**THE PROMISING FUEL LOADINGS FOR THE REACTORS IN THE NUCLEAR CLOSED FUEL CYCLE**

 Modern nuclear power engineering uses open fuel cycles and therefore it has to face one of the most burning issues nowadays - increasing spent fuel volume. The worldwide volume of accumulated spent fuel is approximately equal to 270—350kt, annual fuel accumulation rate amounts to10kt. There are several management strategies for the accumulated spent fuel: disposal for the open fuel cycle, recycling of the spent fuel and then high level waste disposal for the closed fuel cycle. This problem hasn’t been solved yet, we will have to decide what strategy to choose. Long – term storage of the spent fuel is a deferred decision.

The United States has planned to construct dry repository with the total capacity of ~70 kt in Yucca Mountain. It should be used for safety storage of the spent fuel for the near 10 thousand years [1].

 If we take Yucca Mountain nuclear waste repository as a standard unit, it will be quite clear that we will need 3—5 repositories with the same capacity to store all the accumulated spent fuel. Taking into account that the output of the nuclear power plant is constantly growing, the number of constructed repositories would suffer an exponential increase (fig. 1). The construction of such storages involves great expenses and that would make the whole industry non - competitive.

Fig 1. The construction frequency for the storages similar to Yucca Mountain up to 2100 .

Another strategy is to recycle the spent fuel and to immobilize the high level waste: fission products and actinoids. Uranium and plutonium can be used both in thermal and fast reactors after recycling. In the second case, the burning of plutonium would be more efficient for a new fuel is accumulated. The fission isotopes accumulation rate is a ratio of the fission isotopes production rate to the fission isotopes burning- up rate. For the thermal reactors the conversion ratio is ~ 0,7, for the fast ones it can be > 1. Thus the fast reactors help to boost the recycling of the spent fuel and provide nuclear power engineering with new fuel and that in its turn ensures the reduce in the natural uranium That distinctive feature of the fast reactors facilitate the transition to the closed fuel cycle using the fast reactor with the conversion ratio > 1.

We can evaluate the reduce in the natural uranium from different points of views, depending on the year of the implementation of the fast reactors . In our basic scenario there are fast uranium - operated reactors part of which will be operating on the mixed uranium- plutonium fuel that contain plutonium generated from the spent fuel. We took into consideration several implementation strategies for the fast reactors from 2030 or 2050 with conversion ratio ~1 and 1,2.

Fig 2 compares the integral demand for the natural uranium depending on the year of implementation of the fast reactors to the basic scenario of the nuclear power engineering development where there are no fast reactors . The experts argue that natural resources of uranium amount to 16 mln.tn. and that is the key point in choosing the strategy [5].

Fig.2, shows that even if we recycle plutonium that was generated from the spent fuel, by the end of the 21st century we will need nearly 25 mln.tn. of the natural uranium to develop nuclear power engineering on thermal reactors. That exceeds the available resources of the natural uranium in 9mln tn.

A significant reduce in consuming of the natural uranium in the middle of the 21st century can be obtained through the implementation of the fast reactors with higher conversion ratio and shorter hold- up time of the spent fuel before the recycling.

 It seems rather difficult to implement this strategy due to high radioactivity and power density of the spent fuel The situation is becoming more and more complicated due to the requirements to shorten the hold- up time of the spent fuel boost the burning out of the fuel in fast reactors which are aimed at increasing the efficiency of the nuclear fuel cycle closure. For instance, the promising fast reactors should have the burning – out index equal to 120 GW\*d/tn. That is twice as much as for the thermal reactors. Fig.3. displays the reduce in afterpower in terms of hold - up time for the different burning stages of the spent fuel

 Nowadays PUREX allows to recycle the spent fuel from the thermal reactors with the burning out index no more than 50—60 GW\*d/tn. if the fuel was held up for more than 5 years The similar restrictions are imposed on the transportation of the fuel [6].

 While recycling the fuel with high burning – out index by implementing plutonium uranium extraction we should mix this fuel with the spent fuel of the reactor blankets. Thus we will be able to reduce the energy release to the normal level.

Hold- up , years

Рис. 3. The afterpower *Е*  of the fuel with the burning - out index 40 *(1)*, 50 *(2)*, 60 *(3)*, 100 GW\*d/tn *(4)*

Price arbitrary units ,

Hold up , years

Fig 4 The recycling price evaluation of 1kg of. The spent fuel in terms of the burning out index and 20 *(1)*, 40 *(2)*, 60 *(3),* 100 GW\*d/tn *(4)* и holding up time , The price of the spent fuel recycling with the burning – out index 40 GW\*d/tn. and holding up time of 5 years *(5)*

 Fig.4 indicates that the recycling of the spent fuel with the holding – up time of 1 year will be 10 times more expensive than the recycling of the basic water – water energetic reactor fuel and with a holding – up time of 3 years it will be 5 times more expensive. Of course in this case the nuclear fuel cycle closure has no sense, because for the fast reactors with the conversion ratio ~ 1 and 1,2 and the holding – up time of the spent fuel more than 20 years the share of such reactors would be quite low and that would prevent us from reducing the natural uranium consumption Moreover the long term hold- up of the spent fuel spoils the plutonium because 241Pu disintegrates. The distinctive features of the PUREX in terms of the energy release and specific radioactivity of the recycling spent fuel restrict its use in nuclear power engineering systems with fast and thermal reactors with the closure of the nuclear fuel cycle and facilitate the development and implementation of new technologies that will be not so vulnerable to radioactivity of the recycled spent fuel .

 **The hold-uptime in terms of burning out index, compared to the basic spent fuel index, per annum**

|  |  |
| --- | --- |
| Index  | Burning out , GWd \*сут/tn  |
| 50 | 60 | 100 |
| Power density Activity: α ßγ  | 6,5>2066,5 | 7,5>206,58 | 16,5>201113 |

Let’s consider another possible solution to this problem.

 Some problems of spent fuel recycling that depend on the high burning out index and the high level of radioactivity can be solved by heterogeneous distribution of the raw and fission components in the reactor In thermal reactor the heterogeneous distribution of the fission and raw components was examined as exemplified by thorium This approach was originally devised for Изначально этот подход был разработан применительно high temperature gas-cooled reactor [8, 9]. In this case the fuel rods contained microfuel. Microfuel is a ceramic core made of u**ranium dioxide** (fission component) or thorium dioxide(raw component ), which is locked in the capsule that consisted of the multi - layered ceramic coatings . This framework ensures a high burning out index of the fissile components and that makes possible to dispose the spent microfuel without recycling. Fissile products generated in raw microfuel can be reused while closing of the fuel cycle.

Consequently, the basic principle of the heterogeneous structure is to ensure the high burning – out level of fissile feed stock in the fuel rods, so that this components won’t require fast recycling. The heterogeneously distributed in the active zone or in the blanket reactor components contain new fissile material with lower level of radioactivity and can be recycled after the short hold- up time

The evaluation of the spent fuel management in heterogeneous zone - when the fissile and raw isotopes were separated revealed that the heterogeneous zone ensures the highest burning - out level. The fissile isotopes work at their full capacity, the secondary isotopes are generated in the conversion zone. After the irradiation in the reactor the energy release will be slowing down more in the zone where we see a raw isotope (fig 5).With the appropriate reloading frequency the fissile productivity in these zones would be quite low and the conversion ratio could amount to 2.

***Fig.*** 5 The afterpower Е and the burning – out index of internal 120 GW/d. tn and external20 GW/d.tn layer of the heterogeneous fuel rod by the average burning out index of *(2)*40 GW/d/tn. in comparison with the burning out index of 40 GW/d/tn. and the holding up time of 5 years *(3)*

 Thus the analysis of nuclear close fuel cycle development should rest on the principle of the minimal radioactivity, we should continue studying the new methods of the spent fuel recycling as well as devising new types of reactors which will allow to hold the processes of generating energy and accumulating fuel separately.