DEMONSTRATION ACCELERATOR DRIVEN COMPLEX FOR EFFECTIVE INCINERATION OF ^{99}Tc AND ^{129}I

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Abstract

Design of an ADS complex for transmutation of ^{99}Tc and ^{129}I is discussed. The complex contains following units: a linear accelerator or proton cyclotron with small current, a neutron producing target and a sub-critical blanket. A schema of a linac with superconducting systems is proposed. Versions of Pb-Bi and tantalum targets are considered. The special design of a channel-vessel type of blanket is outlined.

1. Introduction

The atomic power engineering exists for more than 40 years. One of the main problems of atomic power engineering is radiation safety of power plants and long-lived radwaste management. Nuclear transmutation is one of the alternative technologies of radwaste management. The nuclear transmutation consists in the incineration of radioactive nuclides by neutron irradiation. For production of neutrons, a sub-critical reactor (which in this case is called blanket) with neutron source can be used. A neutron source is a neutron producing target and proton accelerator. A neutron source permits to have excess neutrons, which can be used for transmutation. This electronuclear system is called accelerator driven system (ADS). The conceptual researches conducted recently by Russian and foreign nuclear centres and institutes show a prospectivity and technical feasibility of an electronuclear method of neutron production for radwaste transmutation.

In the State Scientific Centre of Russian Federation Institute of Theoretical and Experimental Physics (SSC RF ITEP) electronuclear technology of radwaste incineration is studied for a long time. It is directed to decrease radiation risk in connection with the opportunity to reduce the amount of radwaste at the expense of ADS. The development of ADS represents an example of high technologies used for deciding on one of the complex problems of modern engineering.

2. Choice of nuclides for transmutation

What are reasons to choose nuclides for transmutation? The main danger in radioactive wastes is determined by two types of long-lived nuclides: fission products and actinides accumulated in spent nuclear fuel. Their half-life is from hundreds up to millions years. Among basic fission products, the main contribution in radiation danger during the first 300-1 000 years is given by ^{90}Sr and ^{137}Cs with half-life 30 years. A further storage, it is given by ^{99}Tc ($2.1\cdot10^5$ years) and ^{129}I ($1.6\cdot10^7$ years). ^{129}I is dangerous because it can be accumulated in the human body.

For ^{90}Sr and ^{137}Cs destruction, a too high neutron flux is necessary. These nuclides can not be transmuted and they can be put in surface storage facility. Among the other fission products, ^{99}Tc and ^{129}I should be transmuted. Processes of ^{99}Tc and ^{129}I transmutation have specific physical features. At ^{99}Tc transmutation, the chain of conversions at step-by-step neutron capture by secondary nuclides is:

$$^{99}\text{Tc}(20/340)\ ^{100}\text{Ru}(5/11)\ ^{101}\text{Ru}(3/100)\ ^{102}\text{Ru}(1/4)\ ^{103}\text{Rh}(145/1100)\ ^{104}\text{Pd}(0.6/16)\ ^{105}\text{Pd}(20/98)\ ^{106}\text{Pd}(0.3/6)\ ^{107}\text{Pd}(2/90)$$

Values of thermal cross-sections and resonance integrals of reactions (n,γ) are given in brackets. Short-lived intermediate nuclides are not shown. Initially, only ^{99}Tc is presented in a target. During irradiation, a 8-step neutron capture, a nuclide ^{107}Pd-with half-life $6.5\cdot10^6$ years is produced. This nuclide is radiotoxic, however its amount is low. The other intermediate nuclides are stable. At ^{129}I transmutation, the analogous chain is:

$$^{129}\text{I}(27/36)\ ^{130}\text{Xe}(26/14)\ ^{131}\text{Xe}(85/900)\ ^{132}\text{Xe}(0.5/46)\ ^{133}\text{Cs}(29/440)\ ^{134}\text{Cs}(140/54)\ ^{135}\text{Cs}(9/62)\ \text{Ba}$$

Two nuclides are presented in initial target: ^{129}I and ^{127}I. An amount of ^{127}I in spent fuel of PWR is about 22% of ^{129}I. A main product of a transmutation is ^{132}Xe. At 7-step neutron capture, long-lived ^{135}Cs with half-life $2.3\cdot10^6$ years is produced. Its amount is important.

Thus, stable nuclides will be formed as result of transmutation with rather low content of new radioactive nuclides. Thermal neutron flux of about $5{\cdot}10^{14}$ cm^{-2}s^{-1} is desirable for transmutation and that is technically feasible at modern level of nuclear engineering.

3. ADS structural scheme

ADS differs from common-type reactor by the sub-criticality of a blanket. This fact excludes an opportunity of blanket runaway on prompt neutrons and increases a level of nuclear safety.

The different basic schemes of ADS are possible: with horizontal and vertical disposition of a target and blanket; with top and bottom supply of target by proton beam; with one accelerator and several blanket and on the contrary, one blanket and several accelerators. The target can be solid (for example, tungsten, lead, uranium) or liquid (for example, lead, lead-bismuth, melted salts).

4. Design of a blanket

The blanket is the most complex unit in an ADS. Its design can vary by the type of fuel, coolant, construction scheme, etc. For transmutation of ^{99}Tc and ^{129}I, facility with high neutron flux of the order of $5{\cdot}10^{14}$ cm^{-2}s^{-1} is necessary. It is developed in [1]. Parameters of such facility are submitted in Table 1. The blanket is of channel-vessel type with heavy water as coolant and moderator. The choice of heavy water is explained by an opportunity to have great volume for irradiation of target materials and by a wide experience of heavy-water reactor development and operation.

Table 1. **Parameters of heavy-water blanket of ADS**

Thermal power, MW		1 100
Electrical power, MW		350
Proton beam current, mA		15
Energy of protons, MeV		1 000
Multiplication factor		0.97
Neutron flux density, cm^{-2}s^{-1}		up to $5{\cdot}10^{14}$
Consumption of ^{235}U or ^{239}Pu, kg/year		305
Temperature of a coolant	on input of fuel assembly, ^{0}C	270
	on output of fuel assembly, ^{0}C	300
Rate of ^{99}Tc transmutation, kg/year		120
Rate of ^{129}I transmutation, kg/year		35
Number of consumed reactors VVER-1000		4

Such a design can be realised, as the technical parameters are not intense. Neutronic characteristics can be improved in case of use of a sectioned blanket with neutron valve which are now studied in various Russian nuclear centres.

5. Neutron-producing target

An important element of a design is neutron-producing target. Targets with liquid lead-bismuth alloy [2] or solid tantalum target [3] can be used for offered ADS. Total feature of these targets is their location in central part of a blanket and vertical configuration. Main parameters of two variants of lead-bismuth target are given in Table 2. The offered target is designed for high proton current and power.

Table 2. **Main parameters of lead-bismuth target**

	Variant 1	**Variant 2**
Beam current of 1-GeV protons, mA	111	166
Proton to neutron ratio	29	29
Thermal power of a target, MW	77	116
Flow for cooling of a target, m^3 per hour	200	200
Maximal temperature of shell, °C	600	680

Tantalum target with power of 25 MW is more preferable for ADS designed for ^{99}Tc and ^{129}I. It is made as a set of 15 flat horizontal cylindrical disks with thickness of 30 mm each, with internal channels for a coolant. Thermal parameters of this target are presented in Table 3.

Table 3. **Thermal parameters of tantalum target**

Target power, MW	25
Flow of cooling water, kg/s	212
Maximum temperature of a surface, °C	193
Pressure of water, MPa	1.63
Temperature of cooling water, °C	30
Maximum temperature increase in a channel, °C	48
Maximum heat density, kW/m^3	$9.5 \cdot 10^5$

These thermal parameters of a target are rather moderate, that permits to hope for its reliable operation. It is necessary to note that use of a solid target permits to refuse special membranes which separate the vacuum volume of accelerator and target.

6. Conceptual project of the linear accelerator

The linear accelerator of protons for the ADS is chosen in connection with the necessity of high current of protons with intermediate energy of 0.8-1.5 GeV. For ^{99}Tc and ^{129}I transmutation, currents of the order of 10 mA is required.

A modern variant of linac for the ADS with current of 30 mA and proton energy 1 GeV [4] is constructed under single-channel scheme. Mode of operations is continuous, on the contrary to existing proton accelerators which operate in pulsing mode. The accelerator consists of injector, initial part, intermediate part, and main parts. In table 4, the main calculated characteristics of a linac with superconducting accelerating resonators in main part giving a rate of acceleration 15 MeV/m are presented. Use of cryogenic accelerating system and high rate of acceleration results in significant decrease of linac cost in comparison with cost of the “warm” accelerator.

Table 4. **Characteristics of linac with cryogenic resonators**

Length of linac	135
Efficiency of resonators	1
Efficiency of HF-generators with supply	0.65
HF-power, MW	33
Electric power supply, MW	52
Efficiency of linac	0.55

7. Technical problems to take into consideration

- *Blanket*: it is necessary to determine experimentally the greatest possible value of effective multiplication factor which could completely exclude probability to increase it above unit in any mode of operation. This will allow increasing considerably a level of nuclear safety in comparison with power reactors. It is necessary to choose a type of fuel and target. One of possible decisions consists in solution of ^{99}Tc in coolant, that claims the substantiation of water-chemical mode.
- *Neutron producing target:* important question is maintenance of uniformity of proton beam interaction with target surface.
- *Accelerator:* it is necessary to check experimentally cryogenic resonators which are a basis of accelerating structures. Resource tests of klystrons for high-frequency system should be made.

There are a number of other technical questions.

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