Modeling of Activity Evolution in Lead Target of SAD Subcritical Assembly

A. Polanski[1,2], **S. Petrochenkov**[1]
[1] *Laboratory of Information Technologies, JINR*
[2] *Soltan Institute for Nuclear Studies, Otwock-Swierk, Poland*

Construction of the electronuclear installation consisting of the existing 660 MeV phasotron and a subcritical multiplying blanket with a target (SAD) is planned in JINR-Dubna. The blanket consists of a set of fuel assemblies (FA) installed around the target. The number of the FA's is chosen in such a manner that the neutron multiplication factor in the unit will not exceed 0.98. In such a case supplementary neutrons are needed to start a chain reaction. The neutron source is the target emitting neutrons under irradiation with the 660 MeV proton beam. The lead and steel casing of the target gains induced activity under irradiation of the installation with the proton beam with energy 660 MeV. The SAD project is developed under assumption that the target will be replaceable to expand the experimental program and in search for an optimal design and materials: therefore the option for reloading the target must be pre-considered. Hence, it is required to ensure a proper radiation shielding to store the target assembly and to estimate the equivalent dose around the target during the reloading operations. Such calculation was carried out for the lead target in a steel casing and lead blocks surrounding the target [1].

Lead Target of SAD Subcritical Assembly.

The lead target consists of a two-millimeter stainless steel casing which appears as a structure which imitates the external profile of the assembly made of seven hexagonal prisms with a flat-to-flat dimension of 34 mm mounted with an increment of 36 mm (See Figure 1) and a bottom and lid (also made of stainless steel) hermetically welded to them. The cavity is later filled with lead. Cylindrical cavity with diameter 58 mm and length 179 mm is made at the entrance point of the beam into the target to provide optimal conditions for neutron generation. Twelve lead blocks are placed around the target. A hexagonal lead block is made of a hexagonal stainless steel tube with a flat-to-flat dimension of 35 mm with an internal diameter of 33 mm and a stainless steel shank and lid hermetically welded to it. Internal cavity is also filled with lead. The total mass of the target is 52 kilograms; the mass of the lead block is 7,7 kg.

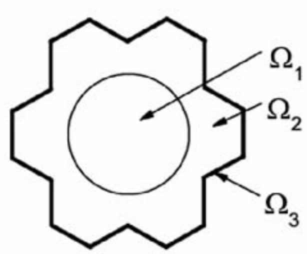

Fig. 1: Layout of the lead target and subdivision zones (Ω_1, Ω_2, Ω_3) used for modeling

Methods used for calculations and results.

Calculation of radioactive isotopes induced by protons from the accelerator beam and secondary neutrons was accomplished using the program MCNPX. Meanwhile the target was subdivided into three zones (See Figure 1): central cylindrical area with diameter 58 mm (Ω_1), second layer (Ω_2) – includes the remaining lead and the target casing made of stainless steel which comprises the external third layer (Ω_3). This subdivision is introduced to consider uneven distribution of radioactive nuclides caused by difference of processes occurring in each zone and the variety of materials used in the target and casing. Thus, processes of high energy fission of lead nuclei caused by interactions with accelerator beam protons occur in the central zone. In the second layer surrounding the central zone activity is caused mainly by secondary particles generated in high energy processes. Generation rates for each nuclide in all three zones of the target assembly have been obtained as a result of calculations. The following operation mode has been further chosen: the installation is running under uniform load for one calendar year, during the time the beam is fed into the target for 1000 hours. After that the assembly is cooled down.

To determine the density function and activity for each isotope at any arbitrary moment of time for the chosen operation mode it is necessary to solve the Cauchy problem for the set of kinetic equations (i =1, 2, ... I) at the finite time segment t [t_{min}, t_{max}].

$$\begin{cases} \frac{dN_i(t)}{dt} = \Lambda_i^t + \sum_{k\neq i} \lambda_{ik}^r N_k(t) - \lambda_i^d N_i(t), & i \in [1, I], \\ N_i(t_0) = N_i^0, & i \in [1, I], \end{cases}$$

where $N_i(t)$ – number of nuclei of the i-th type at the moment of time t, Λ_i^t- generation rate for the i-th nuclide in nuclear reactions, λ_i^d- probability of nuclear decay for such nucleus per unit time; λ_{ik}^r- probability of a nuclear decay for a nucleus of the k-th nuclide when it is converted into the nucleus of the i-th nuclide; I – number of isotopes considered in the task. Contribution into the total activity of nuclides generated as a result of two or more reactions is small (<0.5%). Therefore this case was not considered. To solve the task in the central zone (Ω_1) we had to consider 1311 radioactive isotopes with non-zero Λ_i^t at start time. During the calculation the number of isotopes increases up to 1328. The program calculates activity of the system during the time interval from t_1=1000 seconds to $t_{max} \approx$ 27 years. As a result of calculations, we received 100 activity points along the time variable equidistant in logarithmic scale. Algorithm to solve the system is discussed in [2]. Data library for radioactive decay JEF 2.2 was used in calculations. Time dependences shown in Fig.2 and Fig.3. have been obtained.

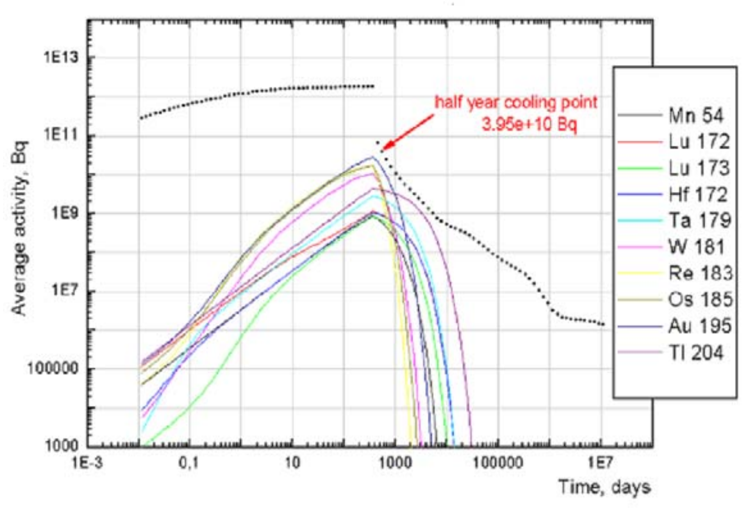

Fig. 2: Total activity of the lead target as well as isotopes the most active after half a year since the shut down of the SAD

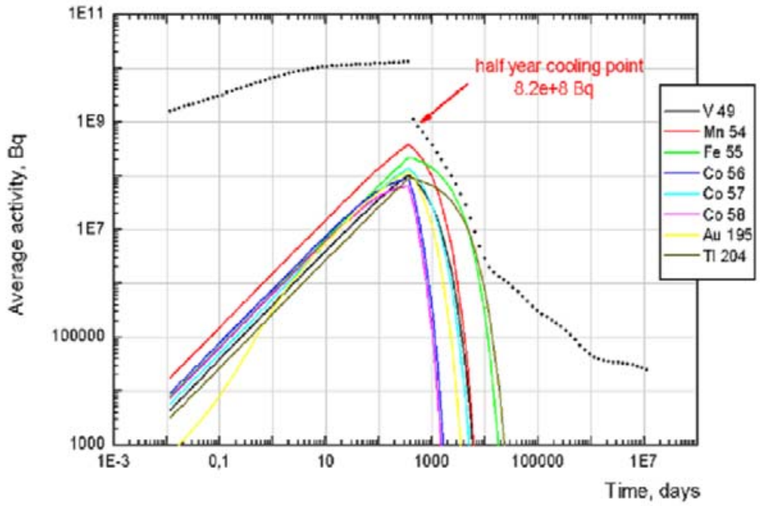

Fig. 3: Activity of the lead blocks surrounding the target as well as isotopes the most active after half a year since the shut down of the SAD

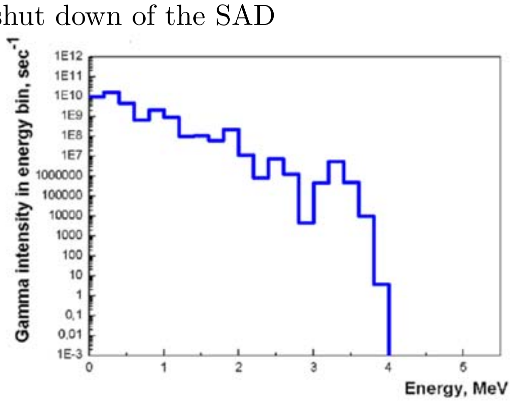

Fig. 4: Gamma intensity in the energy bin (gamma quanta with energy in the limits of one bin of the histogram) in the target (Ω)

It has been assumed that the cooling time prior to the startup of reloading operations is equal to half a year. Point of total activity after the half year since the installation shut down is marked in Figure 2 with an arrow. It is clear from the Figure that the activity of the target at this moment will be equal to $3{,}95\cdot10^{10}$Bq, and that of one of the lead blocks will be equal to $8{,}2\cdot10^{8}$ Bq. Further on gamma ray spectra have been obtained by using the JEF 2.2 Library (See Figure 4).

The spectra were caused by the decay of radioactive isotopes in target zones (Ω_1, Ω_2, Ω_3) presented in Figure 1.

References

[1] *A.Polanski, S. Petrochenkov.* Modeling of Activity Evolution in Lead Target of SAD Subcritical Assembly. 3^{rd} High-Power Targetry Workshop, September 10–14, 2007, Bad Zurzach, Switzerland.

[2] *S. Petrochenkov.* Simulation of activity evolution of lead target for the subcritical assembly Bulletin of PFUR, 2005, Vol 4, No 1.