PARTICULAR REQUIREMENTS TO THE LINAC − DRIVER OF A SUBCRITICAL BLANKET

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Abstract

One of the possible and widely discussed accelerators application is their use as drivers of the subcritical fission blankets. The subcritical blankets are considered to be the most promising means for the destruction of the nuclear power long-lived radioactive wastes, such as fission products and transuranium isotopes. The blanket configuration is described which uses the heavy water as the moderator and the molten salt as the fuel. This combination provides possibility of achieving a very high level of thermal flux in the blanket which is very useful features for the wastes destroying facility, since in such flux level even the isotopes with the very low capture cross sections burn effectively. The influence of the accelerator mode operation on the subcritical blanket safety increasing has been considered. It is concluded that from the point of view of blanket safety the most appropriate mode of accelerator operating is the pulse one. In such the mode of accelerator operating the problems of blanket state monitoring and reactivity reliable control can be resolved most effectively, thus greatly increasing blanket safety. The optimal relationship between the pulses length and frequency is discussed and for the blanket of concern some desirable regimes of the accelerator-driver pulse operating are proposed.

INTRODUCTION

In the Moscow Institute of Theoretical and Experimental Physics (ITEP) the development of the Accelerator-Driven Systems (ADS) has been carried out for more than a dozen years now, regarding both the accelerator and blanket designs. A highly efficient blanket configuration has been proposed and is being developed that is a Heavy Water subcritical Reactor with the Molten Salt fuel (HWR-MS).

Major part of efforts is devoted to assuring the blanket nuclear safety. It was concluded that the most crucial safety point is the necessity of a subcritical blanket eigenvalue on-line monitoring and controlling. Concluded too was the fact that the measures having commonly been proposed for this purpose based on the blanket thermal power at the fixed linac power monitoring are not suitable for the blanket configuration of practical interest. For the connection between blanket power and eigenvalue in not direct and may vary in those blanket as a result of fuel planned reloading or of some unforeseen events.

A highly reliable method for eigenvalue monitoring is proposed which accuracy strongly depends on the linac mode operation. Some requirements to such a mode of operation were elaborated for the HWR-MS type blankets, which in general terms are valid for the other types of blankets as well.

HEAVY WATER SUBCRITICAL REACTOR WITH MOLTEN SALT FUEL AS THE BLANKET OF AN ADS

Concept description

According to HWR-MS concept the core configuration is very similar to that of the conventional channel type heavy water moderated gas cooled reactors [1]. Main difference is the fact that the conventional solid fuel pins in the fuel channels are now replaced by the liquid molten salt ones. The material for both those, so called, liquid fuel pins cladding and the channel tubes is the special composite graphite constructional material "argalon", having low absorption cross section, high thermo-mechanical and radiation resistance properties and high thermal conductivity as well. Liquid salt fuel circulates up and down in the different pins within the channel, now called as "the fuel module", without ever leaving it except for refuelling.

As compared with the conventional heavy water concept this drastically simplifies the on-line reloading, which now is really the continuous one, and allows the continuous fission products (including xenon) removal thus considerably improving core neutron balance and consequently the fuel cycles characteristics. Safety both the nuclear and thermal one will also increase due primary to the low reactivity compensation worth required and both the liquid salt and graphite inherent high thermal margins. Still all the heavy water advantages as a moderator as well as the main conventional heavy water reactor designs project proven decisions do remain. Such a combination provides the following facility's distinct properties.

- Extremely high neutron balance due primary a) to a low parasitic neutron capture in the structural materials, coolant and moderator; b) to the possibility of on-line fuel refueling and fission product permanent removal.
- Possibility of:

a) operational (without facility shutting down) neutron spectrum shifting in the broad margins – from that practically fast to a highly thermolized one;

b) operational thermal neutron flux level changing from ~5 10^{13} to ~(2-4) 10^{15} n/cm^{2}s.

The possibility of the operational neutron spectrum and flux changing is due to the system inherent high neutron balance. System is able to reach critically at the extremely low fission isotopes in molten salt concentrations, by orders of magnitude lower than those limited by solubility. At that thermal neutron flux of a very high level can be reached. The system also may be critical at the fuel concentration close to those solubility limited as well, which can be achieved by the proper changing in the fuel the ratio between the fissile and fertile (or the goal) isotopes. At that the thermal flux level drops and the spectrum shifts toward the fast region practically up to those the fast reactors inherent ones.

Such the possibility is of a particular usefulness in the nuclear wastes destroying, for some of the isotopes involved require the fast spectrum where their fission is appreciable, whereas the destruction of some other ones requires the high level thermal spectrum much more suited for the extremely low absorbing isotopes effective capturing. So the possibility is available for the optimal transmutation strategy choosing where spectrum and flux level will be changing conforming the specific isotopes predominating fraction at each current time moment and finally allowing practically total waste quantity involved into the fission products transforming for a quite reasonable (not more than ~ 20-30years) period of time.

Performances assessments

The results of some preliminary calculations have shown that: a) in the uranium - thorium cycles the breeding regime may be achieved with the BR ~1.02 - 1.04 ; b) in the minor actinides from LWR destroying and for the transmutation cycles of ~25 years duration more that 99% of the minor actinides involved would be transformed exclusively in the fission products

MAIN ADS PROBLEM AND WAY OF RESOLVIND

Necessity for a permanent subcriticality level monitoring

For both the critical system and the subcritical one the prompt neutrons due uncontrolled system run away (the most severe accident for any multiplying system) will be precluded if the following relation holds at any time of system operation -*t*:

$$k_{eff}(t) + \Delta\rho_{pot} < 1 + \beta_{eff} . \quad (1)$$

$k_{eff}(t)$ - system eigenvalue at time t ; $\Delta\rho_{pot}$ - maximal possible value of positive reactivity which potentially might be introduce into the system; β_{eff} - delayed neutron fraction.

In the critical systems the only fact that the system thermal power $W_{sys}(t)$ = const guarantees the relation $k_{eff}(t)$=1 holding, and the system proper value of $\Delta\rho_{pot}$ in turn guarantees that of the relation (1), thus the latter monitoring means merely keeping the time constancy of the system thermal power, which is rather simply realized in practice.

In the subcritical systems, however, the only fact that both the blanket power – $W_{bl}(t)$ and the accelerator one – $W_{ac}(t)$ are time constant does not at all mean that the value of $k_{eff}(t)$ is time constant too.

This is due to the fact that in a subcritical system the blanket thermal power arc wise proportional external neutrons multiplication - $\mu(t)$ depends not only on the system eigenvalue - $k_{eff}(t)$ but on the external neutrons efficiency – $\omega(t)$ as well (Ref. [3]), according to relation

$$\mu(t) = \omega(t)\frac{k_{eff}(t)}{1 - k_{eff}(t)} . \quad (2)$$

Thus, an ADS system's values of blanket and accelerator powers, blanket eigenvalue and external neutrons efficiency are related as follows

$$W_{bl}(t) = C \times W_{ac}(t)\,\omega(t)\frac{k_{eff}(t)}{1 - k_{eff}(t)} , \quad (3)$$

where C – some particular ADC system proper constant.

In the HWR-MS ADS of concern, as well as for the most ADS of practical interest, the on-line fuel and goal isotopes reloading in the blanket is to be realized. This procedure governs the value of k_{eff}, thus in doing so the on-line k_{eff} value monitoring has to be realized to guarantee relation (1) holding. On-line reloading does affect the value of ω as well which, in principle, is not measurable and can be obtained only by calculation. Moreover the letter value may be affected by any accidental system's inner failures which, during system operation, can not be detected by the system staff.

From above it follows that for any ADS of practical interest, including that if concern:

- on-line permanent k_{eff} value monitoring **is absolutely imperative from the safety point of view;**
- such a monitoring, as seen from relation (3), **can not be realized via commonly proposed methods** based on accelerator and blanket power on-line measuring and some in principle new methods have to be developed and used.

Approach to resolve

The analysis carried out in the Moscow Institute of Theoretical and Experimental Physics led to the following conclusions.

The most reliable way of blanket k_{eff} value on-line monitoring is k_{eff} on-line calculation based on some proper chosen blanket characteristics on-line measuring at the moments when blanket is not influenced by accelerator, that is **when blanket and accelerator are disconnected.**

For the ADS permanent operation that means that **the accelerator operating mode should be the pulse one**. Blanket time depending characteristics have to be measured between the successive pulses and time interval between the letters should be long enough to allow the blanket to reveal its inherent physical properties necessary for k_{eff} value father exact on-line numerical calculations.

Concluded also was that in the blankets of practical interest such a subcritical system time dependent characteristic as the neutron flux time decay constant can not be used as a basis for k_{eff} value calculation. Those blankets as a rule have volumes with very different physical properties, which leads to the neutron flux space shape over the blanket volume time altering during the flux decay – the fact that means that in these cases such a thing as the flux time decay constant does not exist whatsoever.

It was proposed to developed and create the full-scale three dimensional numerical model of the real blanket which exactly simulates all the blanket prompt neutrons due dynamic processes in the real time scale.

This numerical computer model is to operate in parallel with the real blanket operation. All the real blanket conditions changes, inner and external reasons due, (fuel burnup, inventories loaning and unloading, control devices positions altering, proton beam characteristics and so on) are to be simultaneously reflected in the numerical model.

A continuous computer comparing is to carry out of the flux time shapes measured between the beam pulses at some properly selected locations within the real blanket core and those provided by numerical model for the corresponding locations.

For those flux time shapes are strongly affected by the blanket eigenvalue (even though flux decay constant does not exist), any unexpected changes in blanket eigenvalue which have taken place in the real blanket for some reasons but not reflected in the numerical model will be momentarily detected by the time shapes comparing. Moreover, if such comparing is carried out at a number of properly selected locations, by shapes comparing and using a corresponding computer code the reasons of eigenvalue changing may be identified, and some others unforeseen blanket conditions changes, though not influencing eigenvalue but in some way affecting the blanket safety, can be detected as well.

Forecast method

The full-scale three-dimensional numerical modeling of prompt neutrons dynamics in the real time scale has no world analogies .A new approach to the modeling of the prompt neutrons dynamic is proposed and developed in ITEP. The approach is realized in the so-called forecast method [2], based on determining the contribution of the system current time moment's state into the system state at the following fixed time moments, with the forecast results summing while system successive going to the new time moment

MAIN REQUIREMENTS TO A LINAC

The most reliable neutron flux time shape comparing would be realized when there exists a time interval of blanket and accelerator temporary disconnection no less than ten prompt neutrons mean life times.

So, if: T_0 – mean prompt neutrons life time in the blanket (sec); τ_p – proton pulse length (sec); f - pulse frequency (Hz) then the following relation should be hold

$$1/f - \tau_p \geq 10T_0 . \quad (4)$$

Relation (4) establishes the upper limit on the pulse frequency. The lower frequency limit (irrelevant from the point of view of blanket reliable monitoring) is to be determined by the desire that the disconnected interval be short enough to exclude the possibility of blanket temperature changing and that the frequency be high enough to provide sufficiently high mean beam current.

The above considerations appear to be valid for all types of blankets. For the HWR-MS blanket of concern the prompt neutrons mean life time depends of the fuel inventory used in a particular fuel cycle and varies in a wide range as

$$1\times10^{-3}\ \text{sec} \leq T_0 \leq 5\times10^{-3}\ \text{sec}$$

According to the fact that the conventional values of pulse lengths are much less than this time range the only requirement posed by HWR –MS type blanket is that the pulse frequency be of the order of ~20-25Hz. This frequency values are quite appropriate from the point of view of blanket thermal properties and sufficient beam mean current achieving as well.

CONCLUSION

• The most crucial ADS nuclear safety problem is the necessity for on line blanket eigenvalue monitoring.

• The highly reliable way of this problem resolving is the eigenvalue on line calculating based on comparing the flux time shapes measured in blanket and provided by its working in parallel numerical model during the time intervals of accelerator and blanket disconnection.

• Thus, the most preferable mode of accelerator operation is the pulse one. At that the values of pulse frequency and pulse length should provide a disconnected interval no less than of the order of ten blanket prompt neutrons life times.

• For the highly efficient blanket of HWR-MS type being developed in ITEP the pulse frequency is to be of 20-25Hz.

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