CRITERIONS FOR COMPARISON OF DIFFERENT RESEARCH REACTORS

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Abstract

The report describes the problem of comparison of different research reactors and the evolution and modern state of Russian approaches to this problem.

Research reactors have the very different parameters and there is no one approach to the definition of the criterion for the assessment of the reactor. During the evolution of research reactors Russian scientists offered to use a lot of such criterions. The most known criterions are:

Power of the reactor;

Neutron flux density;

Quality of the reactor;

Productivity of the reactor;

Price of neutron.

The report discusses advantages and disadvantages of using of these criterions.

Now the problem of comparison of different research reactors has an interest because we discuss the different possibilities of reducing of enrichment of uranium. In this case it’s necessary to compare the same reactor but with different fuel (high and low enriched).

The problem of comparison of different research reactors has a long and very interesting history. Research reactors are very different by types, power, conditions of exploitation and so on. The main purpose of operation of research reactors is to provide experimenters with neutrons flux of different spectrum and intensity. The quality of the experiment depends from the level of the neutron flux and the value of the background of neutrons with another energy and gamma-rays, the volume of experimental channels and many other conditions. It’s clear that very difficult to define such criterion which can allow to compare the very different reactors. One reactor has a big power but small sizes of experimental channels another has a very long duration of operation but a small level of the density of neutron flux. After all for different period of the operation of the same reactor the criterion would be different.

Now it’s interesting to discuss this problem also in connection with the necessity to compare the research reactors before and after reducing of enrichment of uranium in them. In this case there is a necessity to compare the same reactor but with different type of the fuel.

During many years in Russia a broad and deep discussion on the problem of comparison of different research reactors were take place. We can consider the evolution and modern state of Russian approaches to this problem.

In the beginning designers and operators of research reactors used the only one value for comparison of research reactors - the **power** level of the reactor. In every cases this criterion can be used for the first research reactors in many countries. <u>If the power bigger the reactor is better!</u> May be it’s right because the experimental possibilities of reactor is approximately proportional to the power level and the concrete experimental program at the new reactor is not yet definite. In the practice of assessment of safety of the reactors the power plays the role of the main criterion to the present day. Power of the reactor also defines the class of the reactor. Very conditionally it’s possible apply to the low class reactors with power level below 1 MW, to second class - with power above 1 MW and below 20 MW and to third class - with power higher than 20 MW.

Absolutely clear that this criterion is not applicable to the case of comparison of research reactors in the case of reducing of enrichment of uranium. In this case the power level stays the same before and after reducing of enrichment and there is no result of the reducing of enrichment.

As research programs of reactors were developed the different criterion may be used. The most important for experimenters is **the density of neutron flux**. Using of this criterion proposes that the experimental program reached the relatively high level. This criterion can be used in the case of RERTR program and at the first stages of our national program it was the only one criterion for comparison of different variants of reducing of enrichment. But really that it’s necessary to know how much reducing of neutron flux is possible for experimenters. Usually for small power reactors the value of the density of neutron flux is not so important and by this reason the reducing of enrichment is relatively easy for these reactors (another reason is that various margins are much more at these reactors that at the high power reactors). Experimenters at high power reactors require the very high neutron flux and its experimental program are very sensitive to the level of the flux. So in this case the reducing of the density of neutron flux is not desired. In principle the neutron flux can be the same before and after reducing of enrichment but it requires the changing of geometry (smaller volume of the active core) that can be impossible in many cases during thermohydralic limitations. Another possibility of retaining of neutron flux at reducing of enrichment is increasing of the power level of the reactor. But this way is very complicated in consequence of the problem of the new license.

Further development of research reactors required that designers of reactors and operational organization shall be estimated the price of the additional increasing of neutron flux.

By this reason S.M.Feinberg introduced the new definition: **"Quality of the reactor"**[1] and defined it as:

$$\mathbf{Q = F^{max} / W,}$$

where F^{max} - maximum density of neutron flux in experimental channels of the reactor;

W - power of the reactor.

But the questions are: "What and where are the flux?" General answer is absent. It may be the density of the thermal or fast neutron flux. It may be the density of the neutron flux in the trap, loop or ampoule channels or at the bottom of horizontal channels. These are questions for designers of the reactor and users of experimental channels.

Typical value of the quality for "good" reactor is 3-5*10^{13} t.n./(cm^2*c*MW) in flux trap, 2-2.5*10^{13} t.n./(cm^2*c*MW) in reflector. Disadvantages of this criteria are the absence of the influence of the burnup of the fuel to this parameter and the non evident proposal that all values of neutron flux are equal for experimenters.

During the 60th- 80th - years this criterion was very popular in Russia. It's very convenient to use it in the case of the design of new research reactors. In this case the designer can vary the power level and another parameters of the reactor and choice the optimum (maximum) value of the quality. But in many cases more important to increase not the value of quality but the value of the density of neutron flux. If we have no limitations on the reactor power we can prefer the reactor with smaller value of the quality but with the bigger value of the density of neutron flux. Really it means that the power of reactor must be bigger and it's possible at the design stage.

In the case of RERTR problem the application of this criterion is not so convenient because the power of research reactors must be the same practically in all cases before and after reducing of enrichment and neutron flux would be smaller owing to additional absorption of neutrons in uranium-238. By this reason the comparison is not representative.

For to take into account the value of neutron flux V.A. Tsykanov offered to use the criterion of **productivity of the reactor** [2]. The productivity of the research reactor - **P** is the sum of the productivity of experimental channels - $\mathbf{P_{ch}}$ that is equal to

$$\mathbf{P_{ch} = V * F},$$

where **V** -volume of the channel,

F - mean value of the neutron flux in the channel.

Another approach was proposed by Prof. Yu.Petrov from PNPI (Gatchina). He offered to consider the productivity as the number of pulses in experimental apparatus [3].

The productivity includes the volume of the channel and in this sense this criterion is better than the quality of the reactor. But the burnup also is absent and reactors with different values of neutron fluxes can have the same productivity although it's clear that the reactor with bigger neutron flux is preferable in comparison with the reactor having the lower neutron flux.

The most often this criterion was applied to the comparison of high power reactors and may be more convenient to use it in the case when experiments are not sensitive to the value of the density of neutron and important only the total quantity of neutrons in experimental channels.

This criterion also is not convenient for application in the case of reducing of enrichment because in every cases the productivity of the reactor with smaller enrichment is smaller than productivity of the reactor with higher enrichment.

When the research reactors reached the high level it was clear that the most preferable criterion for comparison shall be exist on the base of the economic parameters. In any sense it is possible to speak about so-called **"price of neutron".**

There are many definitions of this parameter but may be more successful is the definition of Yu.Petrov [4]:

$$\mathbf{S \sim a * g * W / (n * x * F) + c / (n * F)},$$

where **W** - power of the reactor;

F - mean value of the neutron flux in the experimental channels;

n – number of experimental channels;

x - burnup of the fuel in relative units;

g – price of one gram of the fuel including the cost of fabrication of fuel elements and assemblies;

c- sum of the operational costs and capital costs;

a – coefficient between gram of fissionable uranium-235 and energy released in reactor, usually it equal to 1.25 g/MW-days.

It's necessary to say that Yu.Petrov defined this value as reactor component of the cost of one pulse in experimental apparatus.

First term in this definition is fuel component and it is inverse proportional to the quality of the reactor.

For the low power reactor first term is relatively small. It means that cost of the fuel is not so important and it is possible to use the fuel with relatively big price.

But for very high power reactors the first term is big and define practically all operational costs of the reactor or another words the cost of the production of neutrons and correspondingly the pulses in experimental apparatus.

There were a lot of attempts to complicate of this criterion. The authors offered to take into account the volume of the experimental channels, the more high price of the neutron in the channels with more high flux level but the structure of the definition were the same (see for example [5]). It's important to take into account operational and constant expenditures. But in general it's possible to say that these attempts were not so successful and this definition is sufficient for estimation of the reactor.

There is difficult to use this criterion for the comparison of different research reactors and reactors in different countries because the methods of calculation of economic parameters are very different. But for the same reactor in different states the comparison is good and representative.

This criterion is very convenient for application in the RERTR problem because in all cases we have the decreasing of neutron flux but the fuel is more expensive. If the power level of the reactor is small the fuel part of the price of neutron is relatively small. And not so important by these reason the price of the fuel. May be this is one reason for more successful conversion of low power reactors to the low enriched uranium.

In many cases the price of the fuel elements and assemblies with low enrichment is higher than the price of high enriched fuel. For example in Russia we have a long discussion about the perspective of using of new fuel because it must be have the relatively high price. On the contrary for neutron fluxes the dependence is another that is the density of neutron flux is lower in the reactor with low enriched fuel.

Simple analyses shows that under conversion only first term (or fuel component) is changed. By this reason it’s necessary to compare the relatively value of such parameter:

$$g / (x^* F).$$

Another values would be the same and therefore this value define the advantages of the way of reducing of enrichment of uranium. But it’s clear that for the correct answer it’s necessary to analyze all economic parameters of the reactor such as operational and capital costs.

If we have an experiment which is critical to the threshold value of neutron flux we must be maintain the value of the neutron flux. But if no the preferable variant of reducing of enrichment would be the same that have the smaller value of the parameter - $g / (x^* F)$.

It’s possible to say that the main reason for the existence of big quantity of criterions for comparison of different research reactors is there is no quantitative criterion of economic effectiveness of scientific research.

The table given below shortly summarizes the results of the discussion on different criterions. Every criterion can be used in several cases but has certain disadvantages.

Conclusions

The problem of comparison of different research reactors has a long and very interesting history.

It is possible to use different criterions for comparison of different research reactors. As research reactors developed the most complicated criterion were used for the assessment of the perfection of them.

The most suitable for comparison of research reactor is complex criterion that takes into account not only physical parameters of the reactor but also the cost of fabrication of fuel. The criterion must be not so complicated. For choose the preferable variant of conversion of the fuel from high enriched uranium to low enriched uranium it’s necessary to analyze all costs for the operation of the reactor.

Table. Criterions for comparison of research reactors

Name of the criterion	Applicability of the criterion			
	Class of the reactor			RERTR
	Low	Medium	High	
Power	Å			
Density of Neutron Flux	Å			Å
Quality of Reactor		Å		
Productivity of Reactor			Å	
“Price of Neutron”			Å	Å

Å means relatively good applicability of this criterion.

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