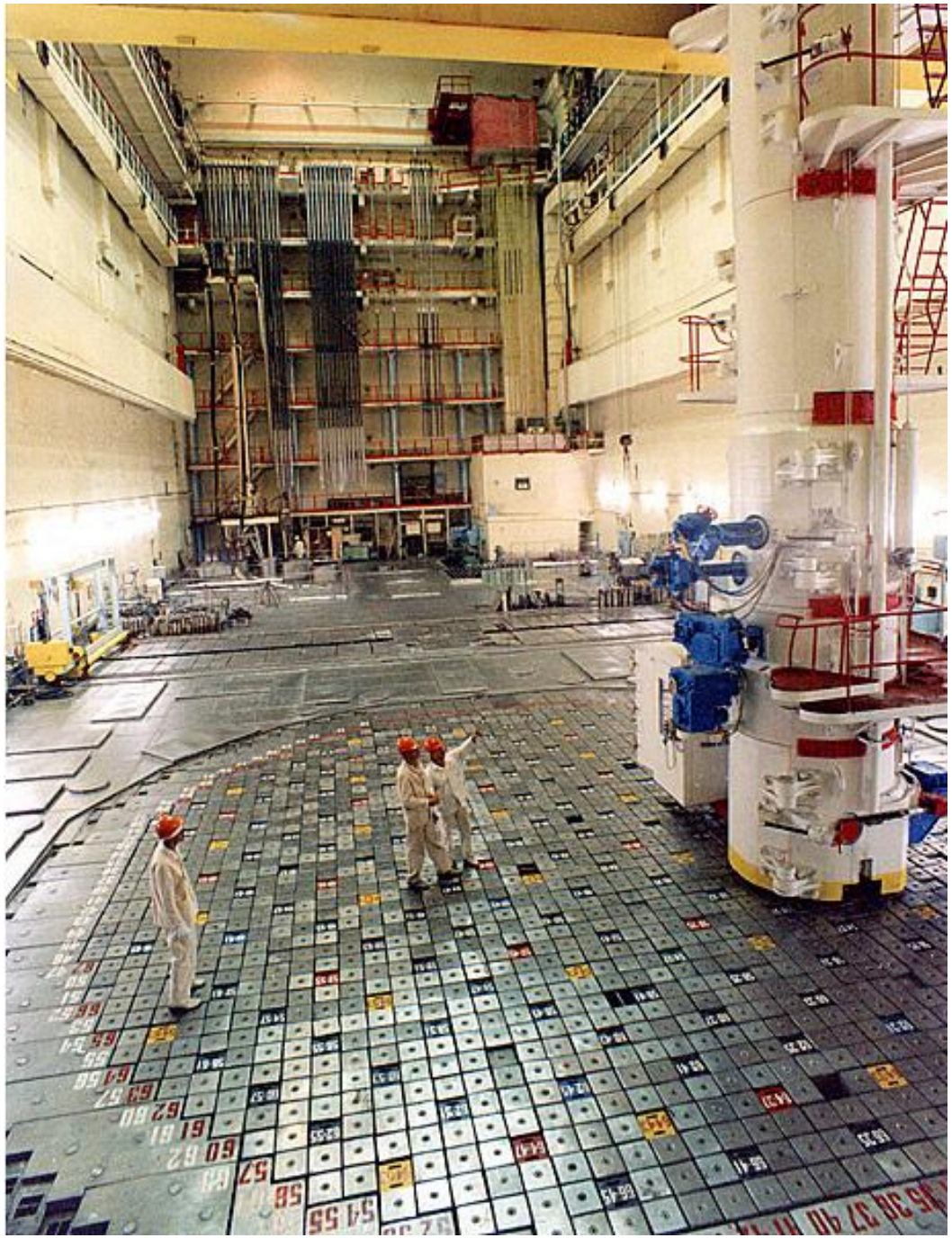


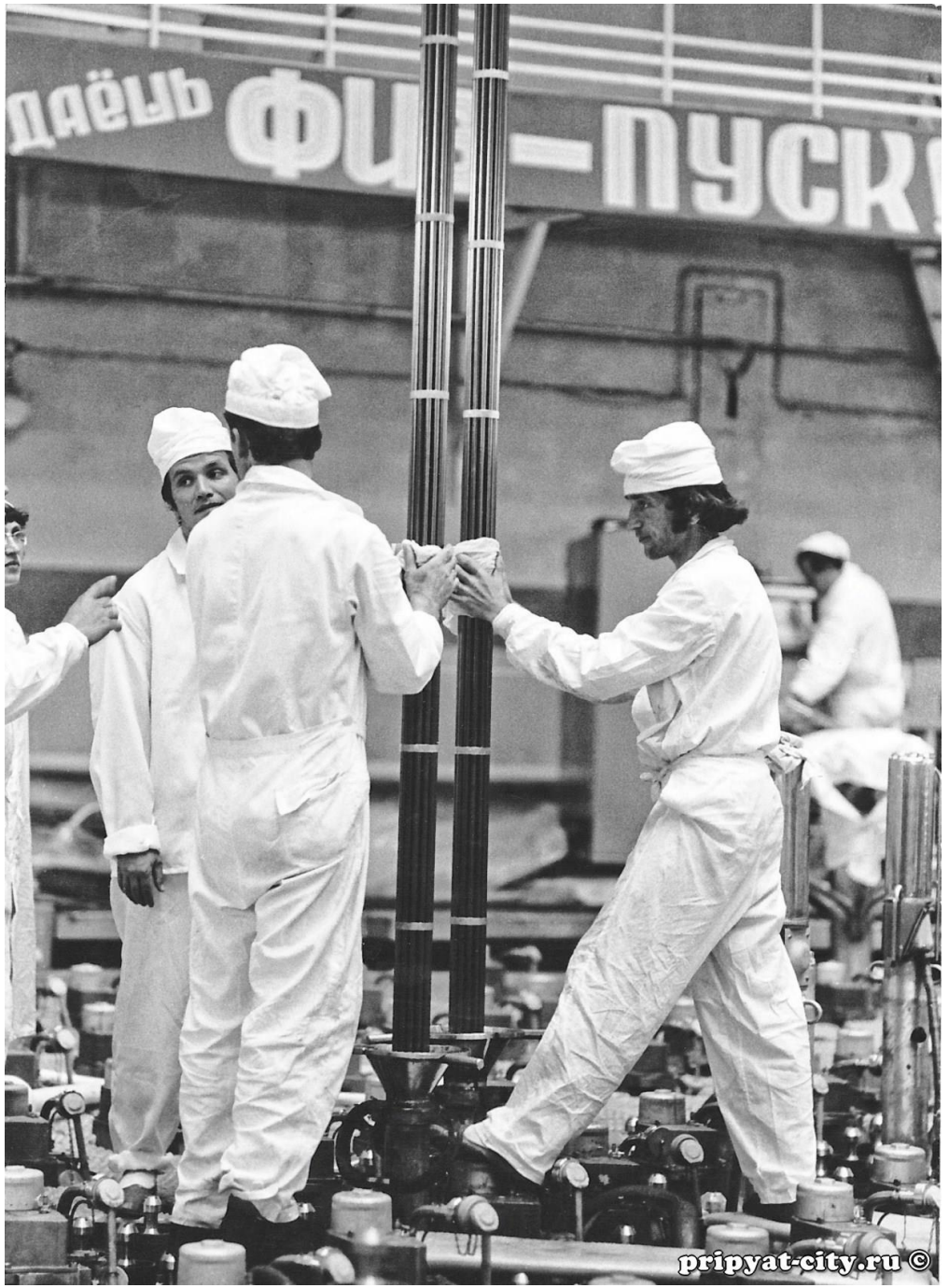
Chief designer: Research and Design Institute of Energy Technology (NIKIET), N.A. Dollezhal

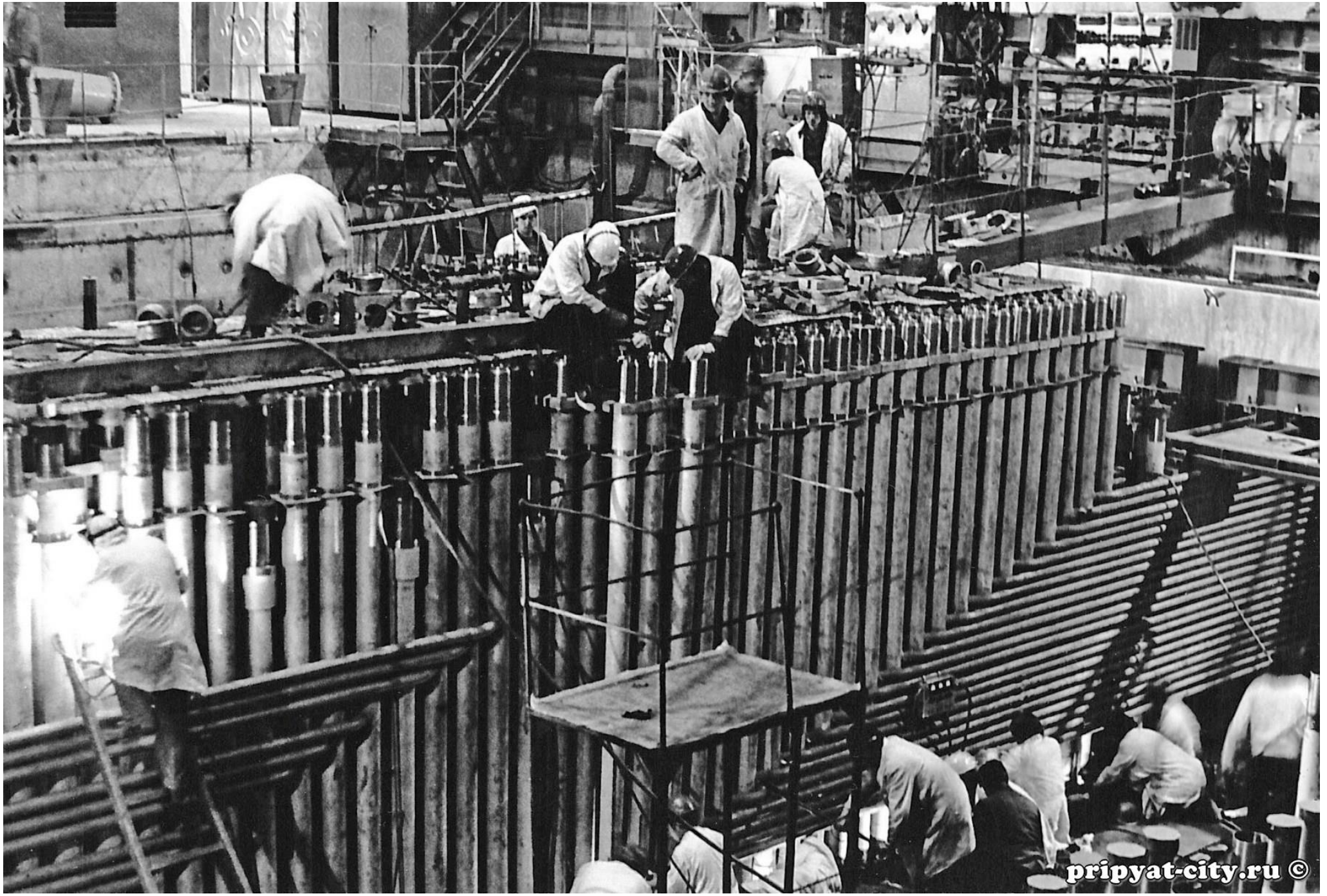
Scientific advisor: Kurchatov Institute of Atomic Energy, A.P. Alexandrov

RBMK-1000, 2ND GENERATION PARAMETERS

Power	**3200 MW thermal**, 1000 MW electric, 2 x 500 MW turbine				
Core size	11.8 m diameter, 7.0 m height				
Fuel Channel (TK)	Total number: 1661; 88mm (outer) / 80mm (inner) diameter				
Fuel (TVEL)	UO2, Enrichment: **2.0 %**, Fuel pellet size: diameter 11.5 mm, height 15 mm Fuel rod: outer diameter 13.6 mm, length 3.5 m. Tube material: Zr alloy, thickness 0.9 mm Total mass of Uranium in core: **194 ton** Designed fuel burnup: 20 MW·d/kg				
Fuel bundle	Bundle length 7 m, consists of 2 sub-bundles (3.5 m) Sub-bundle: length 3.5 m, 18 fuel rods fixed around the central supporting rod Uranium amount per fuel bundle: 114.7 kg				
Coolant	H_2O; inlet: 8.2 MPa @ 270 °C; outlet: 7 MPa @ 284 °C				
Control rods (SUZ)	211 channels neutron absorber: boron carbide in Al alloy; insertion time: 18 s				
		Count	Travel length	Absorber	Displacer
	Emergency protection (AZ)	24	6.55 m	6.55 m	-
	Manual regulation (RR) Automatic regulation (AR 1-3) Local automatic regulation (LAR) Local emergency protection (LAZ/PK)	115 12 12 24	6.55 m	**6.2 m**	**4.56 m**
	Shortened rods (USP), inserted from bottom	24	3.5 m	3.5 m	6.7 m
Critical mass	~21 channels; critical height 0.7 - 2.0 m. Total critical masses ~ 200 (fresh fuel)				
R4 status as of 25.4.1986	**Additional absorbers (DP): 1**, unloaded channels: 1 75% fuel from initial load				




ДАЁШЬ
ПУСК
pripyat-city.ru ©


pripyat-city.ru ©

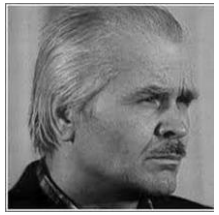

ДСП
ЧАЕС

APRIL 25-26 1986

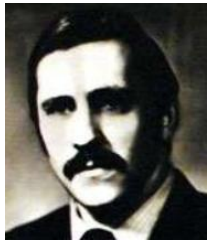
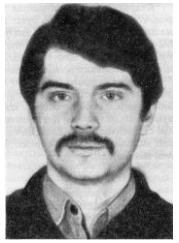
- Reactor shutdown planned for regular maintenance
- Turbine run-down test: determine if in case of a total loss of power, the running-down turbine could provide sufficient power for MCPs until backup diesel generators reach full power (~1 minute required for start and ramp-up)
- Measure vibration characteristics of the turbine (Dontechenergo)

CONTROL ROOM PERSONNEL ON APR-26

- Anatolyi Dyatlov (ZGIS, deputy chief engineer)
- Alexander Akimov (NSB, unit shift chief)
- Leonid Toptunov (SIUR, reactor control)
- Boris Stolyarchuk (SIUB, water pump control)
- Igor Kirshenbaum (SIUT, turbine shop)
- Razim Davletbayev (Deputy head of turbine shop)
- Sergy Gazin (Turbine shop, previous shift)
- Piotr Palamarchuk (ChPNP, Startup and adjustment enterprise)
- Yuriy Tregub (previous shift chief)
- Viktor Proskuryakov, Alexander Kudryavtsev (SIUR trainees)
- Grigory Lysyuk (Electrical engineer)
- Gennadyi Metlenko (Dontechenergo)





CHRONOLOGY OF THE ACCIDENT

25. APRIL 1986

25 April 1986	Shift of A.F. Akimov
01:06	Start of reactor power reduction ORM equals 31 manual control (RR) rods
03:45	Start of replacement of nitrogen—helium gas mixture with nitrogen in the gas cooling system for the reactor graphite stack
03:47	Reactor thermal power is 1600 MWt
04:13-12:36	Sequential measurement of the control system parameters and vibration characteristics of TG 7 and TG 8 at constant thermal power of 1500 MWt
07:10	ORM=13.2 RR rods, but due to a failure in SKALA, automatic controller (AR) rods were not accounted for (at least 2 RR). Thus real ORM ~ 18 RR

25. APRIL 1986

08:00	Shift of I.I. Kazachkov
	Reactor power 1520 MWt, ORM > 16 RR
13:05	Disconnection of TG 7 from the system
14:00	Disconnection of the ECCS (SAOR) from the multipass forced circulation circuit (MPC). Planned to avoid entering of cold water into hot core during test. Disconnecting SAOR takes several hours of manual work, one valve requires ~ 45 minutes for closing.
	Postponement of testing program requested by Kiev power grid controller
15:20	ORM equals 16.8 manual control rods

16:00	Shift of Yu. Yu. Tregub
~20-21:00	Fomin instructed to wait for Dyatlov before starting test.
23:10	Resuming of power reduction allowed by Kyivenergo.
	ORM ~ 26 manual control rods

26. APRIL 1986

00:00	Shift of A.F. Akimov
	Power 760 MWt; ORM 24 rods
	Dyatlov arrives in BSHU-4 about this time.
00:05	Reactor thermal power 720 MW
	Program requirement: 700 - 1000 MW thermal. According to Dyatlov, this was not a mandatory condition (only the maximum level). According to Tregub and Rogozhkin, Dyatlov gave the command to reduce power to 200 MWt and Akimov protested against it. Dyatlov denies giving a command to further reduce power (believes Rogozhkin did). He claims he left BSHU-4 shortly after 0:00 (after a short discussion with Akimov and Metlenko about the program) and returned at 0:35.
00:28	At reactor thermal power of about 500 MWt transfer made from the local (LAR) to global main range automatic power control (AR). But AR-1 was disconnected and AR-2 was not turned on due to unacceptable imbalance. Due to this failure a reduction in thermal power to 30 MW (neutron power=0) happened. SFKRE (system for control of distribution of energy) sensor (D-42) used to measure neutron flux density (cable with Ag-core) doesn't work reliably below power < 1% (32 MW). Side ionization chambers jammed at low power due to high gamma field.
	Tregub says he saw Dyatlov staying next to him when power fall occurred. Davletbaev warned Dyatlov that if power is too low, they will need to disconnect TG-8.

26. APRIL 1986

00:34:03	Emergency fluctuations of water level in steam separator drums.
00:36:24	The EPS (AZ) trip point in response to a pressure drop in the steam separator drums was changed from 55 to 50 kg/cm^2
00:38	Power rise started (Per order of Dyatlov?). Dyatlov claims he returned to the control room at 0:35 and saw operators at SIUR panel, power was 50-70 MWt.
00:42	Power 160 MWt; AR-1 enabled, invalid unbalance on AR-2 removed, ORM=19.7 RR
00:41 - 01:16	Disconnection of TG 8 from the network to determine the vibration characteristics during rundown
01:03	Reactor thermal power increased to 200 MW and stabilized. Seventh main circulating pump was put into operation (MCP No. 12).
	According to Dyatlov, Akimov asked to stay at 200 MWt and not raise to 700 MWt. He claims that he didn't know that the power was reduced to 200 MW until December 1986, when he was arrested.
01:07	Eighth MCP was put into operation (MCP No. 22)

TEST START

01:22:30	Parameters recorded on magnetic tape. Later calculations performed by IAE show ORM=6-7 rods RR
01:23:04	'Oscilloscope on' signal given (Metlenko)
	Emergency stop valves of TG 8 closed. The rundown four MCPs started: MCPs #13 and 23 (section 8RA) and MCPs #14 and 24 (section 8RB)
01:23:10	Design basis accident (MPA) button ("self-made product“) was pressed (delayed by Lysiuk G.V. who didn’t clearly understand the command) to start rundown of the generator excitation system and stop steam feed to the turbine.
01:23:39	AZ-5 (EPS-5) button was pressed; the EPS rods and manual control rods started to move down into the core (except USP rods). Metlenko claims Akimov gave order to push AZ-5 when turbine speed was 2500 RPM. At 2100 RPM he noticed the first explosion. Tregub, Kuhar and Dyatlov also say that first Akimov commanded to shut down the reactor. Lysyuk says first Toptunov shouted that reactor power is rising rapidly, then Akimov jumped to the control panel and pushed AZ-5 (2nd pushing?). According to a note written by Akimov, explosion occurred after pressing AZ-5.

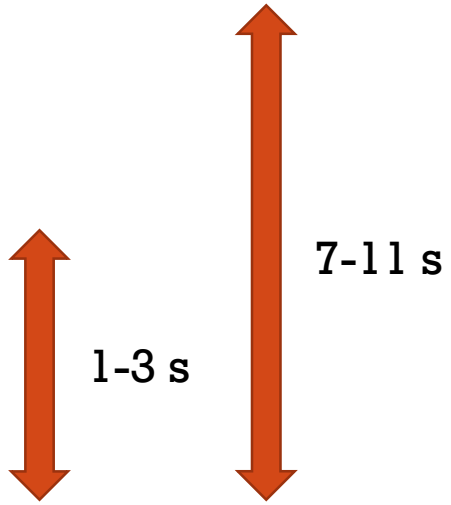
1.23.40 (39) *K06LQI5=1 **АЗ-5 СУЗ**

DESTRUCTION …

01:23:42	Power excursion rate emergency protection system signals on; excursion period: less than 20 s; power doubling period < 1 s, emergency power protection system signals actuated; power exceeded 530 MWt. According to calculations by N.V. Karpan, power doubling period in the lower part of reactor caused by introduction of CPS (SUZ) rods into core/displacing of water (end effect) was 0.33 seconds.
01:23:46	Disconnection of running-down MCPs, remaining MCPs flow rate decreased by 35-40%. Circulation in KMPC stopped – coolant boiling, hydraulic resistance in reactor. Overpressure in reactor space. Depressurization of fuel assemblies, fuel melting, rupture of TK pipes.
01:23:47	Increased pressure breaks compensators in E and OR scheme. Most likely perceived as the first double-blast.
01:23:48	Scheme E blown out, destruction of CZ.
01:23:49	Signal: 'Pressure increase in reactor space; rupture of a fuel channel(s)' – delay at least 1.4s 'No voltage - 48 V signal (no power supply to the servo-drive mechanisms of the EPS) 'Failure of the actuators of automatic power controllers Nos 1 and 2' signals Last DREG entry recorded by SKALA. Power outage. END

... EXPLOSION

1. Vibration of premises and equipment,
   roar with falling frequency and rising power
2. Actuation of all 8 Safety Relief Valves (GPK)
3. Two blasts (explosions) appearing as a merged one
   (bottom)
4. Shaking buildings and structures from the first blasts
5. The last and strongest explosion (above)
   Outside: brilliant/blue flash followed by explosion.
   Sound appeared as a jet breaking the sound barrier.
6. Column of flame, sparks flew upwards



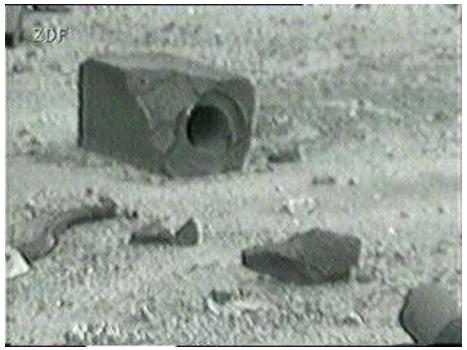
MINUTES AFTER

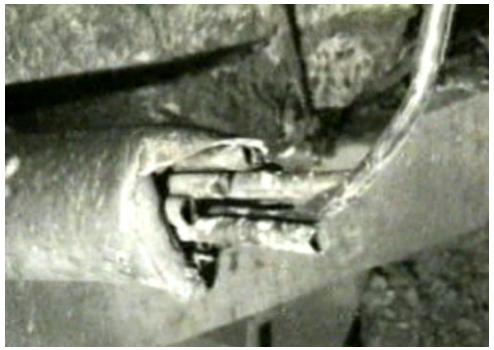
- Attempted to fully insert CPS rods
- Command to supply of water into reactor
- Thought a hydrogen explosion occurred
- Electrical short-circuits, white dust, ozone smell, premises blocked by debris
- Loss of power to critical equipment. Damaged high-voltage (750 kV) rails.
- Electrical engineers called to restore power to critical parts.
  Water supplied to cool reactor causing short-circuits.
- Heads of stations and shop foreman automatically notified.
- “General radiological accident” issued (Akimov).

SITUATION IN TURBINE HALL

- Damaged roof, falling debris and pieces from reactor
- Multiple fires
- Broken oil lines under fire
- Streams of boiling water
- Pieces of nuclear fuel and graphite scattered (5th transformer opposite a phone booth)
- Actions to remove hydrogen from generator and drain oil from pumps
- Spreading of fire to other units would result in a disaster
- Firefighters not involved – only NPP staff allowed to operate inside
- Small inflammations on roof of turbine building. Mostly doused with sand or gauntlets. Serious heat sources only on roof of reactor 3 building (Pravik).

RADIATION ASSESMENT





- Nikolay Gorbachenko at dosimetry panel,
- All measurement instruments at panel off-scale
- DRGZ radiometer up-to 3.6 R/h – off scale. Instrument up-to 1000 R broke down, another one blocked by debris. Gorbachenko surveyed station with the low-scale dosimeter, at 2:00 went outside with Dyatlov (1:40 Dyatlov does first inspection outside).
- Levels in BSHU-4: 3-5 R/h. Inter-city calls cut off by KGB.
- 2:30 S.S. Vorobyev (civil defense) arrived at plant and immediately did measurements using a DP-5 device (up-to 200 R/h), which went off-scale in several places. Observes graphite outside Unit4 (near dining room). Reported to Bryukhanov, but he refused to believe, ordered him not to cause panic and to leave. Lyutov tells not to panic about graphite.
- Vorobyev did a new reconnaissance with Solovyev (2 devices), also went to Pripyat (10 – hundreds mR/h in city). Reported also to Civil Defense of Kiev region.
- ~5:00 Gorbachenko replaced by Krasnozhon (dep. chief of radiation safety), at 7:30 still claimed 3.6 R/h. Samoylenko insisted that radiation is immense.
- ~6:00: Vorobyev goes outside again to measure graphite, meets Telyatnikov who says it's from reactor which is destroyed.
- 10:00: Mobile detachment of Kiev Civil Defense (col. V.V. Grebenyuk) arrives in Pripyat. At 12:00 reliable measurements are known.

26TH APRIL NIGHT

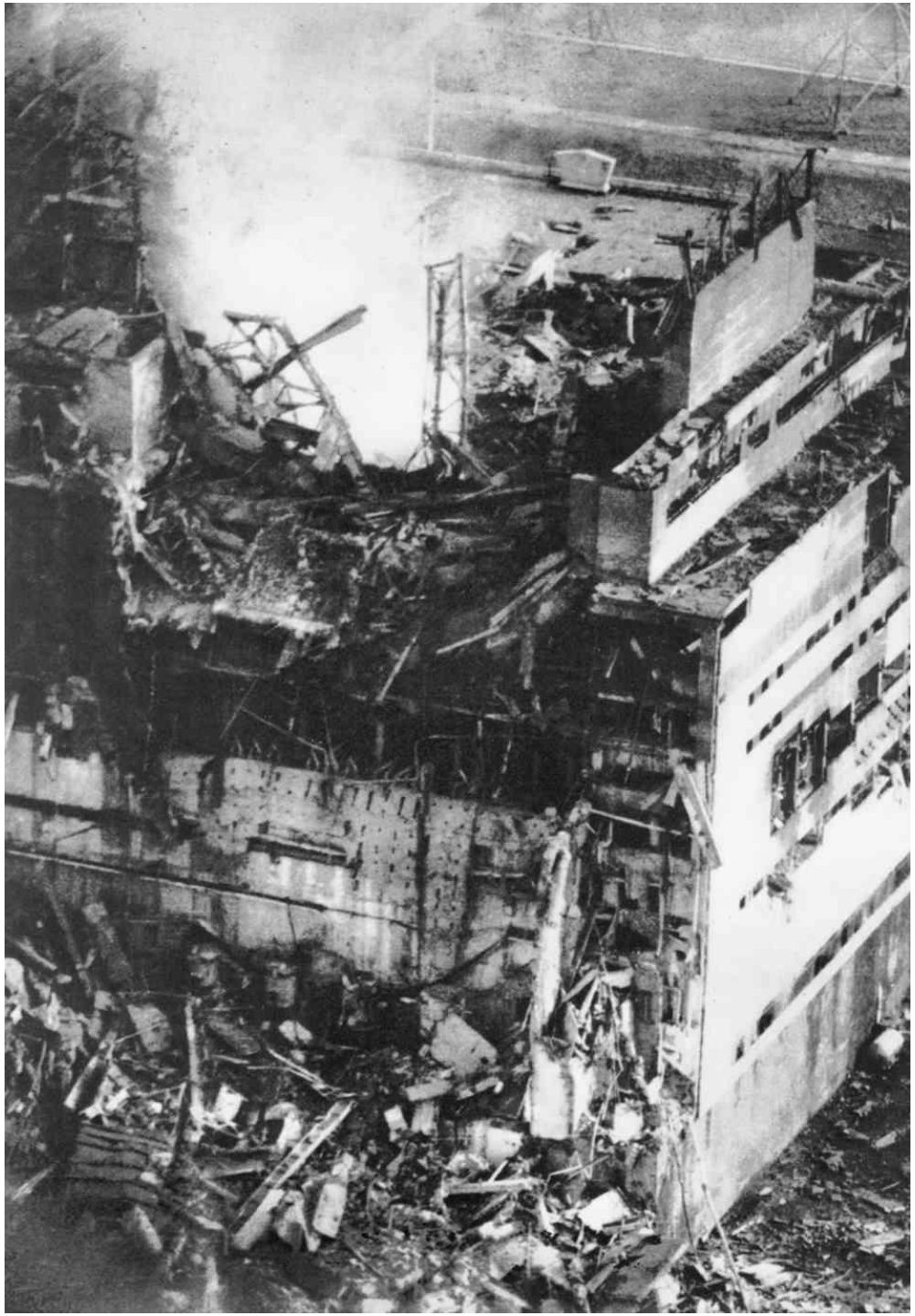
- 2:00: Bryuchanov arrives, moves management into underground shelter under ABK-1.
- 3:00: Bryuchanov knows radiation levels reach 200 R/h
- 4:00: Order from Moscow to feed water into reactor.
  Y. Bagdasarov decides to shut down unit 3.
- 5:00: G.V. Berdov (major general of UkSSR MVD) arrives
- 6:00: Babichev replaced Akimov
- 6:15: Sitnikov, Chugunov, Akimov, Toptunov, Kovalenko, Orlov, Uskov in BSHU-4, decide to feed water from BS, need to open valves in room 712, mark +27.
- 6:35: Fires completely eliminated by fire fighters
- 7:00: Over 1000 MVD personnel securing areas. Exits from Pripyat blocked.

26TH APRIL MORNING

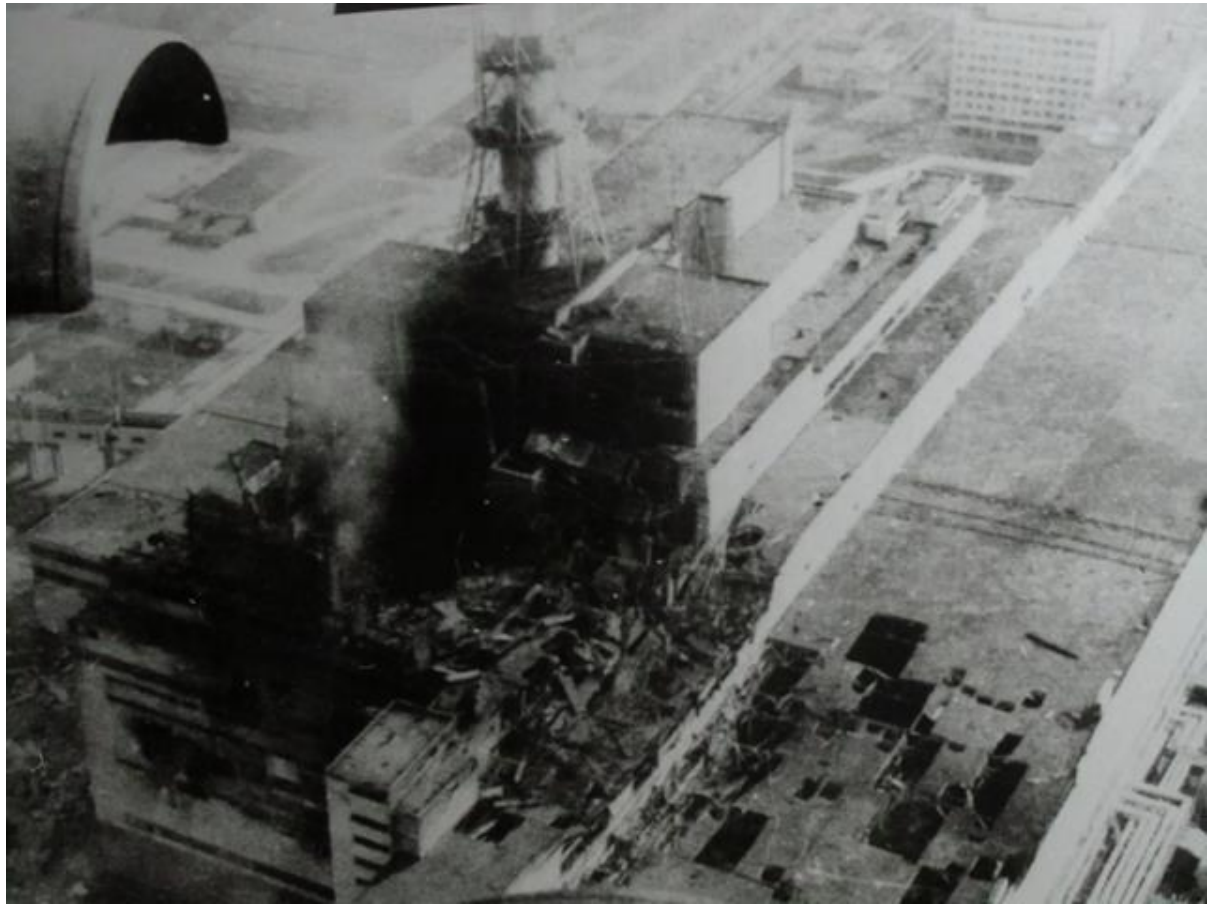
- 7:40: V. Smagin came to replace Babichev. Took Lyutov (dep. chief for science) to observe from backup control room graphite thrown out. Met Sitnikov who visited CZ and roof of Unit C. With Breus replaced Akimov and Toptunov (Orlov, Uskov stay) opening valves in room 712. Returned to BSHU-4. Akimov, Toptunov in serious condition taken to medical unit. Others follow shortly.
- 9:00: Emergency feedwater pump stopped, no more water in BS. Fomin still insisted on feeding water.
- 10:00: Sitnikov (after visiting premises including CZ and climbing with Chugunov onto Unit 3) reported to Fomin and Bryuchanov that reactor is destroyed.
- 10:00: Power (backup 6 kV) restored to unit 4 by electricians.
- Bryuchanov requests evacuation of Pripyat, but his report didn't specify higher (true) levels of radiation. It was denied by Scherbina. Levels described required at least warning of population, which wasn't done.
- N. Karpan, A. Kriat, A. Gobov (Nuc. safety department, Nuc.-Phys. Laboratory): a re-criticality is to be expected by 19:00 due to Xe decay. Repeatedly told Lutov and Fomin (and Bryuchanov through S. Parashin) about this and requested Boric acid to be fed into the core. Director ordered this, but material wasn't delivered.
  In case of open reactor, air cooling for 6 hours sufficient to prevent fuel melting due to residual heat. No sense in pumping water into reactor.

26TH APRIL NOON

- ~12:00: V. Perminov evaluates spectrometry results of material deposited outside. It shows fission products and 17% Neptunium.
- Several persons report that water pumped into reactor doesn't reach it and instead causes contamination of other premises.
- Important decisions couldn't be made locally, always waiting for higher authorities.
- 13:00: First specialists arrived: B. Ya. Prushinskiy and Ye.I. Ignatenko (Soyuzatomenergo chief and deputy chief engineer), V.S. Konviz (Gidroproyekt), K. K. Polushkin and Yu. N. Cherkasov (NIKIET), Ye. P. Ryazantsev (Kurchatov institute)
- ~14:30: First flight in MI-6 helicopter (Prushinskiy, Polushkin, Rasskazov). Reactor lid of bright cherry color.



First photos taken on 26th at approx. 14:30 by Anatoliy Rasskazov



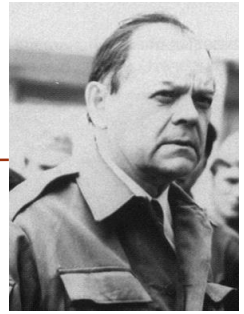
Reactor: smoke, steam, red glow, white/blue flashes in 10s intervals

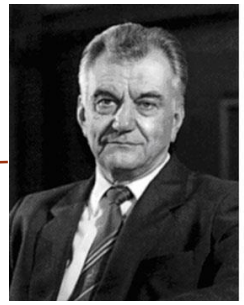
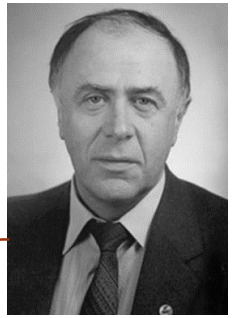
26TH APRIL AFTERNOON

- ~15:00?: Government commission arrived: Shasharin, Maryin and Kizima (head of ChNPP construction) upon arrival inspected Unit 4 from outside; observed scattered graphite
- 17:00 Shasharin, Mariyn, Sidorenko, Legasov(?) flew in helicopter over plant. Lid color was bright yellow.
- Preparation for evacuation of Pripyat started (Bedrov?)
- In the night Scherbina, Shasharin, Legasov took helicopter to observe the plant.
- Brychanov flew 3 times around reactor
- 20:00: Re-criticalities started and lasted until 4am of 27th. More than 10x increase in gamma radiation and for the first time neutrons (20 n/s.cm^2) registered at the north side of Unit-4 (Abramov).
- 21:00 Shasharin ordered to shut down Units 1 and 2
- Over 10,000 m^3 of water was pumped into the reactor. The fact that this water did not reach the core was known to the station management. This was in reports of many people including Y. Yudin (deputy head of department of centralized maintenance), V. Babichev (NSB), V. Smagin (NSB), A. Kryat and the others.

GOVERNMENT COMMISSION

- 1st commission:
  - B.Ye. Scherbina, deputy chairman of council of ministers
  - L.P. Drach, Scherbina's consultant
  - A.I. Mayorets, minister of energy and electrification
  - A.N. Semenov, deputy minister of power
  - G.A. Shasharin, deputy minister of power for NPP
  - V.F. Sklyarov, minister of power of Ukraine
  - V.V. Maryin, head of nuclear power sector of CPSU
  - A.G. Meshkov, deputy minister of medium machine building
  - V. A. Sidorenko: Deputy Chairman of the Gosatomnadzor
  - M.S. Tsvirko, chief of Soyuzatomenergostroy
  - V.A. Shevelkin, deputy chief of Soyzenergomontazh
  - V.N. Shishkin, deputy chief of Soyzenergomontazh
  - V.K. Pikalov, colonel general, head of USSR chemical forces
  - B.P. Ivanov, colonel general, deputy head USSR civil defense
  - Ye.I. Vorobyev, deputy minister of health
  - Yu.N. Shadrin, assistant to general procurator
  - V. A. Legasov, E.P. Velikhov, IAE




12

1ST GOVERNMENT COMMISION MEETING

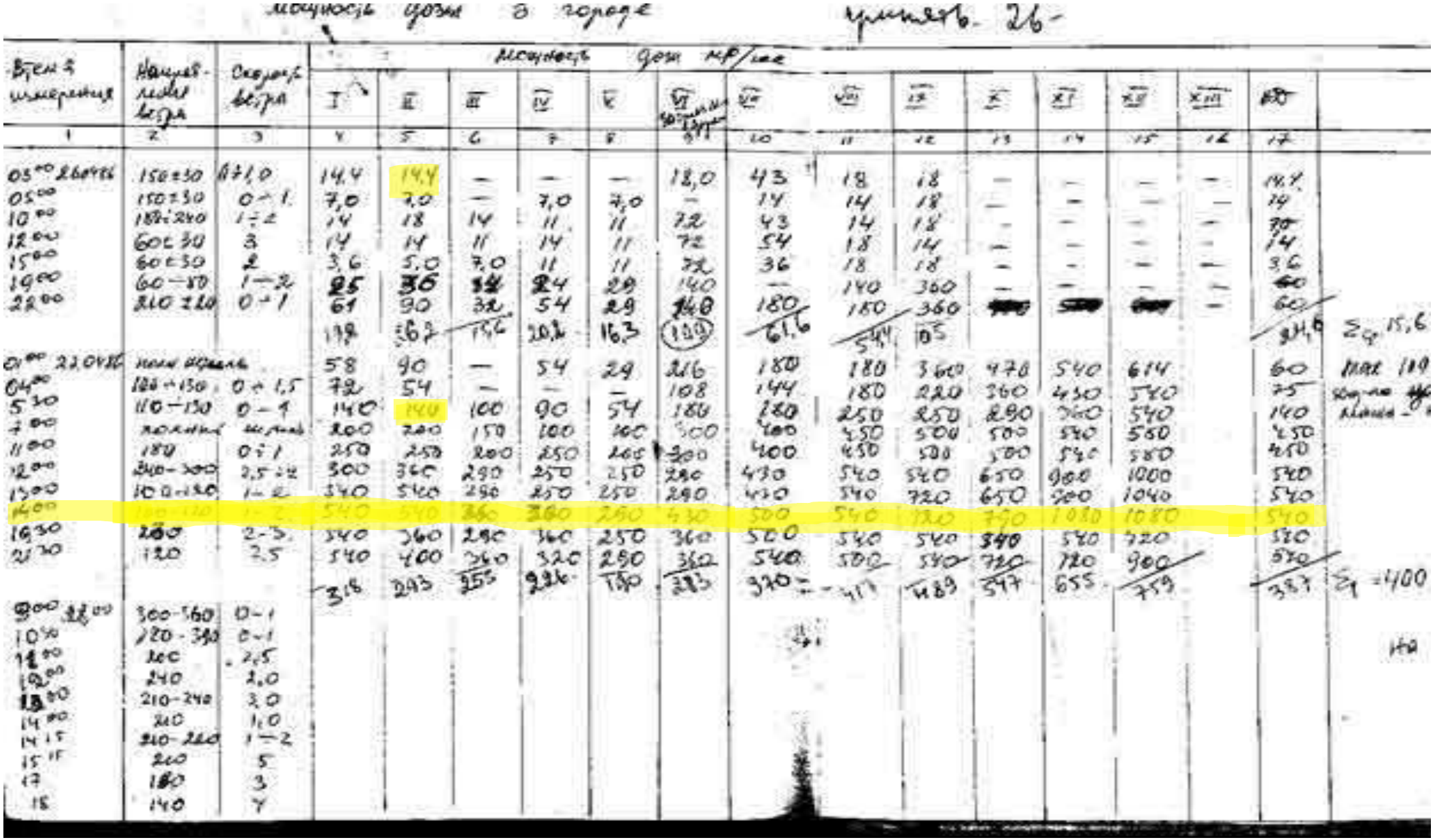
- Afternoon in Pripyat
- Shasharin reported that reactor was destroyed
- Maryin reported his observation, scattered graphite and destruction
- Gamanyuk (1st secretary of Pripyat gorkom): No panic, ordinary life in city.
- Unknown radiation situation, assumed to be high. Vorobyev reported measurements exceed 250 R/h in several places.
- Turovskiy: examined patients exceed lethal dose 3-5 times. Required evacuation.
- Bedrov correctly assessed radiation situation and took steps
- 21:00: Scherbina arrived
- 23:00: Ivanov informed Scherbina about radiation situation in Pripyat and asked for prompt evacuation
- Order to evacuate is issued by the chairman of the regional executive committee on the basis of a report by the director of the nuclear power plant and radiation assessment data. Requires Ministry of Health approval.
- Scherbina postponed the decision until morning of 27th
- Scherbina ordered Shasharin, Meshkov (deputy ministers) and Antoshkin (major gen.) to fill first bags with sand for helicopters

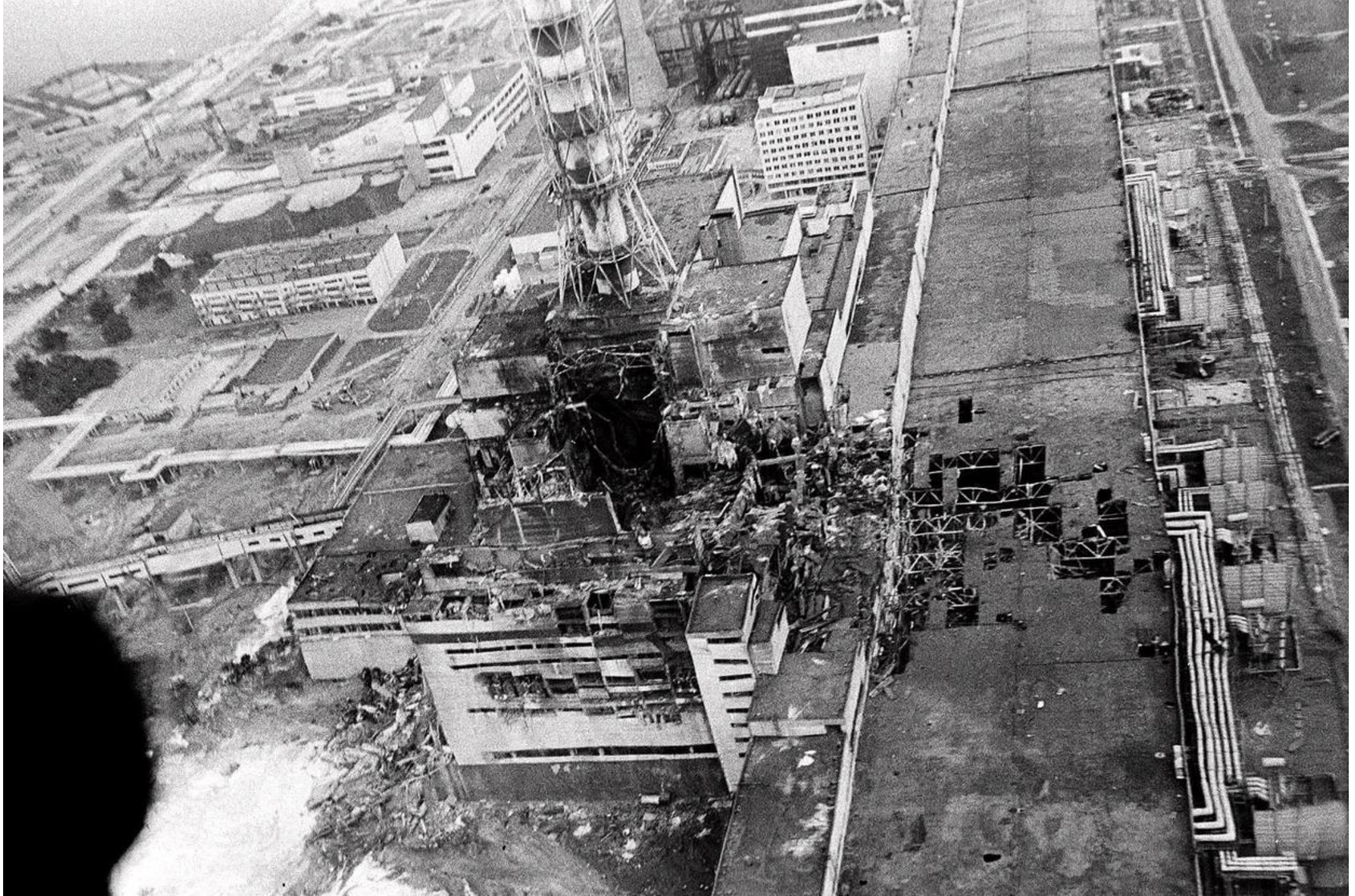
27TH APRIL

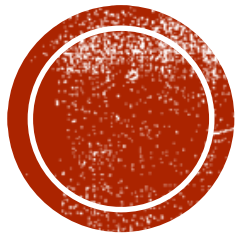
- A column of 600 buses and 230 trucks left Kiev (and another 350 buses moved from other cities) in the direction of Pripyat.
- 7:00: Shcherbina (and ministry of health) decides to evacuate. Pikalov proposes not to hurry.
- 14:00: Evacuation of Pripyat begins (5 to 15-fold increase in rad levels on 27th)

Street name	Measured rates in mR/h	
	26.04.1986	27.04.1986
Kurchatova Str.	22	320
Sportivnaya Str.	16	250
Hydroproektorskaya Str.	20	230
Stroitelei Str.	16	250
Squire at city park	86	280
Druzhba narodov Str.	62	380
Entusiastov Str.	53	520
Ohneva Str.	115	490
Labaratory of External Dosimetry	25	340

Exposure dose rates in chosen spots in Pripyat (mR/h)



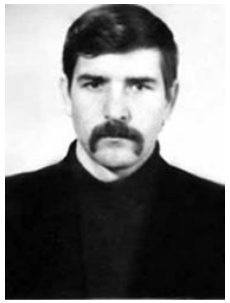




VICTIMS (FIRST)

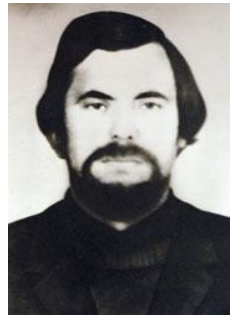
- Valery Khodemchuk: died immediately in northern MCP room. Body never recovered

- Anatoly Kurguz: 3 open doors from the CZ, scalded by radioactive steam

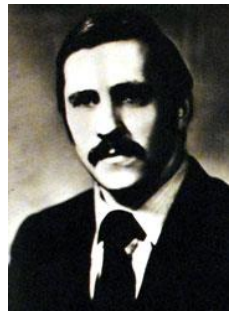


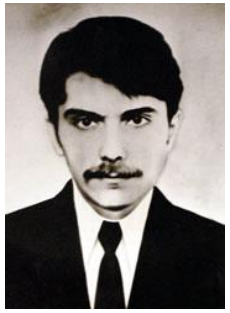
- Viktor Degtyarenko: close to MCP, scalded by hot steam

- Vladimir Shashenok: On duty under reactor's feedwater unit level +24 (Room 604). Found unconscious and pinned down under a fallen beam. Broken spine and ribs, deep thermal and radiation burns.



- Viktor Proskuryakov and Aleksander Kudryavtsev sent to CZ to insert SUZ rods manually.





- Valery Perevozchenko: went to rescue Khodemchuk in MCP room and others, looked into the reactor

- Alexander Akimov, Leonid Toptunov, Ivan Orlov: attempted to restart feedwater flow into the reactor

- Anatoly Sitnikov: ZGIS, sent by Fomin to survey the premises and reactor hall

- Aleksander Lelechenko: deputy chief of electrical shop, went 3 times inside to switch off electrolyzers and remove hydrogen, attempted to supply voltage to pumps

- Klavdia Luzganova: security guard for spent fuel storage

- Yekaterina Ivanenko: security guard

TURBINE AND ELECTRICAL SHOP

- Turbine hall operators: V. Brazhnik, A. Novyk, K. Perchuk, Y. Vershinin




- Electrical engineers: A. Baranov, Y. Konoval, V. Lopatyuk, A. Shapovalov



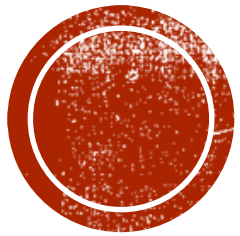

- Kharkov Turboatom plant (in Mercedes car parked inside): V. Savenkov, G. Popov

FIREFIGHTERS

- NPP Fire Rescue Unit:
  - L. Telyatnikov: survived until 2004
  - V. Pravik: head guard
- 6th Fire Rescue Unit of Pripyat:
  - V. Ignatenko: squad commander
  - N. Vashchuk: squad commander
  - V. Kibenok: head guard
  - V. Tishchura: senior firefighter
  - N. Titenok: firefighter

"A glow can be seen in the central reactor hall. Nothing could burn there except the "piatachok" (E-scheme). So together we decided that this glow came from the reactor".

Total: 15 fire departments, 69 fire fighters



CAUSES OF ACCIDENT

- Large reactor dimensions, difficult to control
- Positive feedback (steam-void coefficient of reactivity)
- Unstable low power operation, difficult to control
- Control rod design, slow insertion
- Insufficient power monitoring and reporting
- Lack of supervision from Nuclear safety department during shutdown
- Insufficient documentation, operating instructions
- Personnel errors

OPERATIONAL REACTIVITY MARGIN

- ORM = Positive reactivity that a reactor would have if control rods would be completely withdrawn. Simply: equivalent number of fully inserted rods in core
- ORM not mentioned in operating manual as a critical parameter, rather for economical reasons.
- ORM is reported 2x per hour; possible to estimate manually or request calculation (takes ~5 minutes)
- If ORM below 26 rods RR, it was necessary to obtain the authorization of the chief engineer for further operation
- If ORM below 15 rods RR, the reactor had to be shut down
- In a reactor operating at a constant power level, reactivity is always compensated (to zero) by the negative reactivity introduced by control rods. A large value of ORM means an "increased" share of excess nuclear fuel (U235) spent to compensate for this negative reactivity, instead of using fuel for producing energy. In addition, an increased value of ORM carries a certain potential hazard, since it means a sufficiently high value of reactivity that can be introduced into the reactor due to the erroneous extraction of the control rods.

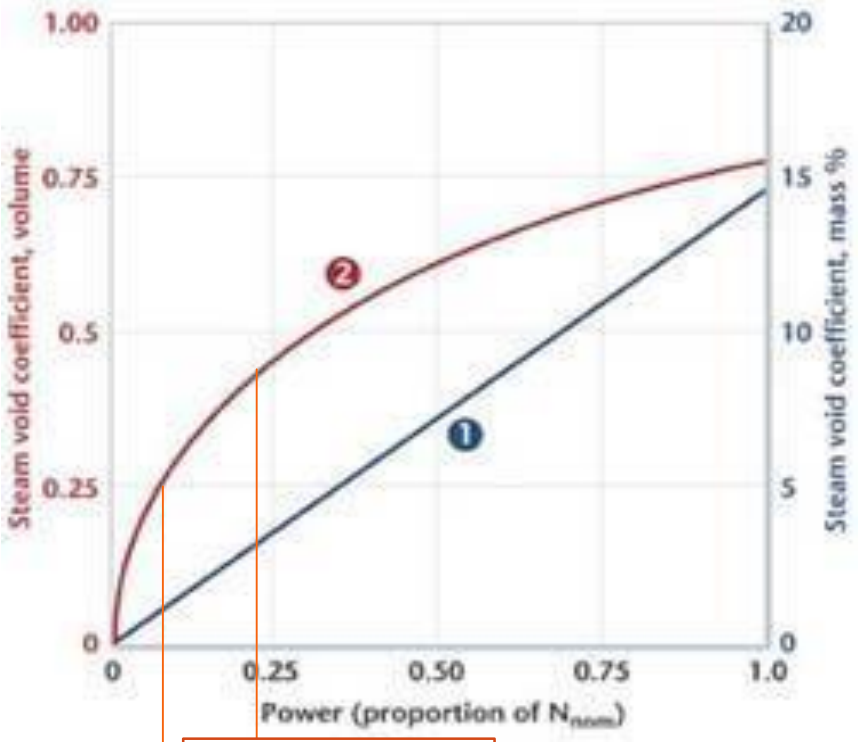
POSITIVE FEEDBACK

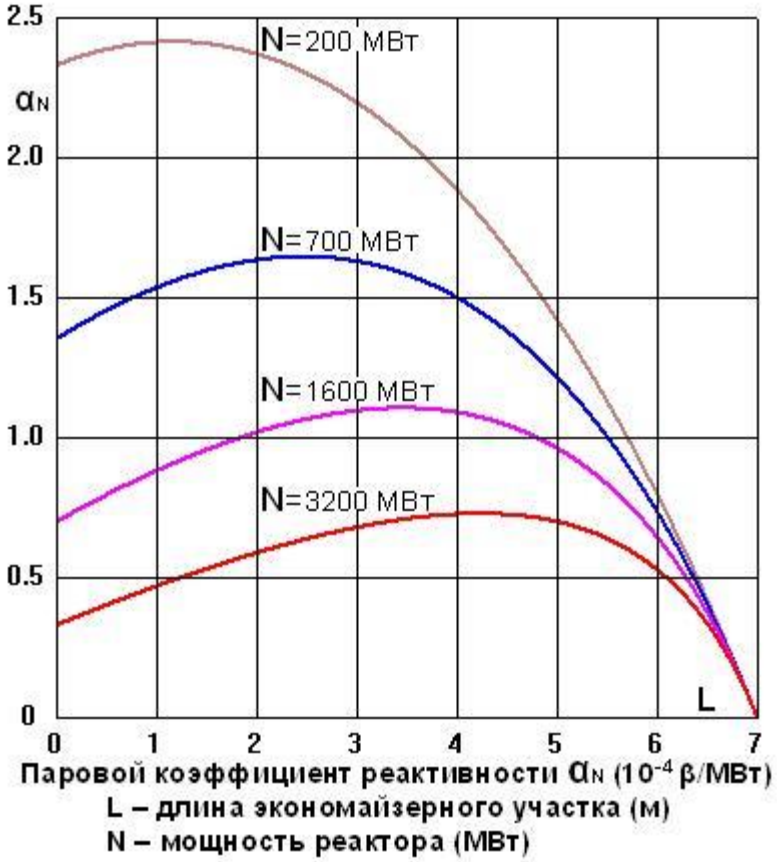
- Positive steam-void coefficient of reactivity: when water (neutron absorber) starts to boil, steam voids produced result in further increase of reactivity => acceleration.
- Compensated by control system so that the resulting coefficient of reactivity is negative.
- Positive values especially during low power operation or higher fuel burn-up.
- Mitigating this effect required increased ORM or presence of additional absorbers in core (DP). ChNPP Unit 4 before accident contained **only 1 DP** ! Why?
- Fuel burnup ~1100-1200 MW-d/t per fuel assembly and with ORM 26-30 manual control rods, the void coefficient of reactivity approached +5 β_{eff}.
  Would require fuel enrichment of 2.4% and 80 DPs to reduce < 1 β_{eff}.

- Changes after accident: Minimum ORM increased to 30, increased additional absorbers to 30.

OPERATION AT LOW POWER

- At a low power level a given power increment results in an increase in steam volume in the coolant which is many times more than at nominal full power (N_{nom}). The resulting fast power coefficient of reactivity, to which the negative Doppler effect of fuel and the positive steam void effect contributed, turned out to be positive.





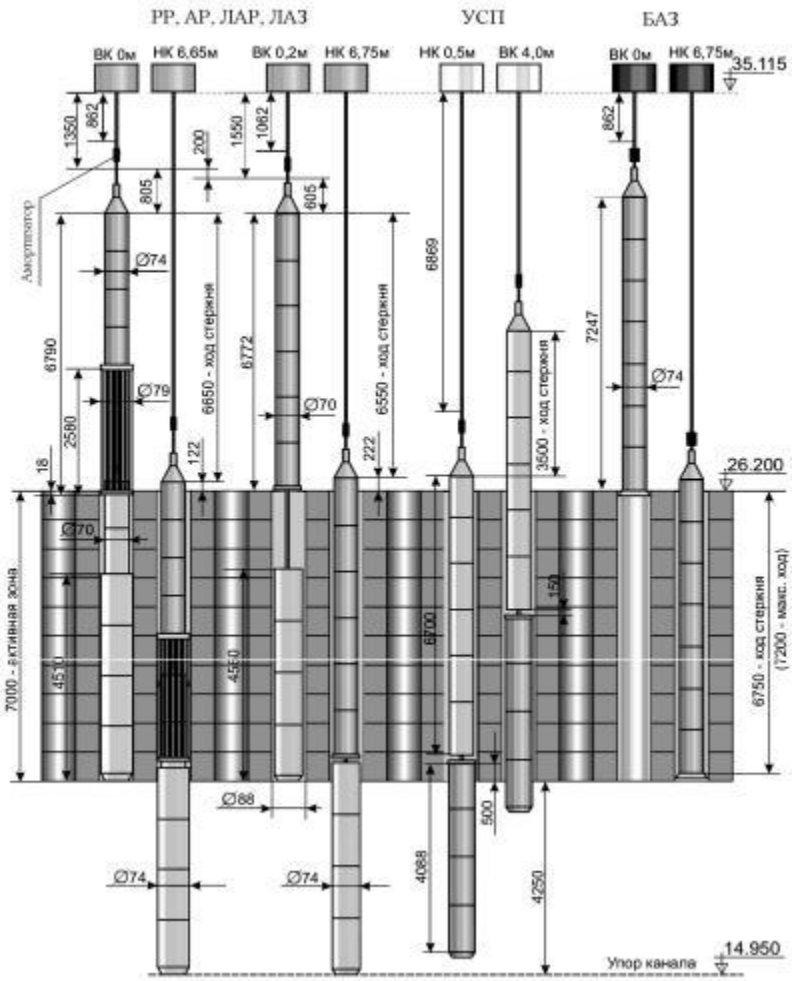
OPERATION AT LOW POWER

- Reactivity calculations performed by designer only at power level >50% nominal.
- No restrictions on operating at low power level in regulations.
- SFKRE (system for control of distribution of energy) sensors used to measure neutron flux density don't work reliably at power below 10% (320 MW). Ionization chambers jammed at low power due to high gamma field. Reactor operated without trustworthy information in transient regimes, especially low power.
- Reactor startup often done blindly, AZ automatically activated, had to start over several times.
  - V.I. Borets: In 1975 at LAES during reactor startup, the problem of operating at low power was observed (low power, low ORM). Attempt to rise power resulted in inadequate reduction of power multiplication period (acceleration!).
  - In 1983 at a Scientific Technical Council headed by A.P. Alexandrov (IAE) shortcomings of the RMBK were intentionally ignored.
  - V.I. Borets: In 1984 during a conference about RBMK held in Moscow (headed by Yu.N. Filimontsev), all known problems of RBMK (low power operation, large positive steam-void coefficient of reactivity, end effect of rods, slow rod insertion) were discussed, but NIKIET refused to accept them. This was documented and distributed to NPPs including ChAES and the management especially chief engineer were informed about this.

CONTROL RODS

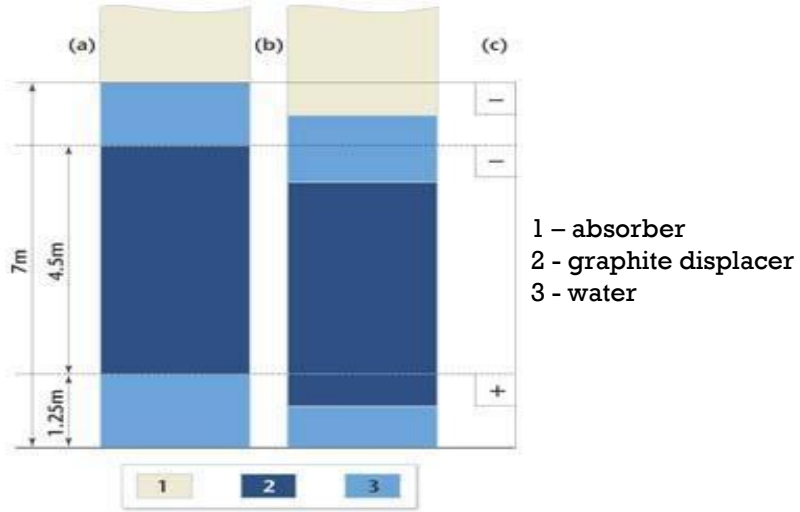
- Total count: 211
- Insertion time: 18 seconds

	Count	Travel length	Absorber	Displacer
Emergency protection (AZ)	24	6.55 m	6.55 m	-
Manual regulation (RR) Automatic regulation (AR) Local automatic regulation (LAR) Local emergency protection (LAZ)	115 12 12 24	6.55 m	**6.2 m**	**4.56 m**
Shortened rods (USP) Inserted from bottom **Not included in AZ control !**	24	3.5 m	3.5 m	6.7 m

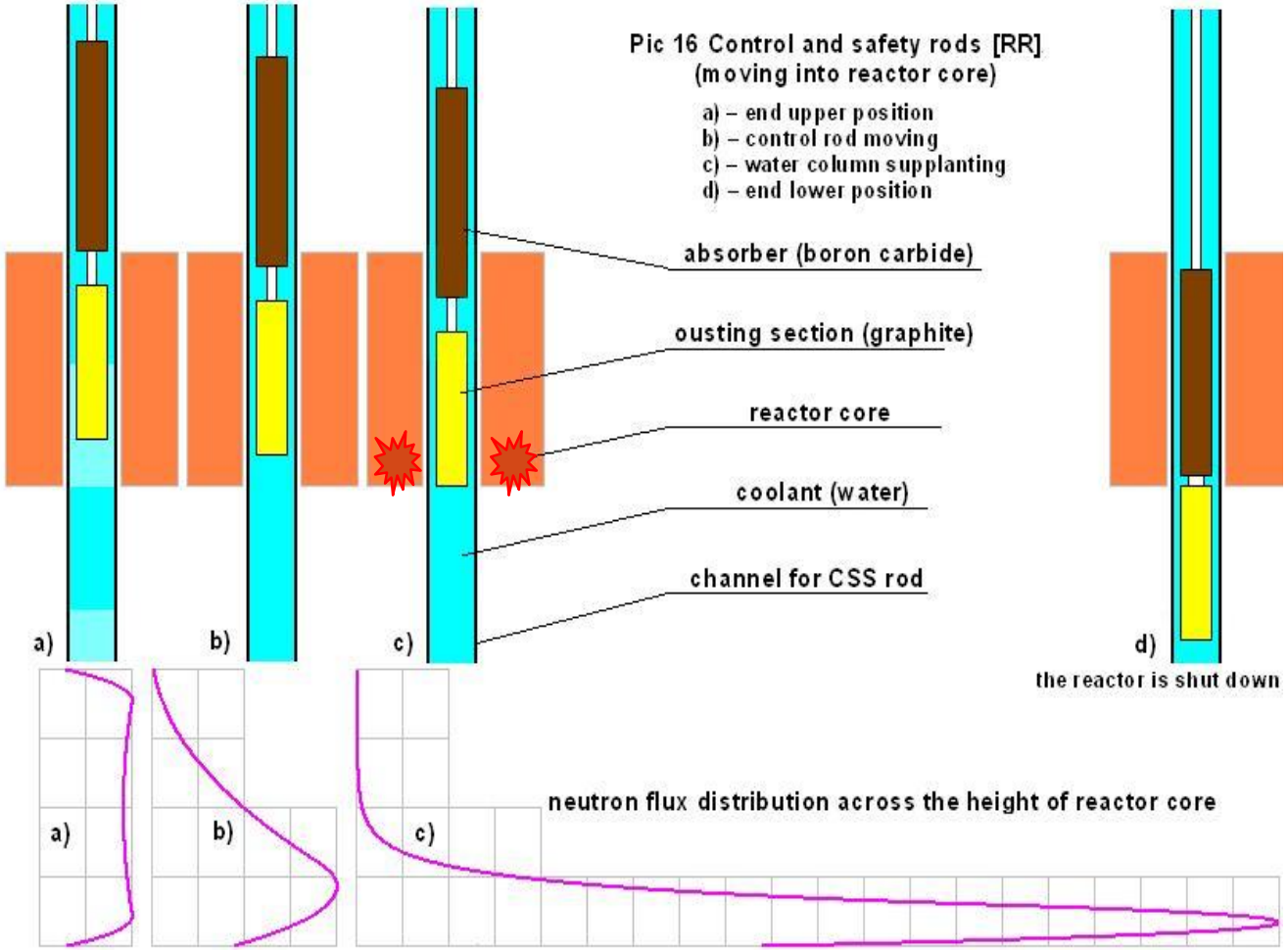


"END EFFECT" OF RODS

- Inserting rods from upmost position displaces water with graphite, which causes increase in reactivity at bottom.
- Thermal neutron absorption cross-section of water is 21 times higher than of graphite.



1 – absorber
2 - graphite displacer
3 - water



CONTROL ROD DEFFICIENCIES

- Observed by A. L. Gobov in 1978/79, notified Kopchinsky, who didn't take appropriate measures (admitted). Also in 1981 at LNPP, recorded by V. Ya. Abakumov.
- Proven in 1983 at Ignalina NPP during startup in presence of NIKIET, IAE and IAES. V. A. Sidorenko (director IAE) notified NIKIET, which promised to take measures.
- In Jan-1984 chief designer notified all NPPs via a letter. Personnel was apparently not made aware.
- AZ signal didn't drive USP rods. Kursk NPP proposed to include it, which was also done in ChNPP Unit 1-3. Was planned to be implemented in Unit 4 during shutdown planned on Apr-25 !!
- Improvements after accident: Increased USP rod count to 32, added BAZ rods (2.5 s insertion time), full-length absorbers, inclusion of USP rods in AZ.

	11	13	15	17	21	23	25	27	31	33	35	37	41	43	45	47	51	53	55	57	61	63	65	
66									7		0		0		0									66
64						0		0		86		7		20		0		0						64
62					0		0		244		0		0		0		20		0					62
60				0		0		H		0		106		0		H		0		0				60
56			0		0		0		0		0		13		0		0		7		0			56
54		0		0		0		26		0		***139***		0		7		13		0		0		54
52			0		13		0		0		7		0		125		7		0		80			52
50		0		H		66		***158***		0		H		7		***158***		26		H		7		50
46	0		0		126		7		0		99		0		33		0		20		139		7	46
44		0		0		7		0		0		***20***		0		79		119		7		192		44
42	0		0		0		0		20		0		7		0		143		0		0		178	42
40		0		0		***139***		H		***20***		7		***20***		H		***139***		0		60		40
36	0		0		0		7		0		0		86		0		0		0		0		70	36
34		176		7		7		7		0		***20***		20		0		99		163		7		34
32	20		125		0		0		20		264		7		13		40		0		20		0	32
30		0		H		0		***158***		0		H		0		***158***		0		H		0		30
26			0		0		0		7		33		0		60		0		26		0		0	26
24		0		20		0		0		0		***139***		7		0		0		7		7		24
22			0		0		0		7		0		0		0		79		0		0			22
20				0		0		H		7		20		0		H		0		0				20
16					7		0		0		0		0		33		0		0					16
14						7		0		13		0		0		0		0						14
12									0		0		0		0		0							12
	11	13	15	17	21	23	25	27	31	33	35	37	41	43	45	47	51	53	55	57	61	63	65	

Immersion depth of control rods [cm] at 01:22:30 of 26/4, ORM = 7.5 rods RR.

Total: 48 linear meters of immersed rods.

Rods immersed to 1 m or more:

- RR: 7
- AR: 8
- LAR: 1
- LAZ/PK: 1
- AZ: 0

L - *USP rods*

L - *AR rods* (don't have displacers)

H - *Sensors (DKE)*

- *G. Dik (station shift supervisor): I believe the personnel couldn't know that operation at low power level shifts a reactor into nuclear hazardous condition. It was not mentioned in the regulations that working with the effective equivalent fewer than 15 control rods shifts a reactor into nuclear hazardous condition.*
- *I. Kazachkov (former Unit-4 shift supervisor): We did not know that operation with the effective equivalent (ORM) fewer than 15 control rods shifts a reactor into nuclear hazardous condition.*
- *N. Shteinberg (former station chief engineer, later deputy head of Gosatomenergonadzor and chief investigator of the accident): We knew that we dealt with reactor designed with drawbacks. We had learned how to control the reactor and adapted ourselves to intricacy and unpleasantness of control. But we did not know that some of operation modes had never been learned out and proved to be safe.*

PERSONNEL ERRORS

- Operating policy required the chief of the nuclear safety department or his deputy to be present at launch or shut-down of reactor.
- Such representative was not present on April 26 !
- N. Karpan: "*On April 25 Anatoly Chernyshev should have worked (a very experienced reactor operator in the past) and he was ready. But the shut-down of the reactor was rescheduled for the April 26. When Chernyshev called the station on April 25 he was said that all test programs had been finished and he might not go to work.*"

- ECCS (SAOR) should be put on stand-by, but not completely disabled. Nonetheless, this had no impact on accident as the relevant signal wasn't detected during the entire phase and ECCS tanks have been destroyed at the beginning of accident.

PERSONNEL ERRORS

- Test program requirement: power level 700-1000 MW thermal.

№ п-п	Наименование работ	исполнитель
2.1.	Нагрузку блока снизить до 700…1000 МВт тепловых	НСС

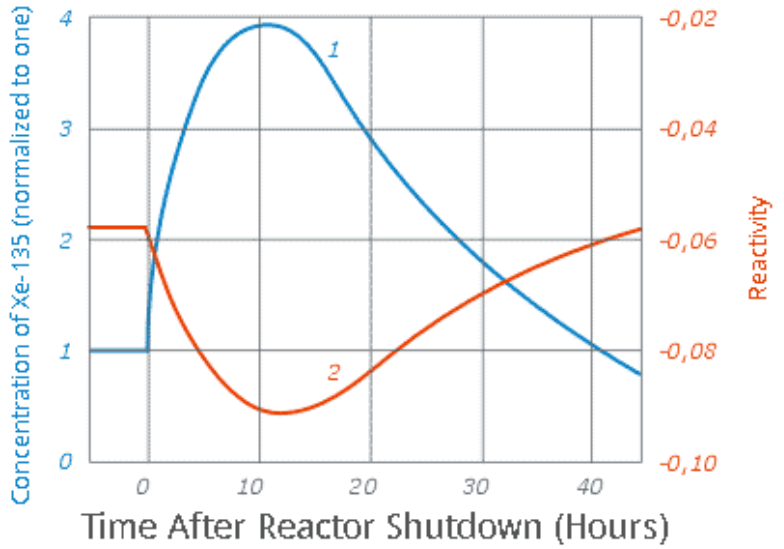
- Dyatlov claims this was not a mandatory level.
- 26.4. 0:00 reactor operating at 720 MW(t), but further reduction in power requested. Who gave this command and what was the target level ? Dyatlov ?

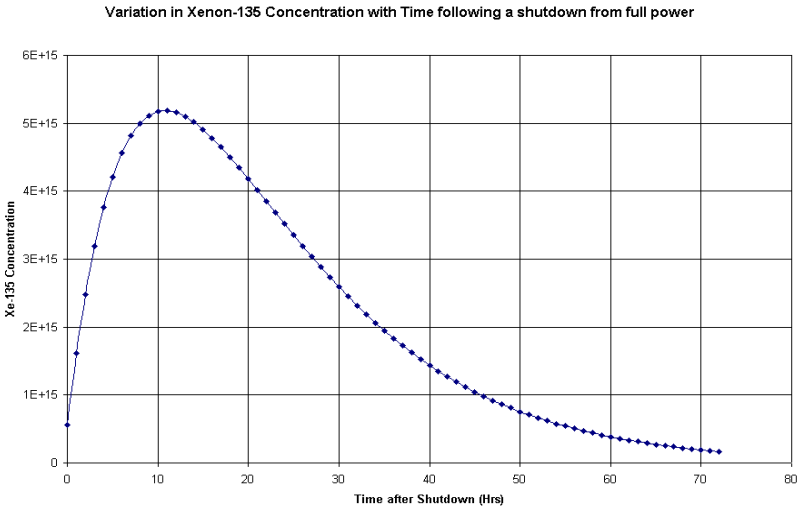
- *A. Kryat (Head of the Nuclear-Physical Laboratory):*
  "I became acquainted with the schedule of reactor discharge and power level decreasing from 1600 MW to 300-200 MW (thermal). This was a draft document. I said that I would not approve the level of 300-200 MW (thermal). 1000-700 MW (thermal) was required because operation of the reactor at less than 700 MW (thermal) leads to loss of reactivity. This mode is also inadmissible for the PRIZMA system intended to control a reactor physical condition. I raised my voice against this in the work meeting guided by Dyatlov. I said that operation at 200 MW (thermal) leads to loss of control."

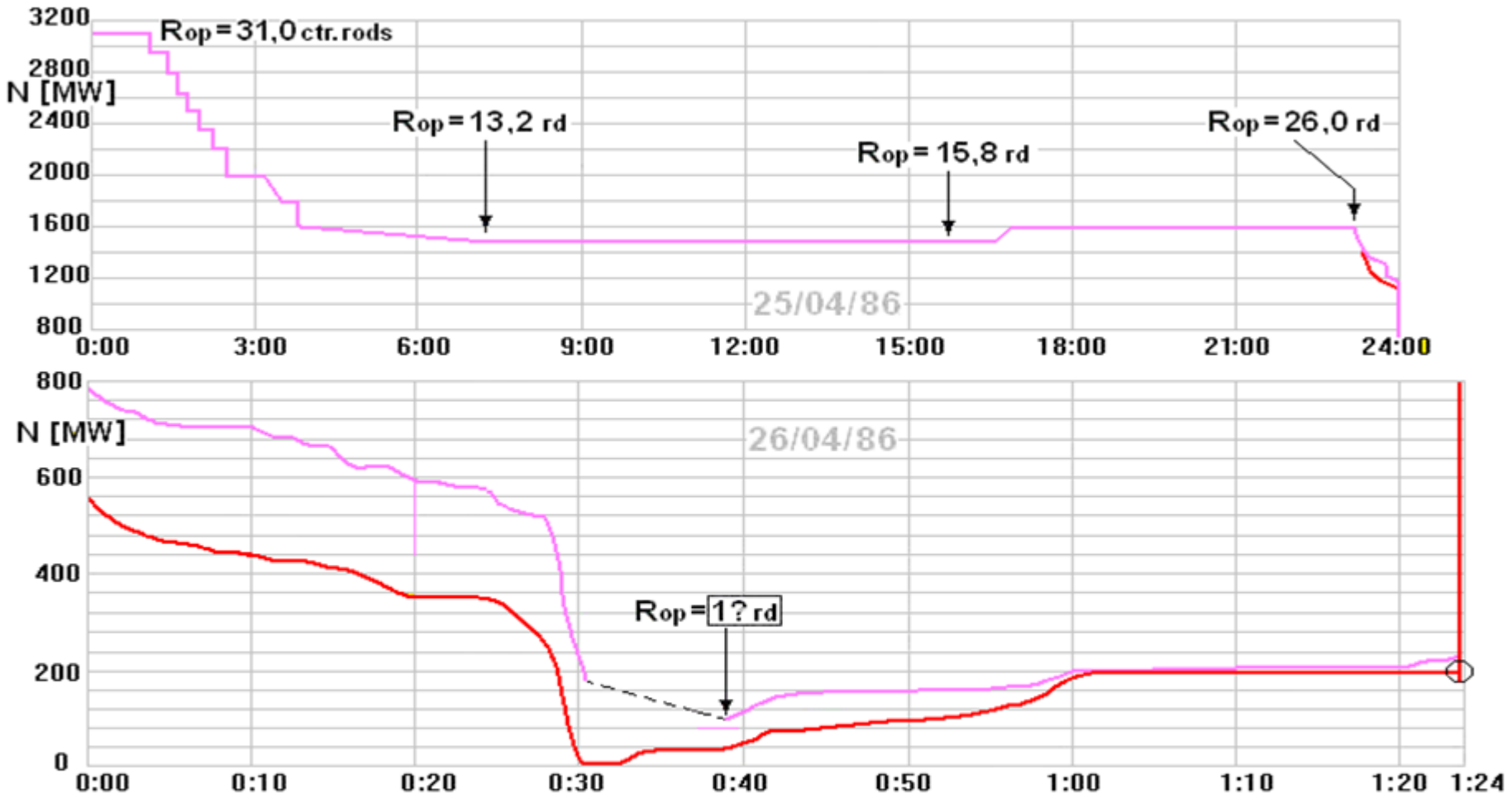
RESTARTING A POISONED REACTOR

- At 00:38 power 20 MW(t) (neutron=0), command given to raise power. Who, why?
- Reactor in "iodine pit" – poisoned by ^{135}Xe, ^{149}Sm
- ^{135}I (6.6h) -> ^{135}Xe (9.2h) -> ^{136}Xe (stable)
- ^{135}Xe concentration peaks 11 h after power reduction
- Requires 72 hours to decay to acceptable levels.
- Requirement on restarting of reactor without passing the iodine pit (regulations):

Power level (% nom)	ORM required (rods RR)
80 - 100 %	50
50 - 80 %	45
50 %	30







Pic 1. Reactor power N (MW) changing for twenty-four hours 25/04 and for time till its destruction 26/04

power by PPDDCS (sensors of the interreactor control system)

power by SIC (sensors of automatic control system) expansion of emergency process

1?rd - according to some data 12, according to the other 17–19 (ctr.rods)

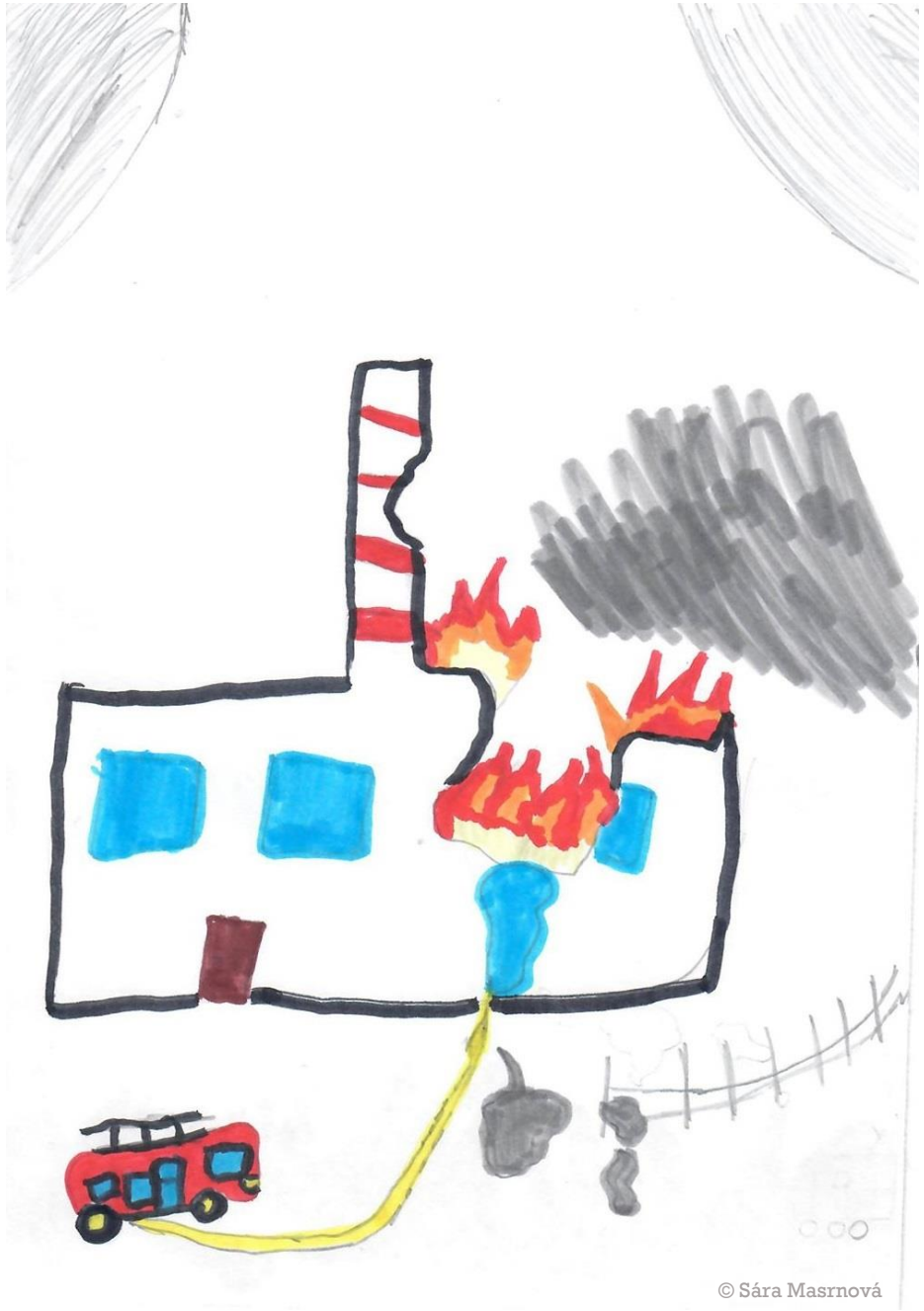
- 3200 ->1600 MW
  20 hours
- 1600 -> ~500 MW
  1.5 hours
- 500 -> 30 MW
  0.1 hours
- 30 -> 200 MW
  0.5 hours

- Georgy Alekseevich Kopchinsky: Head of the nuclear energy sector of the CPSU Central Committee, responsible for RBMK.
  Anonymous testimony: "All conversations and calls on the control panel are recorded. I personally heard these notes. The test manager, the deputy chief engineer Dyatlov, and the operational staff understood that it was impossible to do this (to increase power. - Auth.). Dozens of instructions and regulations for the operation of the reactor strictly prohibit such actions! But Dyatlov was called by Kopchinsky, an employee of the all-powerful Central Committee of the CPSU, and ordered the fourth reactor to be brought to capacity ..."

  «Все разговоры и звонки на щите управления записываются. Я лично слышал эти записи. Руководитель испытаний, заместитель главного инженера Дятлов, и оперативный персонал понимали, что делать этого (поднимать мощность. — Авт.) нельзя. Десятки инструкций и регламент по эксплуатации реактора категорически запрещают подобные действия! Но Дятлову позвонил Копчинский, работник всесильного ЦК КПСС, и приказал выводить четвертый реактор на мощность...»

FINAL EVENTS

- 1:23:04: Ready to perform test. MPA button pressed, TG run-down started.
- TG characteristics measured, all going smooth, no warning signals. Reactor should be stopped after finishing test.
- 1:23:40: AZ-5 pressed. Reason?
  a) Emergency: reactor was already unstable and accelerating. Analysis of signals doesn't confirm this.
  b) Test end: AZ-5 was pressed as the test was finished.
- All SUZ rods (except USP) start entering the core. Low ORM (6-7 rods RR) - most rods in the uppermost position, 1.25m column of water at bottom displaced by graphite. Instead of ceasing reactor, additional positive reactivity added.
- 01:23:43: Excess power alarms, high rate of power increase. Reactivity added by AZ-5: +0.8 $ß_{eff}$ to the bottom part of core.
- 01:23:47-50: Sharp reactivity increase due to coolant boiling, acceleration on prompt neutrons (supercriticality), exponential power growth.
- Rupture of TK, release of TVELs, water expelled from reactor. Explosions.



THANK YOU !