INTRODUCTION

Safety handling of radioactive wastes is an urgent problem of the nuclear industry. Within the framework of this issue the various ways how to dispose the wastes and their impact on the environment are discussed and examined.

The radioactive wastes are products, materials, substances and biological objects which are contaminated with the radioactive substances to the extent exceeding the values which are stipulated by the applicable regulations as well as cannot be used for further production or for other economical purposes due to the technical – economical or other reasons. [Rybalchenko, 1994].

The wastes originate during uranium mining and production of uranium concentrate, isotopic enrichment, nuclear fuel production, uranium dioxide-to-uranium hexafluoride conversion, processing of radionuclides generated in the NPP core as a result of the neutron capture and nuclear heavy nuclide fission as well as a result of neutron activation of some nuclides contained in the moderator, coolant or structural materials.

The issue of nuclear safety when handling the wastes was not duly treated due to the low uranium and plutonium concentration in the wastes. However under some circumstances, for example, when the concentration increases during the storage or conditioning as well as when the nuclear material is not controlled in the equipment the wastes can pose a threat as the self-sustaining chain reaction can occur.

That is why it is necessary to consider conditions under which the self-sustaining chain reaction can occur while handling the wastes containing low concentration of fissile materials in the form of uranium and plutonium. It is necessary to study the effect which waste composition, humidity, fissile material distribution, container’s type, reprocessing methods, density, enrichment etc. have on $K_{ef}$.

The examination covers the typical wastes which are generated by the plants belonging to the fuel cycle and considered useless from the technical-economical point of view for further reprocessing to extract the fissile materials as well as the plants which are involved in the waste storage, disposal, bituminization, cementation, vitrification including the wastes containing the fissile materials. In this respect we can also consider the liquid wastes with the total uranium concentration of 1 – 5 mg/l.
which are disposed in the tailing pit or condensed as well as low- and medium-active solid wastes containing fissile materials in the form of precipitation, rubber, graphite, furnace ceramic, polyethylene articles etc.

While the specific content of fissile materials in the wastes is low the volume of the wastes buried makes up thousands of cubic meters in some places and the total amount of the fissile materials is tens, hundreds, thousands of kilograms. This does not exclude a possibility of self-sustaining chain reaction. As an example of the self-sustaining chain reaction which occurred under conditions similar to a waste disposal site we can consider the natural nuclear reactor formed in the uranium mine in Gabon (the ore deposit in Oklo). 1900 million years ago when the uranium enrichment made up ~3.6% as to U-235 at the mass fraction of the subsoil waters in the layer being ~6%, the natural nuclear reactor was created and was working under slow boiling conditions during hundred thousands of years. The fission became possible when the uranium oxide content in the ore was ~10% as to mass. This corresponds to ~3 g of U-235 per kg. This content may be accumulated in the solid waste disposal sites as well. Once again this emphasizes the virtual importance of the problem in question.

The processes which happen with the wastes are individual for each disposal site. They are dependent on the waste type (liquid or solid), a series of chemical and physical processes and require investigations in each specific case. Besides, due to the variety of different waste types and uncertainty about their composition it is difficult to exactly determine the mixture contents to carry out the nuclear safety analysis.

**DISPOSAL STORAGE FACILITIES.**

The disposal storage facilities can be divided in the following types:

1. **Liquid waste disposal storage.**

An example of such a disposal site is a storage of highly active wastes in Hanford, liquid waste disposal sites located in the plants belonging to the nuclear fuel cycle, liquid waste deep-laid disposal storage. (GChK, CChK, NIAR) and others.

The possible solutions of the nuclear safety for some liquid waste disposal sites are described in the papers of [Rybalchenko, 1994], [Rogers A., 1997], [Greenborg J., 1997], [Vnukov V.C., 2000], [S.Kouzmine, 1997]. In the above papers the nuclear safety is assured by limiting the concentration of the fissile materials in the solutions to be drained and in the precipitation. For example, when the containers with the liquid highly active wastes are subjected to the nuclear safety analysis in Hanford the plutonium concentration is selected as a safety criterion.

The issue how to select the waste composition to ensure the conservative assessment is also important.
2. **Solid waste disposal storage.**

At present the modern method for handling solid wastes is to store them in drums. The solutions of nuclear safety when storing the radioactive wastes in drums are given in the papers of [Vnukov V.C., 2000], [Fiona M. Olivie, CA201PG], [Hopper C., 1997], [Anno J., 1995].

At handling with the wastes it is necessary to know about numeric values of nuclear safety parameters. For example, the land burial of the liquid wastes at the experimental-industrial area in NIIAR meets the nuclear safety requirements provided that the total nuclide concentration of plutonium, U-235, americium, curium is not more 0.01 mg/l. This value is determined by the waste handling process.

For solid wastes the nuclear safety widely used parameter is a specific content of fissile material in grams per waste kg.

For cementation of low-active solid wastes at the research-and-production combine “RADON” the safe Pu content in wastes is 0.156 g/kg when taking the most conservative assumption that the wastes consist of plutonium and graphite. Similar values are applied for U-235 – 0.25 g/kg.

As it can be seen the quantitative criteria of the nuclear safety vary in the wide range.

**TASK AND SOLUTIONS**

Within the framework of the present research the following tasks are set:

- Developing methods for calculating K-factor of the systems containing low concentration of the fissile materials mixed with various nuclides being a part of wastes, verification of calculation methods;
- Developing nuclear safety limits and parameters for waste disposal;
- Making physical and mathematical models to calculate consequences of design and beyond design accident in the mortuary and disposal sites;
- Developing recommendations to issue nuclear safety regulations for waste handling.

At present the scientific activities relating to the above issue and carried out in USA, UK, France have been observed. The influence which the composition of wastes containing various uranium enrichment, isotopic composition of plutonium, such components as SiO2, CaF2, Ca(CO3), MgF2, graphite, beryllium, lead, water, iron and others has on K_{ef} of wastes.

To accomplish the above tasks, at the first step we carried out the research work to determine a quantitative criterion of the nuclear safety for the fissile material containing wastes – safe surface density (g/cm²). The required calculations were performed for uranium mixtures (to be conservative the U-235 enrichment was taken as 100%) with water, graphite, beryllium, lead, SiO2, MgF2.
Due to the fact that it is difficult to determine the safe surface density experimentally, as a rule, it is calculated by means of the calculation methods. For this purpose the approved software complexes MMKFK-2 [Polevoy V.B., 1996] and SCALE 4.4a [NUREG/CR-0200, 1982] were used.

Software programs MMKFK-2 and SCALE 4.4a are verified in a rather wide range of moderator - fissile material ratios. However, for the very low concentration of fissile materials mixed with the materials being a part of wastes the calculation error is unknown due to the lack of the critical experiments in this field.

Consequently, at the present stage the only possibility to determine the calculation error is to compare the calculation results by applying two or three independent programs.

In the complex of MMKFK-2 programs the neutron transfer in the epithermal (or entire) area of energy is simulated in the subgroup approximation as per MKPA program by using 26-group library of constants BNAB-78,85. Thermalization at $E<1\text{eV}$ is simulated in the 40-group approximation by using physical module MOFITT and library of constants TEPKON-90.

For criticality calculations the program SCALE 4.4a used the control module CSAS1X, including modules XSDRNPM and KENO V, which applied 238-group library of neutron sections ENDF/B-V.

The calculations were made for the system (the endless two-dimensional plate) with one meter concrete reflector from the top and from the bottom. The above system is specific for disposal sites where the wastes are placed into the specially dug pits or tanks and poured with concrete.

The following calculation method was used: for the specific U-235 concentration the plate thickness was determined at which system’s $K_{ef}$ was $\approx 0.95$. On the basis of the above plate thickness the surface density was determined for this uranium concentration. The above procedure was repeated till the number of points required for plotting the dependence between the safe surface density and U-235 concentration was obtained.

Table No1 gives the $K_{ef}$ values for the corresponding minimal surface density for each mixture obtained by using calculation programs of SCALE 4.4a and MMKFK-2 complexes.
Table No1. Comparative calculation results obtained by means of SCALE 4.4a and MMKFK-2 programs.

<table>
<thead>
<tr>
<th>Mixture</th>
<th>( \xi ), g/cm(^2)</th>
<th>( K_{\text{ef}}, \text{MMKFK-2} )</th>
<th>( K_{\text{ef}}, \text{SCALE 4.4a} )</th>
<th>( \sigma, % )</th>
</tr>
</thead>
<tbody>
<tr>
<td>(^{235}\text{U} + \text{SiO}_2)</td>
<td>0.62</td>
<td>0.9487</td>
<td>0.9511</td>
<td>-0.25</td>
</tr>
<tr>
<td>(^{235}\text{U} + \text{H}_2\text{O})</td>
<td>0.289</td>
<td>0.9485</td>
<td>0.9450</td>
<td>+0.37</td>
</tr>
<tr>
<td>(^{235}\text{U} + \text{Be})</td>
<td>0.0603</td>
<td>0.9460</td>
<td>0.8809</td>
<td>+6.88</td>
</tr>
<tr>
<td>(^{235}\text{U} + \text{C})</td>
<td>0.0513</td>
<td>0.9471</td>
<td>0.9422</td>
<td>+0.52</td>
</tr>
<tr>
<td>(^{235}\text{U} + \text{Pb})</td>
<td>2.719</td>
<td>0.9479</td>
<td>0.8830</td>
<td>+6.85</td>
</tr>
<tr>
<td>(^{235}\text{U} + \text{MgF}_2)</td>
<td>0.294</td>
<td>0.9468</td>
<td>0.9498</td>
<td>-0.32</td>
</tr>
</tbody>
</table>

where \( \xi \) - surface density, g \(^{235}\text{U}\) per cm\(^2\); \( \sigma = ((K_{\text{ef}, \text{MMKFK-2}} - K_{\text{ef}, \text{SCALE}}) / K_{\text{ef}, \text{MMKFK-2}}) \times 100, \% \).

**CONCLUSIONS**

The calculation results given in Table No1 demonstrate that for \(^{235}\text{U} + \text{MgF}_2\), \(^{235}\text{U} + \text{C}\), \(^{235}\text{U} + \text{SiO}_2\) and \(^{235}\text{U} + \text{H}_2\text{O}\) mixtures the difference in the calculation results makes up around \(~0.5\%\) in \( K_{\text{ef}} \) consequently, the above data can be recommended as the normative parameters of the nuclear safety.

For \(^{235}\text{U} + \text{Be}\) and \(^{235}\text{U} + \text{Pb}\) mixtures the difference is around \(^7\%\), that is why the further investigations are required to find out the discrepancy reasons.

**Gratitude.**

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