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WAYS OF SOLVING THE PROBLEMS OF RADIATION SAFETY AND ENVIRONMENTAL PROTECTION IN HANDLING RADIOACTIVE WASTE AT ATOMIC POWER STATIONS IN THE USSR

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Abstract

The report discusses the basic trends in the work being done to protect the environment in the process of removing and burying liquid and solid radioactive waste from Atomic Power Stations in the USSR. The report also describes the existing methods of handling waste materials, formulates the principle requirements of the State Sanitary Inspection with regard to ensuring the radiation safety of the population when waste materials are disposed of, gives some of the results of hygienic and radioecological research on the problem of the safe processing and burial of radioactive waste from APS's.

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The problem of ensuring the radiation safety of the population and protecting the environment from radioactive contamination in the process of developing atomic power engineering is receiving much attention in the USSR. The problem is being given a comprehensive solution. The basic trends in the work being done in this field are as follows: the improvement of the design of atomic reactors aimed at reducing the release of radioactive substances into the atmoshere; the selection of sites for APS's with favourable natural conditions that will help to reduce the effect of radiation on the population and the environment; the regulation of the radiation safety standards and sanitary requirements relating to the protection of the environment that must be complied with in the design, construction and operation of APS's; the improvement of the processing flowsheets and disposal methods for liquid and solid radioactive waste that will ensure compliance with the hygienic and ecological requirements regarding the protection of the soil, reservoirs and ground waters from contamination; the systematic radiation monitoring of environmental radioactivity by the outer dosimetry services of atomic power stations and by the specialized laboratories of the State Sanitary Inspection of the Ministry of Public Health of the USSR. In addition to that, extensive scientific studies are being made into the laws that govern the migration of radionuclides in natural media as well as in water and ground biological chains in order to improve the sanitary standards, provide a basis for determining the size of sanitary protective zones around APS's, evaluate and predict population exposure doses with due regard for the prospects of further development of atomic power engineering.

The evaluation, regulation and prediction of the population exposure to the gas and aerosol discharges from atomic power stations in the USSR and the theoretical approaches to determining standards for population irradiation from the radioactive matter released by the APS's in the USSR are discussed at length in two other reports submitted to the Conference /1, 2/. For this reason the present report mainly concentrates on the problems of ensuring radiation safety and environmental protection in the process of handling liquid and solid radioactive waste at APS's in the USSR.

As they operate, atomic power stations produce relatively large quantities, in terms of volume, of liquid and solid waste materials of the intermediate and low levels of radioactivity that are contaminated by mixtures of a complex radionuclide composition. The liquid waste at an APS consists of the primary circuit coolant when replaced or when seeping through due to a leak in the equipment, the water of the decay reservoirs for used fuel elements, decontaminating solutions, solutions used in ion-exchange filter recovery, water coming from the special laundries, decontamination stations for equipment and special vehicles, and from some other sources.

The solid radioactive waste at an APS consists mainly, of separate components and units of reactor equipment, tools, special clothing articles and individual personnel protection means, wiping rags, filters from the gas purification systems, etc. The total amount of liquid and solid radioactive waste to be processed and disposed of varies at different APS's. It depends on both the design peculiarities of the reactors, the condition of the reactor core and the nature of the technological procedures at the APS. The amount of waste materials increases considerably, for example, when large-scale repairs are undertaken, which usually coincide in time with nuclear fuel recharge.

In the USSR it is a universally accepted practice to process all liquid radioactive waste immediately at an APS using the evaporation and ion-exchange methods. The concentrated waste (the heels left over after evaporation), ion-exchange resins, pulps, primary coolant, when being replaced, are collected and piped to special storage reservoirs for moderately radioactive waste.

Experience has shown that at various times the amount of moderately radioactive liquid waste accumulated at an APS ranges between 0.5 and 1.5 m^3/year per I mw(el) of the reactor capacity. Calculations predicting requirements for the reservoirs to store such waste materials can be based on a quantity of about I m^3/year per I mw(el). Moderately radioactive liquid waste accounts for about 99% of the total number of radionuclides contained in waste materials. The specific radioactivity of concentrated liquid waste in reservoirs is in the range of 10^{-4} to 10^{-2} Cu/l (in the liquid phase). As waste materials are being stored, the suspended radioactive solids gradually settle to the bottom of the reservoirs. Unless bubbling is used, the greater part of some of the radionuclides goes down to form part of the sediment.

To gain information for predicting the possible migration of radionuclides in the rocks in the event of reservoir unsealing analyses of the chemical and radionuclide composition of moderately radioactive liquid waste have been made at a number of APS's on samples taken directly from the reservoirs. The liquid waste has been found to have a strongly alkaline reaction (pH 10-13) and a high degree of oxidability (4-12 gr of O_2/l). The dry residue varies from 100 to 270 gr/l and is represented mainly by sodium carbonates, sodium hydrocarbonates, sodium chlorides, sodium sulphates, sodium nitrates, sodium phosphates and sodium oxalates.

Characteristic of the liquid waste of the PWR type of reactors is the presence of sodium borates. The waste contains dozens of gr/l of detergents and about I gr/l of ethylene diamine tetraacetic acid (EDTA). The liquid phase of the waste was for the most part contaminated by caesium-137 (70-90%); also present were caesium-134, ruthenium-106, cobalt-60, antimony-125 and strontium-90. The percentage ratio of these radionuclides differed in different waste materials and depended on the decay time. The content of ruthenium-106 and cobalt-60 varied over a wide range: 0.2÷14.4 /and 0.I÷II.L/ respectively. The activity of antimony-125 amounted to only 0.1÷1.5/. The contamination of the liquid phase of the waste by strontium-90 was insignificant. This radionuclide accounted for only some tenths of one per cent and less of the total radioactivity of the waste. But at the same time strontium-90 and cobalt-60 were responsible for most of the radio activity of the sediment on the bottom of the reservoir.

For an assessment of the migration characteristics of radionuclides in the rocks and in case they find their way into the aquifers, it is important to point out that the radionuclides of caesium and strontium in APS waste are almost entirely in the cationic form, while ruthenium-106 and cobalt-60 are essentially in the anionic form. About 10% of ruthenium-106 and also antimony-125 had the form of neutral molecules. A few per cent of cobalt-60 were found to have the form of cations and neutral molecules /3/.

On the basis of the chemical forms which radionuclides were found to have in liquid waste and as a result of experimental tests, it has been concluded that in the event of waste leakage from storage reservoirs caesium and strontium radionuclides will be absorbed by the rocks mainly within the storage site area. In static experiments on natural sorbents (morainic sandy loam and rich clay with a cation-exchange capacity of 1.3 and 3.4 mg-equiv /l respectively) it was found that in the course of three hours contact the rocks had absorbed 96-100% of caesium-137, 80-90% of strontium-90, only about 10% of cobalt-60, while the sorbtion of ruthenium-106 and antimony-125 was negligible. Therefore, on reaching the aeration zone cobalt-60, ruthenium-106 and antimony-125 willeasily penetrate the underlying rock layers with the rate equal to that of waste leakage. It has been experimentally proved that the high migration mobility of cobalt-60 is due to both the presence of EDTA in the wastes and the alkaline medium. The lowering of EDTA concentration by diluting the waste with low-mineralised water resulted in cobalt-60 gradually changing to the cationic form. In the event of APS wastes of moderate radioactivity getting to the aquifers, cobalt-60 should be expected to change to the cationic form and be absorbed by the water-bearing rock, while ruthenium-106 and antimony-125 will migrate with the rate equal to that of the ground water flow.

The view of the potential danger, should leakage in some waste storage reservoirs occurs, associated with contamination of either surface, or underground waters or the nearby water basins in the area where the wastes are discharged, a great deal is being done in the USSR to prevent such situations. APS waste storage reservoirs are made of reinforced concrete and are lined on the inside with stainless or carbon steel (in the "a can in a can" fashion). Metal reservoirs are also used and always provided with pans for collecting possible solution leakages and with leakage signalling systems. Level gauges are installed in the reservoirs. Special equipment enables the waste to be pumped, into standby reservoirs should the need arise.

Considering the actual level of radioactivity in APS wastes and their low thermal yield, decay reservoirs are not artificially cooled. To protect the ground waters from contamination, a number of observation wells are bored into the upper aquifer in the waste storage site area of an APS, from which samples of water are taken regularly and tested for radioactivity. At the initial stage of the waste storage site operation the background characteristics of the chemical composition of the ground waters are, as a rule, determined. Similar investigations are envisaged as an additional monitoring method in cases when some reservoirs have been found to be leaking.

For economic reasons and in accordance with the requirements of APS's for a period of five years the construction of reservoirs for storing liquid waste is carried out in stages. The storage of moderately radioactive liquid waste in decay reservoirs at APS's is regarded in the USSR as a stop-gap measure. In future these waste materials will be solidified, mainly by means of bitumenization, and will be stored in solid state in surface and underground storage vaults until disintegration of the radionuclides is practically complete.

To solve the problems of protecting the environment in the process of disposing of low-activity waste, the USSR has established a lower limit of concentration of radionuclides in water and solutions that fall into the category of "radioactive waste". Classed as liquid radioactive waste in accordance with the "Principle Sanitary Regulations for Work with Radioactive Substances..." /4/ are all waste materials in which the concentration of radionuclides exceeds the amount of the permissible concentrations (PC) of the corresponding radionuclides in water according to the "Norms of Radiation Safety (NRS-76)". The PC mentioned above is that found in the drinking water used by the population /5/.

Low-activity liquid waste from APS's is processed in the USSR, the purified water being reused in a return cycle of industrial water supply. It is prohibited to use this water in shower baths and for washing linen. As a result a certain amount of surplus (overbalance) contaminated water is accumulated. The volume of this water varies from a few dozen to a few hundred cubic metres a day. Its specific radioactivity is low: from 10^{-10} to 10^{-7} Cu/l for some radionuclides. The water of the shower baths at an APS is not purified since its contamination is negligible. It is collected together with the surplus water in the accumulative reservoirs or is mixed with the latter in the process of being removed from the APS.

In conformity with the stringent regulations of the State Sanitary Inspection regarding the protection of APS cooling ponds from radioactive contamination, low-activity effluent, which with its level of contamination does not fall into category of radioactive waste, is removed from APS's in various ways. At the Novo-Voronezh APS, for instance, the effluent is poured onto the specially equipped plots of filter fields in the sanitary and protective zone. To discharge it into the River Don is forbidden. At the Beloyarsk APS such effluent undergoes additional biological treatment at a biological station where some natural sorbents (silt) are used. It is only after this that under the supervision of the radiation monitoring service the effluent is discharged into a marsh. At the Leningrad APS the low-activity effluent is discharged, after an extra about 100-fold dilution with inactive industrial and storm sewage, into the littoral zone of the Gulf. The radioactivity of the discharged water is continuously controlled by means of a radiation monitoring instrument and with due consideration to the results of radiometric analysis of representative samples, taken continuously, from the water to be discharged. The sanitary standard (10^{-10} Cu/l of the radionuclide mixture) is maintained directly at the place of water discharge into the Gulf and not after it becomes mixed with the water of the Gulf. The same proncipole of disposing of low-activity effluent is used at the Kola APS (the effluent is discharged into Lake Imandra).

It should be particularly emphasized that in the USSR, unlike some other countries, the water that cools the turbine condensers at an APS is not allowed to be used to dilute the radioactive effluent in order to lower its radionuclide concentration at the place of discharge. We proceed from the assumption that the extent of damage to the flora and fauna of a water basin, its bottom and its littoral zone finally is determined not so much by the concentration of radionuclides in the water being discharged as by the aggregate amount of radioactivity of the discharged radionuclides. It is particularly important to keep this in mind when using water storage basins, ponds and stagnant littoral sea zones as cooling reservoirs.

The established Soviet practice of treating liquid wastes and low-activity effluents has proved itself to be perfectly good. In our country there is, in fact, no danger of any water basins situated in the vicinity of an APS becoming contaminated. The cooling ponds of an APS are regarded as basins that can have an unlimited number of economic uses. At the Kola APS, for example, an experimental breeding farm has been set up with the thermal water in the discharge canal being used to breed trout, bester and other valuable species of fish. So far no accumulation of radionuclides in the tissues of even fast-growing fish that can be attributed to the APS effluent has been observed. In the River Don, at the Beloyarsk water storage basin and in the Koporsk Inlet of the Gulf of Finland the radiation conditions are quite satisfactory. In all those areas there are beaches near the APS, places where bathing and fishing is permitted.

To provide a basis for such stringent requirements on the protection of APS cooling ponds a wide range of radioecological investigations /6, 7/ have been undertaken to study the effect of heat on the accumulation of radionuclides in the tissues of fish and bottom-dwelling invertebrates used for food. It has been established as a result of these investigations that a rise in the temperature of the water by 5-8° which actually occurs in areas reached by the thermal waters of large APS's, leads to an increase in the rate of radionuclide accumulation in the tissues of hydrobionts, while non-equilibrium accumulation coefficients for caesium-137, cobalt-60, manganese-54, iron-59, chrome-51, antimony-125, phosphorus-32, zinc-65, iodine-131 in fish muscles are increased by 2-5 times. Particularly sharp, as great as 15-fold at times, was the increase that was experimentally observed in the accumulation of mercury-203 in fish and bottom-dwelling invertebrates. This is not probably due to an increased rate of accumulation only but possibly also to an increase in the solubility of mercury under the effect of the heat factor.

In determining standards for the discharge of radionuclides into water basins we have been guided by the principle of allotting a small quota, not more than 5% of the dose limit for the exposure of individuals in the population, to a given source of irradiation considering the presence of a variety of other possible sources of irradiation. We also take account of the fact that the water of these basins can be put to a number of uses (drinking and industrial water supply, the watering of cattle, irrigation, fishing, bathing).

The USSR has positive experience in the disposal of liquid radioactive waste by using aquifers located deep in the earth and securely insulated from the surface fresh waters, for example, in the vicinity of the Ulyanovsk APS. This method of disposing of liquid waste can be used only if there are favourable hydrogeological conditions.

The underground burial of waste makes it possible to discard, wholly or in part, the complex technologica process of waste treatment that calls for radiation protection measures. It also makes it unnecessary to build storage vaults for radioactive liquid waste, pulp and bitumen products near the surface of the ground.

Apart from the hydrogeological conditions, the possibility of making an underground liquid waste graveyard is determined by the sanitary conditions and the economic uses of the surrounding territory. The site of the graveyard and its nearest neighbourhood must be provided with a sanitary protective zone within which the use of the underground resources will be restricted. The question of the criteria to be applied in establishing sanitary protective zones when using underground graveyards for APS waste disposal was discussed at length earlier /8/.

Considering the nature of the effect of underground radioactive liquid waste graveyards and the tchnological procedures at waste burial grounds, sanitary protective zones consist of three belts.

The first belt includes the territory where the disposal wells are located. This belt usually has an area of about 1.5-2 hectares. There should be no constructions in the first belt that are not related to the work of the burial ground; it is forbidden to use its territory for agricultural or other purposes.

The second belt comprises the territory of the possible spread of the discharged liquid waste over the aquifers used for its disposal. According to the thickness, capacity and other hydrogeological characteristics of the disposal aquifers as well as to the amount and composition of the waste disposed of, the radius of the second belt usually varies from 2 to 5 kilometers. In the second belt it is forbidden to drill deep wells that are not associated with the work of the burial ground and to locate large underground water intakes as well as to carry out any work for extraction of other underground resources since this may destroy the natural insulation of the underground graveyard. The use of the second belt territory for agricultural purposes and for building constructions other than those associated with the work of the APS is not restricted.

The third belt is established in order to rule out the possibility of deep oil, gas and other wells sucking in any stratal water contaminated by radioactive substances. According to the calculations and experience in operating burial grounds and oil fields, the radius of this belt is, depending on the local geological and hydrogeological conditions, in the region of 10-20 kilometres.

A wide range of hydrogeological observations needs to be made, within these three belts, and control must be exercised over the radiation conditions and the implementation of the restrictive measures contemplated.

The underground disposal of liquid radioactive waste is a complex mine engineering and geological process requiring comprehensive hydrogeological, geophysical and other investigations and constant adjustments in the process of the burial ground operation.

Solid radioactive waste from an APS in the USSR is disposed of, just like liquid waste, by being buried in special storage vaults directly within the sanitary protective zone of the APS. There exist standards for, and control is maintained over, the personnel irradiation doses in the process of collecting, transporting and burying the waste. Solid waste is collected, where it is produced into shipping containers according to the dose rate of gamma radiation. Moderately active and low-active waste materials are, as a rule, collected separately. Highly active waste is put in specially shielded containers. The separate collection of waste according to the levels of its activity makes it easier to ensure the safety of the personnel in the process of shipping the waste to the storage ground and also makes for more rational use of the storage vault capacity. When collecting solid waste, measures have to be taken to prevent the contamination of the air by radiactive substances that may escape in the form of aerosol while the waste is being put into containers.

To transport solid waste special vehicles are used, the driver's cabin of which is provided with extra biological shielding. Special studies have been made to assess the extent of the possible air contamination in the process of shipping solid waste with the use of mobile high capacity blast blowers. Radioactivity of the asphalt road surface on roads used by waste carrying vehicles is constantly being monitored. "The Sanitary Regulations for the Design of APS's" /9/ formulates sanitary and hydrological requirements on siting solid waste storage grounds. The basic requirement is that no ground or rain water should be allowed to penetrate into a storage vault. Solid waste storage vaults are built of concrete, they can be of the surface or semi-underground type, and waste materials of different levels of radioactivity are stored in separate vaults. Facilities are provided near storage vaults for monitoring the levels of radioactivity in the ground water. Low-activity waste, mainly building debris showing signs of radioactivity, may be buried in trenches within the sanitary protective zone and covered with earth immediately after a section of a trench had been filled up. The practice of operating the solid waste storage vaults of the operating APS's indicates an almost complete absence of ground water, soil and vegetation contamination in the vicinity of the storage vaults. On the economic side of the problem efforts are now being made to enhance the space factor of the storage vaults mainly by introducing waste compression at all APS's.

Solid waste is not burned up at APS's in the USSR although at the Zagorsk central station of waste disposal an electrical furnace for incinerating waste is operating successfully. The sanitary regulations allow the incineration of waste materials at APS's but only on condition that the requirement on prevention of atmospheric contamination by radioactive substances is complied with.

With a view to ensuring the more rational use of natural resources the USSR is now considering the advisability of establishing large regional storage grounds for the long-term burial of solid and solidified radioactive waste for the group of APS's situated in the same zone (republic). It appears that disused mines and specially built underground cavities can be used for this purpose.

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