THE ITEP'S EXPERIMENTAL ADS DISTINCTIVE FEATURES RELATED TO PULSE MODE OF THE LINAC

V.V.Seliverstov, M.M.Igumnnov, V.N.Konev, A.M.Kozodaev, O.V.Shvedov, E.B.Volkov
State Scientific Centre of Russian Federation “Institute of Theoretical and Experimental Physics”

Abstract

The construction of the experimental ADS with 36 MeV, 0.5 mA proton linac is being currently performed at SSC RF ITEP. The main purpose of the facility is the experimental approval of the ADS reliable operation possibility, as well as the development and validation of a subcritical system configuration principles and the methods of control, allowing the nuclear safety increasing when compared with the conventional critical systems. A number of configuration principles and methods of controls being developed in ITEP is considered which will be used in the facility of concern and based in particular on the linac pulse operation mode.

1 INTRODUCTION

The main ADS advantage as compared with the conventional critical system is supposed to be their subcritical operation mode that in principle allows the reactivity accident risk considerable lowering. However, subcritical operation mode with an external source involves some new problems considerably affecting nuclear safety. Most important of those are: a) necessity for the system subcriticality level constant monitoring on an operating system; b) necessity for the methods developing for the system emergency shut down with a failure of a beam trip; c) necessity for establishing the negative feedback between system temperature and system power which allows the system self-shut down at some accidents, e.g. loss of coolant or loss of coolant flow. Those negative feedbacks are inherent to the modern natural safety critical systems but are lost with the direct going to the subcritical operation mode. In ITEP some approaches and methods for those problems resolving are being developed and will be used on the experimental ADS of concern. The latter’s main characteristics are presented in the companion paper [1]. The purpose of the present one is the brief accounting of the developing configuration principles and control methods for ADS aimed at the nuclear safety increasing. Some of those methods impose the certain requirements regarding the linac operating mode. In particular for those problems proper resolving the most preferring linac operation mode is the pulse one, or for the constant current linac operation the possibility for the current short term interrupting (for the time intervals of the order of some prompt neutrons life times).

2 CONSTANT SUBCRITICALITY LEVEL MONITORING ON AN OPERATING SYSTEM

2.1 Necessity for a constant subcriticality level monitoring

For both the critical system and the subcritical one the prompt neutrons due uncontrolled system run away will be precluded if the following relation holds:

$$k_{eff}^{0} + \Delta\rho_{pot} < 1 + \beta . \qquad (1)$$

k_{eff}^{0} - initial (before positive reactivity emergency addition) system eigenvalue;

$\Delta\rho_{pot}$ - maximum possible value of positive reactivity which potentially might be introduced into the system;

β - delayed neutron fraction.

For a critical system (k_{eff}^{0} =1) the possibility of system run away is precluded, if the maximum value of positive reactivity potentially might be introduced does not exceed the value of β ($\Delta\rho_{pot} < \beta$). Such approach is used for all the modern critical reactors of natural safety design.

In the critical systems the only fact of the system thermal power time constancy guarantees its eigenvalue to the unity equality (k_{eff}^{0} =1) and the proper choose of the value of $\Delta\rho_{pot}$ in turn guarantees the relation (1) holding.

In the subcritical systems, however, the only fact that both the blanket power ant the accelerator one are constants in time does not at all mean that the value of k_{eff}^{0} is time constant too.

This is due to the fact that the external neutrons multiplication in a subcritical system depends not only on the system eigenvalue but on the external neutrons efficiency too [2].

As a result if just after a system on power operation starting up the relation $k_{eff}^{0} = k_{eff}^{nom}$ did hold (k_{eff}^{nom} <1 – nominal declared system eigenvalue which does guarantee relation (1) accuracy), then after the system on power operating for some time the only fact of the blanket and the accelerator simultaneous powers time constancy does by no means guarantee that the value of k^0_{eff} is time constant too, and thus that condition (1) does not be violated.

Thus the critical systems control conventional principles based mostly on the of system thermal power monitoring do not effective enough for the subcritical systems and consequently the new principally different ones have to be developed and practically validated.

So going to subcritical mode operation involves the additional problem relating to the necessity for the system subcriticality level constant and reliable monitoring in order to assure the relation $k^0_{eff} \le k^{nom}_{eff}$ holding at all the system operating regimes.

2.2 Subcriticality level monitoring principle

The approach to and the main principles of the reliable monitoring and controlling suitable both for ITEP's experimental ADS facility and for the practical application ADS driven by pulse mode linac as well are developed in ITEP. Principle is based on the developing and using the computer code for the full-scale three dimensional numerical modeling of all of the physical and thermo-hydraulical processes in the real time scale peculiar to the prompt neutrons based ones.

In the real time scale the on-line constant comparing is performed between the measured and calculated system parameters, and their on-line numerical analyses generates a lot of information regarding the abnormal regimes initiating (including the deviation of current k_{eff} value from the nominal one), their nature and working out recommendations for the personal proper actions.

The full-scale three-dimensional numerical modeling of prompt neutrons dynamics in the real time scale has no world analogies. The experimental approval and validation of such methods and codes is the most important condition for their further practical application and thus this fact is that determines the actuality of such methods on the ITEP's experimental facility validation.

The possibility of the full-scale three dimensional prompt neutron dynamics in the real-time scale modeling is due to the developed in ITEP proper method based on solving the dynamic equations expressed in the integral form [3].

2.3 Integral form of the prompt neutrons dynamic equations

Let for all of the prompt neutrons sources be known the initiation probability functions $K(r_0,r,t)$ – probability that a neutron of a given spectrum introduced into the system at the point r_0 at the moment t=0, initiates a prompt neutron at the point r at the moment t.

I.e. are known

$K_p(r_0,r,t)$– initiating function for fission prompt neutrons;
$K_d(r_0,r,t)$– for group 'd' delayed neutrons;
$K_{ex}(r_0,r,t)$– for external source neutrons.

Let further $Q_{ex}(r,t)$ be a given space-time distribution of a given spectrum external source.

Then the system space-time distribution of the fission prompt neutrons birth – $Q_p r,t)$ is defined from the integral equation solution.

$$Q_p(r,t) = \int_V dr_0 \int_0^t Q_{ex}(r_0,t) K_{ex}(r_0,r,t-\tau)d\tau + \int_V dr_0 \int_0^t Q_p(r_0,t) K_p(r_0,r,t-\tau)d\tau + \int_V dr_0 \int_0^t \sum_d \lambda_d C_d(r_0,\tau) K_d(r_0,r,t-\tau)d\tau, \quad (2)$$

where the delayed neutrons precursors $C_d(r,t)$ is defined as

$$C_d(r,t) = \frac{\beta_d}{1-\beta_{eff}} \int_0^t Q_p(r,\tau)\exp(-\lambda_d(t-\tau))d\tau$$

β_d, λ_d – fraction and delay constant of the group 'd' precursors respectively.

When Eq. 2 is solved numerically the fuel zone is divided by the number–N_f of volume elements and the external source zone by that –N_{ex} of ones.

Accordingly, the initiating functions have the following view and meaning

K(i,j,t) – probability that a source neutron introduced into the system in the space volume 'i' at the moment t=0, will initiate a fission prompt neutron in the space volume 'j' at the moment t.

2.4 Method for the initiating function determining

The distinctive feature of the present approach to the prompt neutrons dynamics dealing with and be based on the equations integral form is that all of the initiating functions are to be calculated beforehand, i.e. before the system operation starting and this is done without regarding how much computing time it will take. The system dynamic calculation proper is to start together with that of system operation and be consisted only in Eq. 2 with known initiating functions solving which is a quite simple and an extremely time inexpensive procedure.

Initiating functions are expressed as follows

$$K(i,j,t) = A_i \times G(i,j) \times \omega(i,j,t), \quad (3)$$

A_i – numerical constant.

For the physical meaning – total number of fission prompt neutron initiated in the whole fuel zone by one given spectrum source neutron introduced in the space volume 'i'.

G(i,j) – initiating function space constituent with the normalization for all 'i'

$$\sum_j G(i, j) = 1 .$$

For the physical meaning . Let in the space volume 'i' a time-constant and space uniformly distributed source with a given spectrum be placed.

Then G(i,j) – relative (spatial) distribution over volumes 'j' of the fission prompt neutron birth initiated by the source in the volume 'i'.

ω(i,j,t) – initiating function time constituent with the normalization for all i,j

$$\int_0^{\infty} \omega(i, j, t)dt = 1 .$$

For the physical meaning . Let in the space volume 'i' at the moment t=0 a prompt neutron pulse with a given spectrum be introduced space uniformly.

Then ω(i,j,t) – relative (over time) fission prompt neutrons births distribution in the volume 'j' initiated by a source neutrons pulse in the volume 'i' .

Numerical constant and the space constituents are to be very easily determined by simply solving the source problem for a steady state non-multiplying system with the source located in the volume 'i'. As for the time constituent, in case of the thermal system it is to be determined by the method of successive collisions in a homogenized three dimensional system, that is, the function is to be determined - $\omega_1(r_0,r,n)$ – collision number probability density, i.e. the number of collisions – 'n' (n=0,…∞) that a neutron which having been born as a fast one at the point r_0, having been promptly moderated over the system, has undergone in the thermal region before reaching the point r.

For the systems with the large thermal neutron life time and thus with the large number of thermal collisions (in the ITEP's experimental facility the mean number of thermal collisions is of order of ~500) it is quite appropriate to assume that the time constituent is related to the collisions number density as

$$\omega (r_0,r,t) = \omega_1 (r_0,r,t/\Delta t),$$

Δt – mean time between successive collisions which is to be easily determined by simply dividing the neutron mean life time by the neutron mean number of collisions.

3 PRINCIPLES OF THE NATURAL FEEDBACKS ESTABLISHING

The possibility of the natural feedbacks between a subcritical system temperature and system power establishing is due to the fact that as shown in the Ref. [2] the source neutron multiplication in a subcritical system is determined as $\mu = \omega \frac{k_{eff}}{1 - k_{eff}}$, where ω - external neutron relative importance – ratio of the space integrated real source importance to that of the reference source (imagined external source with the space-energy spectrum the same that the fission neutrons one in the system critical problem).

This means that if the system is configured in such a way that with the system temperature increasing the value of ω will decrease quite naturally, the negative natural feedback between system temperature and system power is obtained For the ITEP's facility such configuration will be obtained by placing between the neutron target and the system fuel zone the so-called buffer zone – a volume of heavy water. This, with the system temperature increasing leads to the value of ω significant decreasing naturally, and in case of adding boron solution into the buffer zone reduces this value practically to zero, thus allowing blanket power lowering to the residual heat level even in case of the beam trip failure.

4 CONCLUSION

1. In the ITEP's experimental ADS facility currently being built the blanket configuration principles and the methods of control will be used and practically validated which allow the reliable subcriticality level on an operating system monitoring, natural negative feedback between system temperature and power establishing and the possibility of the system shut down accomplishing even in case of the beam trip failure as well.
2. Distinctive feature of the reliable subcriticality level monitoring is the pulse mode of a linac operating, which assumes the preference of just that linac mode in the future ADS practical systems. However the proposed method is applicable for the constant current linac as well. Only in this case it is necessary to provide linac with the possibility of beam interrupting every several minutes for quite a little time interval respecting to several (5-10) prompt neutrons mean life times. Without this it would be quite difficult, if possible, to provide the constant proton current ADS with a sufficiently reliable subcriticality level monitoring system, which might put into question their real safety superiority achieving over conventional critical systems.

REFERECES

[1] A.M.Kozodaev and all. "Construction of small-scale multipurpose ADS at ITEP ". This Conference.
[2] V.V.Seliverstov "Analysis of Spallation neutron importance in accelerator-driven target-blanket systems". In Proceedings of the Second International Conference on Accelerator-Driven Transmutation Technologies and Applications, June 3-7,1996. Kalmar,Sweden. p.891-897.
[3] V.V.Seliverstov, O,V.Shwedov. "Point dynamics equations in integral form for the prompt neutrons dynamic in a subcritical system with a pulse source solution".Atomnaia Energia, v.85, iss.2, august 1998, P. 97-107