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Radioactive Pollution of Water: Lessons Learned from Ukraine

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The liquid radioactive waste (LRW) containing man-made radionuclides are formed as a result of operations of enterprises of the nuclear fuel cycle, nuclear power plants (NPP), nuclear-powered fleet, production and use of radioisotope products, and radiation accidents.

The radionuclide composition of solutions is represented by the elements of the nuclear fuel ($^{233,\ 235,\ 238}U$, ^{239}Pu, $^{241,\ 243}Am$), uranium fission products (^{134}Cs, ^{137}Cs, ^{90}Sr, ^{06}Zr, ^{95}Nb, ^{120}I, ^{131}I, ^{144}Ce, $^{103,\ 106}Ru$, $^{152,\ 154}Eu$, ^{140}Ba etc.), and products of the neutron activation of construction materials ($^{58,\ 60}Co$, ^{54}Mn, ^{51}Cr, ^{59}Fe).

Classification of liquid radioactive waste adopted in Ukraine

- high level waste (HLW) – more than 3 $7\cdot10^{10}$ Bq/l;
- intermediate level waste (ILW) – from $3.7\cdot10^{5}$ Bq/l to $3.7\cdot10^{10}$ Bq/l;
- low level waste (LLW) – less than $3.7\cdot10^{5}$ Bq/l.

Classification of the liquid wastes according to the IAEA recommendations

Category	Specific activity *A*, Bq/cm³	Note
1	$A \le 0{,}37$	Not processed
2	$0{,}37 < A \le 37$	No protection
3	$37 < A \le 3{,}7\cdot10^{3}$	Protection possible
4	$3{,}7\cdot10^{3} < A \le 3{,}7\cdot10^{8}$	Protection required
5	$3{,}7\cdot10^{8} < A$	Protection, cooling and processing required

The Kyiv water reservoir

As is argued by the scientists, $5.0\cdot10^{3}$ Ku of ^{137}Cs, $2.0\cdot10^{3}$ of ^{90}Sr and about $5.0\cdot10^{2}$ Ku of ^{239}Pu was received by the Dnipro reservoir cascade since 1986.

Half-life ($T_{1/2}$) and intervention levels (IL) of the most critical radionuclides

Radionu-clide name	^{60}Co	^{90}Sr	^{96}Zr	^{129}I	^{137}Cs	^{226}Ra	^{235}U	^{238}U	^{239}Pu	^{241}Am
$T_{1/2}$	5.27 years	29.1 years	64 days	$1.57\cdot10^{7}$ years	30 years	1600 years	$7.04\cdot10^{8}$ years	$4.47\cdot10^{9}$ years	$2.41\cdot10^{4}$ years	432 years
IL, Bq/kg	41	5.0	150	1.3	11	0.5	3.0	3.1	0.56	0.69

The Kyiv water reservoir

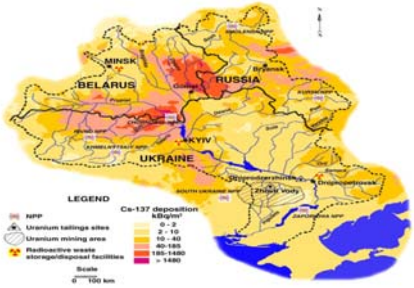
In the long term, radio-ecological significance of the Chernobyl accident for the water bodies is mainly determined by pollution with long-lived nuclides ^{137}Cs and ^{90}Sr, with half-life periods of about 30 and 29 years, accordingly; it means the decrease in radioactivity of these nuclides in 100 years by an order of magnitude only

Radiation background of “black” sands

Apart from the Ukrainian coast of the Azov Sea, black sands are found on the coasts of India, Sri Lanka, Brasilia, and in Russia.

The danger of the Azov sands lies in the fact that they occur in places with high density of local citizens and tourists.

Nuclear waste generated during mining and processing of the uranium ore.



The Ukrainian territories of high radiation and environmental risk

The sources of the liquid intermediate-level waste (ILW) and low-level waste (LLW) at processing plants of the nuclear fuel cycle (NFC) are as follows:

- waste aqueous solutions after the II and III cycles of treatment of uranium and plutonium;
- waste aqueous solutions of units for obtaining the final products of the valuable components in solid form;
- neutralized washing solutions of the extraction agent cleaning unit;
- evaporation sludge of the nitric acid regeneration units;
- solutions after decontamination of the equipment;
- valves, control and measuring instruments and hot zone rooms;
- solutions from the systems of treatment of cooling waters of the irradiated fuel storage basins;
- domestic water of shower-rooms and laundries;
- laboratory wastewaters, and organic solutions containing spent extraction agents.

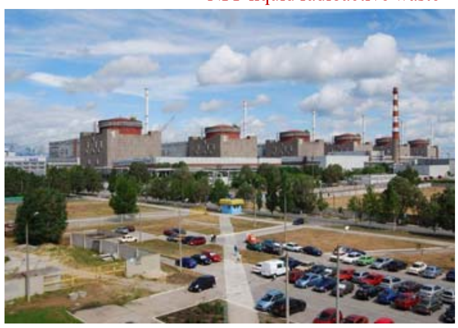
The technical facilities for LRW integrated treatment developed now in Ukraine and abroad, are based, as a rule, on the methods and technologies listed below:

- electro-physical methods;
- chemical methods and technologies;
- ion-exchange and sorption methods;
- methods of filtration with the use of fabric of polymeric membrane materials.

With regard to concentration of salts, the liquid RWcan be divided into three types:

- salt-free waters (waters of NPP circuits, cooling ponds, condensates etc.);
- low-salinity waters (waters from washing, and leaks of circuits);
- high-salinity waters (laboratory, regeneration, decontamination waters).

NPP liquid radioactive waste



Zaporizhia Nuclear Power Plant
(operations started in 1984-1987)

- 31 countries of the world operate 191 nuclear power plants with 449 power units of about 392,536 MW total electric outputs.
- In the territory of Ukraine there are 4 operating NPP and Chernobyl NPP
- Total quantity of the liquid radioactive waste in Ukraine is 42.34 thous. m^3, of which 43.9% is produced by NPP

In the process of NPP operation, the major sources of the liquid radioactive waste are as follows:

– circuit water;
– turbine condensate:
– controlled leakages;
– pulp of spent filter pearlite powder and pulp of ion-exchange resins;
– regeneration waters of ion-exchange filters;
– evaporation sludges after treatment of drain waters;
– laboratory wastewaters;
– uncontrolled leakages of process water,
– washing waters, waters of special laundries, decontamination solutions etc.

The nuclear power plants now implement three principles of the liquid radioactive waste treatment:

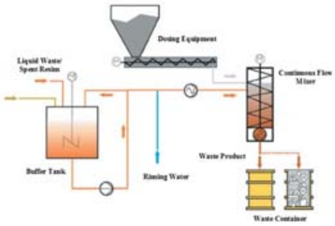
- return of treated waters to the process cycle as fully as possible, at the minimal discharge to the sewage facilities;
- concentration of radioactivity in the residue at the lowest level in order to dump it in the minimum required containers;
- separate treatment of waters or liquid radioactive waste with varying radioactivity and physical-chemical indicators.

Chemical facility of the Zaporizhia NPP: central room of chemical water treatment

Evaporation sludge and filtering materials, together with slurries and lubricants, are stored separately. Spent filtering materials and sorbing agents are supplied by the system of hydraulic transport to the tanks where they are stored under the layer of water.

Usage of state-of-the-art technologies of LRW treatment is the evidence of new scientific and engineering Approaches based on painful Experience of the Chernobyl accident.

Thermal methods



Simplified diagram of RW cementation technology of AREVA NP (Franco-German company)

Since AREVA NP in its cementation technology uses the external mixer, this technology can be easily adapted to various types of containers.
The cement compound is pumped into 200-liter barrels, of container with the volume of 1.5 m^3.

Sorption methods

- adsorption, ion-exchange, co-crystallization, occlusion, adhesion etc.
- reverse osmosis, electro-dialysis, and ultrafiltration

Membrane methods

– membrane processes are reagent-free;

– membrane processes feature selectivity of action towards various substances;

– membrane processes run without any phase transformations, i.e. without conversion from the liquid to the vapor state and vice versa;

– recovery of failed membranes is much simpler compared to that of ion exchange materials, because their quantities are less by a factor of several dozens.

Accumulation of non-conditioned liquid radioactive wastes at NPP, specialized plants and other facilities is becoming one of the major concerns of the nuclear power industry.

Modular LRW treatment complex

The current state of RW treatment at NPP of Ukraine

Zaporizhia NPP (ZNPP) operates:
– 2 deep evaporation units (treatment of evaporation sludge).

*Rivne NPP(RNPP)*operates :
– centrifuging unit (treatment of drain waters);
– 2 deep evaporation units (treatment of evaporation sludge).

Khmelnytsky NPP operates:
– deep evaporation unit (treatment of evaporation sludge);
– unit for incineration of the radioactive oil;
– centrifuging unit (treatment of drain waters).

On March 11, 2011 severe accident occurred at Fukushima-1 NPP in Japan, entailing the damage to the nuclear fuel in the active zone of reactor facilities at power units 1-3 and in theat-reactor (AR) storage of spent fuel of the power unit 4. The accident at Fukushima-1 NPP became the third severe accident in the history of the nuclear power industry. Analysis of the causes of this incident, learning of its lessons, development and implementation of additional measures assume minimization of recurrences of the similar incidents at the Ukrainian NPP, or avoidance of the negative consequences for the human health and the environment in case of their occurrence

Nonequilibrium plasma as a tool for treatment of aqueous solutions containing heavy radionuclides

The early experiments carried out by the author on model samples of solutions containing uranyl nitrate confirmed the earlier assumption on the possibility to convert the dissolved heavy radionuclides into undissolved forms

Summarized results of treatment of high-level aqueous solutions containing heavy radionuclides

Radioactive elements in water	Specific activity, Bq/l		Efficiency ofradiation reduction, n times	
	Initial	Final	α	β
Uranyl:	1567,1	-	1	1
$^{234;\,238}U$;		5,6	98,2	281,4
$^{234;\,238}Th$;		465,5	286,5	3,4
$^{234;\,238}Pa$		69,7	81,2	69,7

Conclusions

The world's nuclear power industry associated with the use and operation of the nuclear energy unanimously acknowledges the unique scientific and practical experience accumulated by the specialists as a result of the accident at ChNPP, and later on at the Fukushima -1 NPP, which allows to take a fresh look at the liquid radioactive waste treatment in view of the integrated support of the environmental safety and human health.

New, still poorly studied, but unique by their nature, compact and energy-efficient technologies of neutralization and disposal of the liquid radioactive waste with the use of sorption, membrane, plasma methods and other modern methods appear to replace the traditional technologies (which are cumbersome and expensive to run), indicating the significant improvement of processes in the nuclear power engineering, environmental safety, and living standards of the plants' operating personnel.

Thank you!