РОСАТОМ

ГОСУДАРСТВЕННАЯ КОРПОРАЦИЯ ПО АТОМНОЙ ЭНЕРГИИ «РОСАТОМ»

FUEL COMPANY OF ROSATOM TVEL

ВНИИНМ имени А.А.Бочвара

Approaches to deal with irradiated graphite in Russia – Proposal for new IAEA CRP on Graphite Waste Management

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The weight of the irradiated reactor graphite

- in the world– 250000 t
- in Russia – 50000 t

The weight of graphite of a reactor unit

- RBMK -1000 – 1800 t
- AMB -100/200 – 900 t

Uranium-graphite reactors in Russian Federation

Type of reactor	Number, status
Plutonium production reactors	13 units, at decommissioning stage
RBMK	11 units, in operation
EGP-4	4 units (Bilibino NPP), in operation
AMB 100\200	2 units (Beloyarsk NPP), at decommissioning stage
AM	1 unit (Obninsk, Kaluga reg.), at decommissioning stage

Estimates of ^{14}C content in the irradiated reactor graphite

Reactor	Specific activity, Ci/t
AMB-100 (Beloyarsk NPP)	1,8 - 3,1
RBMK-1000 (Chernobyl NPP)	0,3
IR-A1 («MAYAK»)	0,5
I-1 (Siberian CC)	50
I-2 (Siberian CC)	30
ADE-3 (Siberian CC)	27
Sleeves (Siberian CC)	1,2

The presence of nuclear fuel in the irradiated reactor graphite

Reactor	Nuclear fuel weight (U) in a stack, kg
AMB -100 (Beloyarsk NPP)	70-150
I-1 (Siberian CC)	7,9
I-2 (Siberian CC)	3,6
ADE-3 (Siberian CC)	8
AV-1, AV-2, AV-3 («MAYAK»)	3-4
IR-A1 («MAYAK»)	2,75

1. Storage/disposal without processing

I-graphite is concreted into the reactor space.

Advantages

- No cost for equipment manufacturing and processing

Disadvantages

- Costs for monitoring and operation

1. Storage/disposal without processing

“In-situ” disposal - the main concept for Russian plutonium production reactors
Russian legislation (The Federal law “About RWM”) provides the transfer of radioactive waste into the category of "special", for which long-time controlled storage and disposal "in-situ" are acceptable “Special” radioactive waste - radioactive waste for which the risks associated with radiation exposure, other risks and costs associated with the recovery of radioactive waste from the point of storage, followed by proper treatment, including disposal, outweigh the risks and costs associated with the disposal of radioactive waste in their location

2. Dismantling of the graphite stack

2.1 Loading of graphite blocks in containers

Disadvantages

- usage and placement of a large number of containers;
- necessity of the construction of an underground storage.

2.2 Utilization of dredged graphite

Advantages

- can be used as an energy source or as raw material for secondary graphite products.

Disadvantages

- contamination of the secondary products by radioactive isotopes, including ^{14}C.

Separation problems of fuel spillage from graphite

Possible decisions

- fuel dissolution in nitric acid;
- fuel chlorination and distillation of chlorides;
- oxidation of graphite in molten salts;
- oxidation of graphite in air flow.

Separation problems of fuel spillage from graphite

	Disadvantages
Processing of graphite with nitric acid to fuel dissolve	➢ the necessity of washing the treated graphite with water and subsequent drying, as a result – formation of the secondary liquid radioactive waste; ➢ volume of i-graphite remains unchanged.
Chlorination of fuel and chlorides distillation	➢ the necessity of chlorination of the entire volume of graphite; ➢ the necessity of use of the complex high-temperature large-size equipment (approximately 6 - 15 times larger than the firebox for burning); ➢ the necessity of creation of a complex gas cleaning system; ➢ corrosion problems due to presence of chlorides; ➢ volume of i-graphite remains unchanged.

Separation problems of fuel spillage from graphite

	Advantages	Disadvantages
The oxidation of graphite in molten salts	➢ elimination of the entire volume of graphite; ➢ partial capture of aerosols and ^{14}C by salt melt; ➢ transferring the fuel spillage in a form suitable for further conditioning.	➢ low rate of oxidation of graphite due to the screening of the graphite by salt melt; ➢ formation of an additional waste - contaminated salt; ➢ discharge of ^{14}C into the atmosphere
The oxidation of graphite in an air flow	➢ elimination of the entire volume of graphite; ➢ the use of combustion equipment significantly smaller volume compared to the equipment using the salt melts; ➢ fuel allocation into a compact phase.	➢ the necessity to create an efficient gas cleaning system; ➢ ^{14}C release into the atmosphere.

^{14}C in an environment

Main reaction of creation	$^{14}N\ (n, p)\ ^{14}C$
Half-life period $T_{1/2}$	**5730 years**
The rate of formation in the atmosphere from space radiation	$4 \cdot 10^{4}$ **Ci/yr**
Exchange pool (atmosphere, biosphere)	$2{,}8 \cdot 10^{8}$ **Ci**
Accumulation in the deep ocean	$3{,}2 \cdot 10^{9}$ **Ci**

Comparison of ^{14}C flow

Space radiation
$4 \cdot 10^4$
Ci/year

Nuclear industry
$(1\text{-}18) \cdot 10^4$
Ci/year

Oxidation of i-graphite from 11 RBMK units per year
$(0{,}6\text{-}5{,}0) \cdot 10^4$ Ci/year

$2{,}8 \cdot 10^8$ Ci
Exchange pool

$3{,}2 \cdot 10^9$ Ci
Deep ocean

Comparison of ^{14}C flow

Situation

Normal operation of each RBMK-1000 unit

Consequences

Technological medium	Production of ^{14}C, Ci/yr	Discharge of ^{14}C, Ci/yr
Coolant	30	30
Gas mixture (He-N)	80 – 220	80-220
Graphite moderator	400	0
Nuclear fuel	90-150	0
Total	**600-800**	**110-250**

Comparison of ^{14}C flow

Situation

^{14}C discharge into the atmosphere during nuclear weapon tests - 1955-1963 years

10^7 Ci

Consequences

Increasing of ^{14}C concentration in the atmosphere by 60%

^{14}C concentration in norm to 2000 yr.

Estimation

Oxidation of i-graphite of all Russian nuclear power reactors (without plutonium-production reactors) gives an emission of ^{14}C

10^4-10^5 Ci

Comparison of ^{14}C flow

Situation

Burning of fossil fuels (coal) on the thermal power plants -

$5 \cdot 10^9$ tons/year

Consequences

The Suess effect - decrease the equilibrium concentration of ^{14}C in atmosphere due to the emission of "dead“ carbon

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Estimation

The equilibrium concentration of ^{14}C in atmosphere

230 Bq/(kg of carbon)

It is possible to burn **30000 tons/year** of i-graphite

(specific activity – 1 Ci/t),

not exceeding the natural concentration of ^{14}C in the atmosphere

Comparison of population exposure doses due to ^{14}C

Source	The effective equivalent dose, mSv/year	Acceptable dose for the population, mSv/year
Space radiation	0,012	1,0
Oxidation of i-graphite from 11 RBMK units per year	0,0018-0,015	

Radiation safety standards for ^{14}C

The maximum acceptable concentration in air	Bq/m^3
For the staff	$1{,}3 \cdot 10^6$
For population	55
Natural background	$3{,}65 \cdot 10^{-2}$

Calculation for the medium-range weather conditions

^{14}C concentration in the near-ground air layer from the source with the power of 1 Ci/day, located on the high of 100m

The distance from the source, km	1	2	4	6	8	10	16	20
A_{tech} / A_{nat}	1,76	2,65	1,76	1,20	0,88	0,69	0,46	0,31

A_{tech} - activity of technogenic ^{14}C
A_{nat} - activity of natural background ^{14}C

The activity of natural background ^{14}C – $3.65 \cdot 10^{-2}$ Bq/m^3

Estimation for the medium-range weather conditions

Oxidation of i-graphite with a specific activity - 1 Ci/t of ^{14}C

Stack height 120 m

There is no production of agricultural products at the nearest territory

It is permitted to burn up to 50 tons per a day

There is a production of agricultural products at the nearest territory

It is permitted to burn up to 4 tons per a day

Technological modes of graphite oxidation in air flow

• The temperature in the furnace volume	900 - 1200ºC
• The speed of air flow through a graphite layer	till 1,0 m/s
• The speed of air flow over the layer	2 – 5 m/s
• The height of the layer of graphite	100 – 300 mm
• Graphite grain size	25 – 35 mm
• Air-fuel ratio	1,45 – 1,50

Unit of the burning of spent reactor graphite

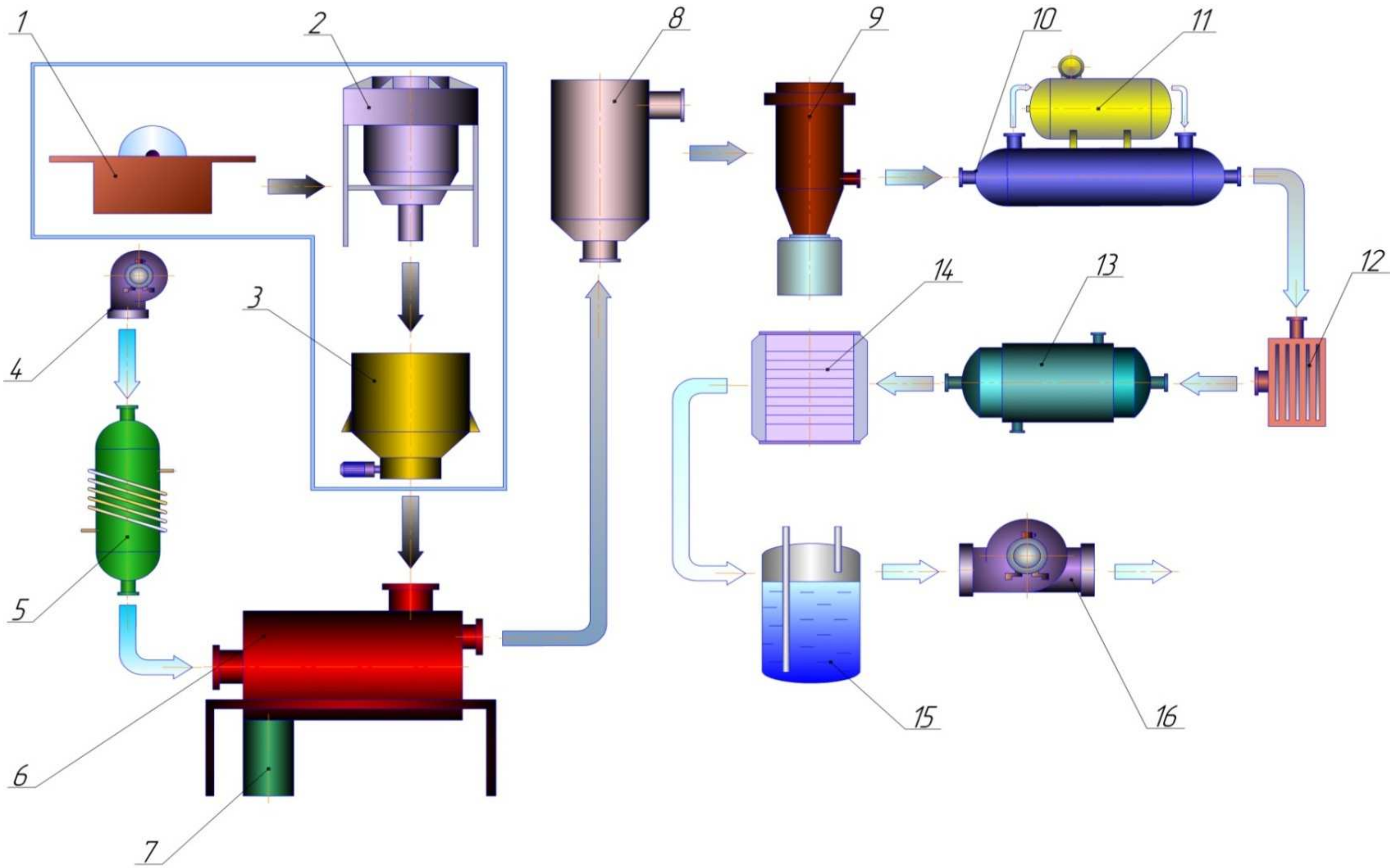
Consist of

- Node grinding graphite blocks
- Dispenser, which provides uniform graphite loading
- Furnace for burning graphite (heating) with a capacity of 1 kg/h
- Knot of afterburner of exhaust gases and aerosols
- Node of collection of the ash residue, which includes a heated bath of molten salt
- Gas cleaning system
- Forced-draught fans
- Smoke exhauster

Technical conditions

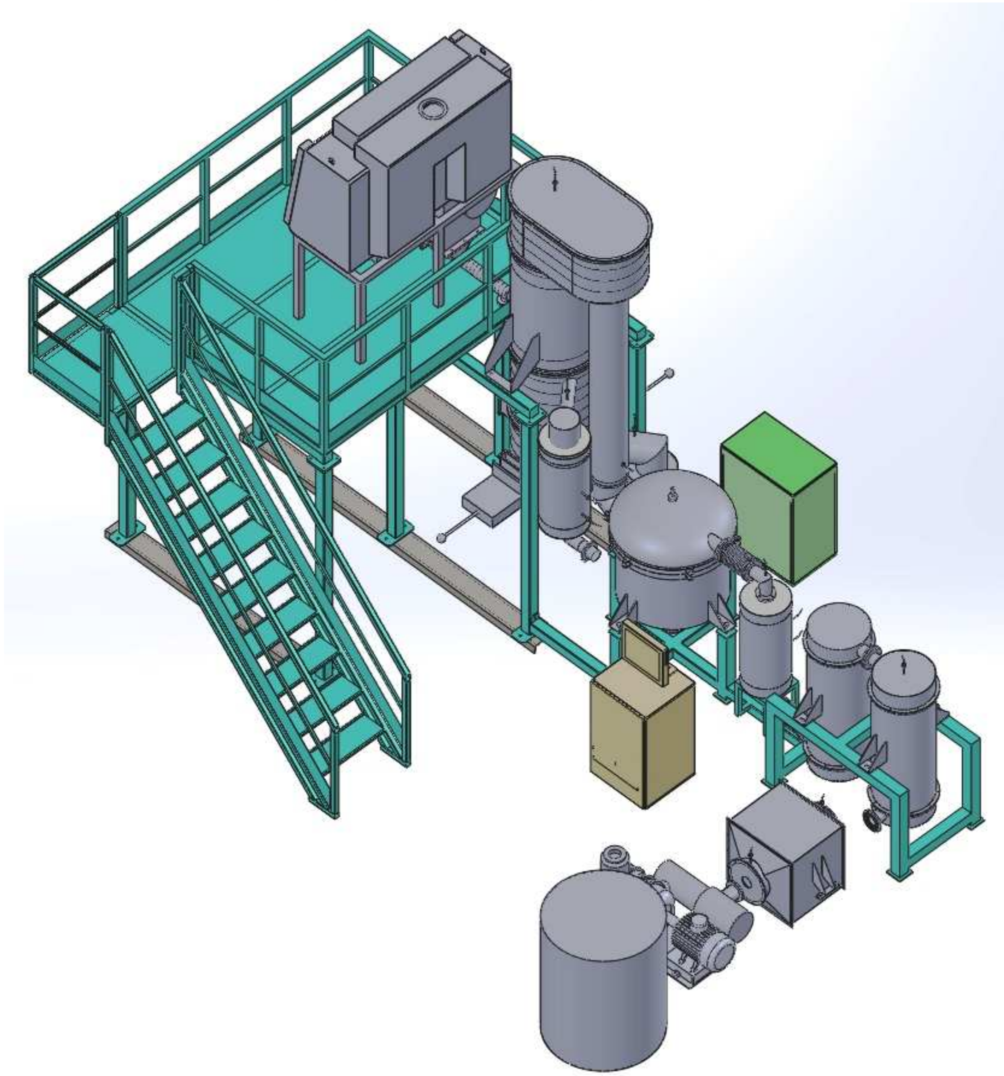
- Furnace and subsequent nodes should be provided by devices to measure resistance to gas flow
- The furnace, the node of afterburner and the metal-ceramic filter should be provided by the temperature measurements
- Before and after each node requires sampling point of gas samples
- Capacity of the unit for air flow – 12 normal m^3/h.
- The speed flow of the supply air – 0,1 – 1,0 m/s

The scheme of unit of the reactor graphite processing by burning



1 – Fragmentation node ; 2 – Milling unit ; 3 – Dispenser; 4, 16 – Gas- blowers ; 5 – Heater; 6 – Node of graphite burning ; 7 – Node of collection of the ash residue; 8 – Knot of afterburner of exhaust gases and aerosols; 9 – Cyclone; 10 – Heat exchanger; 11 – Compressor; 12 – Metal-ceramic filter; 13 – water cooler apparatus; 14 – HEPA filter; 15 – Bubble condenser;

The view of the unit of the reactor graphite processing by burning



Thank you for your attention

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