There is packaging of nuclear fuel on the BN-350 fast breeder reactor, Actau, now. The analysis of criticality while this procedure was done in the Safety Analysis Report [1]. Keeping in mind the planning displacement of the fuel to a site of long-term storage, the criticality assessment of the fuel packed into transportation cask carried out in this paper. Because a type of the cask will used is not specified at present time, here is modeling a transport device in form of a cylinder with one, two, three or four layered wall. These layers are made from different materials such as concrete, stainless steel, water, and lead, i.e. from basic structural materials used by constructing of transportation casks. The special cylindrical drum [2] loaded with four normal fuel assemblies and with inert gas argon is inserted into the cask. According to the standard conservative requirements for criticality analysis the assemblies are taken with the maximal for BN-350, 33%, uranium enrichment. The MCNP [3] Monte Carlo neutron transport code have used in this work. An example of MCNP model of transportation cask with 3-layered wall is shown in Fig.1.

![Fig.1 MCNP Model of a Drum Filled With Four Assemblies And Surrounded With 3-Layered Reflector — Axial Cross Section](image-url)
The calculations performed show that water and concrete are the most effective reflectors in one-layered casks when the wall thickness is under 20 cm (curves 2 and 4 in Figs 2, 3) whereas among the infinite reflectors these are concrete, lead, and water (curves 4, 3, and 2 in Fig.3). An explanation is that the hydrogen is not only a good scatter for neutrons but also an effective moderator for them. So, the mainly fast after uranium fission spectrum of neutrons being shifted toward the thermal energies. At the same time, the lead nuclei good scatter neutrons and only slightly modify their energy. A stainless steel is not so effective reflector due to significant absorption of thermal neutrons.

In case of a two-layered cask, there are different trends of transform of $k_{\text{eff}}$ depending on kind of material, light or heavy, to be chosen for the inner layer. In particular, if thickness of the outer wall to be made of stainless steel is fixed on 10 cm, $k_{\text{eff}}$ sharply increases while increasing of thickness of the inner cask wall made of concrete (curve 5 in Fig.2). This growing exceeds one for the one-layer wall of concrete, curve 4 in Fig.2. This behavior can be explained by an increase of a number of neutrons returning back inside the drum because of reflection from the outer layer, steel. In opposite case, when the outer layer of fixed thickness is the concrete and the thickness of the inner layer, stainless steel, increases beginning from zero, a sharp decrease of $k_{\text{eff}}$ occurs (curve 6 in Fig.2). Such behavior is caused by the reduction of thermal neutron

![Image](image.png)
flux going inward the drum. This reduction takes place, in its turn, due to the fact that a part of the fast neutrons coming from the assemblies is reflected by the inner layer, stainless steel, without noticeable shifting of their energy to thermal area.

If the inner layer is fixed and the thickness of outer layer increases then the fluent, not sharp increasing of $k_{\text{eff}}$ takes place, curves $5'$ and $6'$ in Fig.2. That is easy understood because the scattering of the neutrons as well as their moderation and absorption, flow mainly within the inner cask wall if its thickness is large enough.

**Fig.3** $k_{\text{eff}}$ of a Cask Filled With Four Assemblies. Cases of 1- Layered Cask Wall (Curves 1–4) and 2-Layered One (Curves 5–8; thickness of inner layer is fixed and thickness of outer layer is varied from zero)

It is reasonable to suppose that an most increase of $k_{\text{eff}}$, similar to one on the curve 5 in Fig.2, would be when the inner layer of the cask contains much enough of lightest nuclei with minimal absorption cross section and the outer layer is made of an heaviest material with the greatest neutron scattering cross section and the least absorption one. In this case, the share of fast neutrons to be reflected from the outer layer should be maximal as well as their moderation when returning back to the drum through the inner layer of the cask wall. From the materials under consideration, the water and lead best of all satisfy to the above mentioned requirements. The calculations performed have revealed that the water-lead reflector provides with the most $k_{\text{eff}}$ for the outer layer thickness greater than 15 cm, curves 5 in Fig.3, in comparison with other two-layer combinations (curves 6, 7, and 8 in Fig.3). For the cases when the outer layer
thickness is less than 15 cm the most effective reflector is a water-steel (curves 6 in Fig.3). The curve 9 in Fig.3 is traced along the \( k_{\text{eff}} \) peak values, \( k_{\text{eff}}^{(\text{max})} \), for 4-position drum loaded into two-layered, water-lead/water-stainless, cask. This curve represents the upper limit of \( k_{\text{eff}}^{(\text{max})} \) dependence on the wall thickness when the drum with four assemblies is surrounded with an arbitrary two-layered reflector made of water, lead, stainless steel and/or concrete. Within accuracy \( \chi^2 = 0.00007 \), this dependence can be fitted with a simple rational function

\[
k_{\text{eff}}^{(\text{max})} = b + cx / 1 + ax,
\]

where \( x \) is a reflector thickness in centimeters, \( a=0.113cm^{-1} \), \( b=0.162 \), and \( c=0.068cm^{-1} \).

Calculations for different variants of three and four-layered reflectors have provided \( k_{\text{eff}} \) values not exceeding \( k_{\text{eff}}^{(\text{max})} \) limit, curve 9 in Fig.3, for two-layered configuration. To explain this result, one should keep in mind, that a multi-layered wall can be effectively considered as a single-layer one having the same total thickness and some averaged characteristics for neutron scattering, moderation and absorption. This averaged material can not, in any case, slow neutrons better than best light moderator, on the one hand, and reflect better than best heavy infinite reflector, on the other hand. Therefore, the conservative assessment (1) obtained for the two-layered reflector can be also applied to any multi-layered systems constructed from the chosen list of materials: concrete, water, lead, and stainless steel.

Thus, the conclusion is that for any multi-layered transportation cask consisting of concrete, water, lead, and stainless steel in any their combination and containing the 4-position drum with the 33% enriched BN-350 reactor assemblies, \( k_{\text{eff}} \) value will not exceed the 0.6. Or rather, there is \( k_{\text{eff}}^{(\text{max})} \) dependence on the wall thickness of any cask with multi-layered construction of the wall; this dependence is described by the curve 9 in Fig.3 or by the function (1).

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