ACTIVATION OF THE CONCRETE IN THE BIO SHIELD OF ITER

C o n t e n t

A b s t r a c t

Calculations of neutron spectra in different parts of the tokamak building of ITER are performed. A computational geometry model of the tokamak building is prepared using MCNP-4C. The model includes adequate material composition and geometry description of the main parts of the tokamak for PPCS plant model A [1]: toroidal field coils, vacuum vessel, shield, blanket structure, first wall, divertor, 14.1 MeV neutron source. The design and the dimensions of the bio shield are taken from the current ITER design [2].

MCNP calculations of the neutron spectra in the bio shield (concrete) of ITER are performed, using the neutron spectra in TF coils calculated at UKAEA [1] as external neutron source.

The neutron spectra in the concrete calculated by MCNP are used as input data in the code EASY99 for estimations of the activation of the concrete in the bio shield around the tokamak.

The time evolutions of the maximum (in the bio shield floor) and minimum (in the bio shield side walls) specific activity (Bq/kg) and dose rate (Sv/h.) of the main dominant nuclides in the concrete are evaluated and compared for 3 different concrete types, used as biological shield in the PWR and BR3 reactors.

1. Calculation model of the tokamak building

A computational model of the tokamak building, including the tokamak and the bio shield around it is prepared using MCNP-4C. The calculation model is presented at Fig. 1, 2. The descriptions of the main parts of the tokamak are summarized in Table 1. The material composition and the dimensions of the different parts of the tokamak are defined on the base of the data in Tables 1÷5 in [1]. An approximate model of the divertor was included. It consists of a homogeneous mixture of stainless steel as structure, and water as coolant [1]. The divertor is located at the bottom of the model. The design and the dimensions of the bio shield are taken from the current ITER design, as described in [2]. The main parameters of the DT plasma [1] are summarized in Table 2.

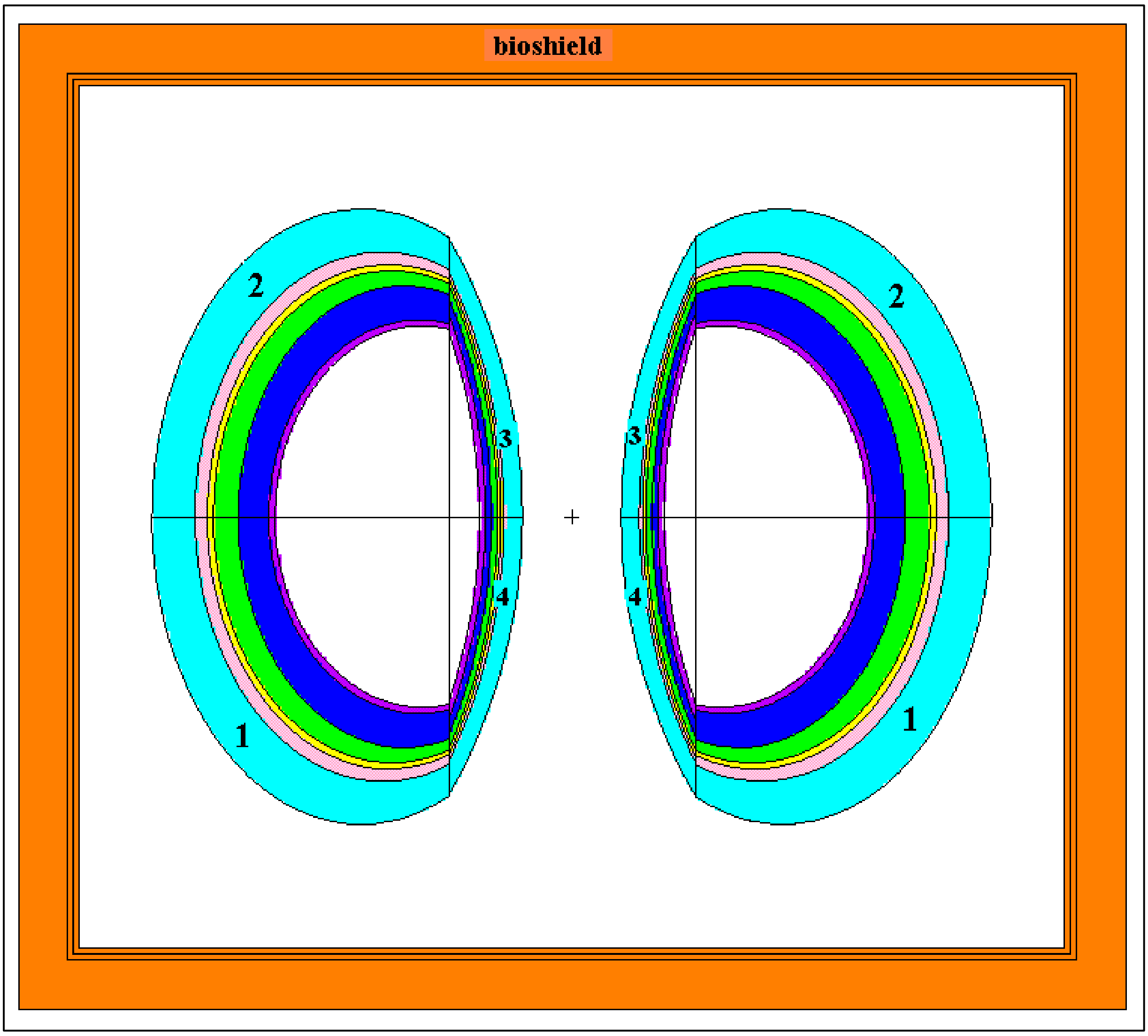


Fig. 1. Calculation model of tokamak building of ITER.

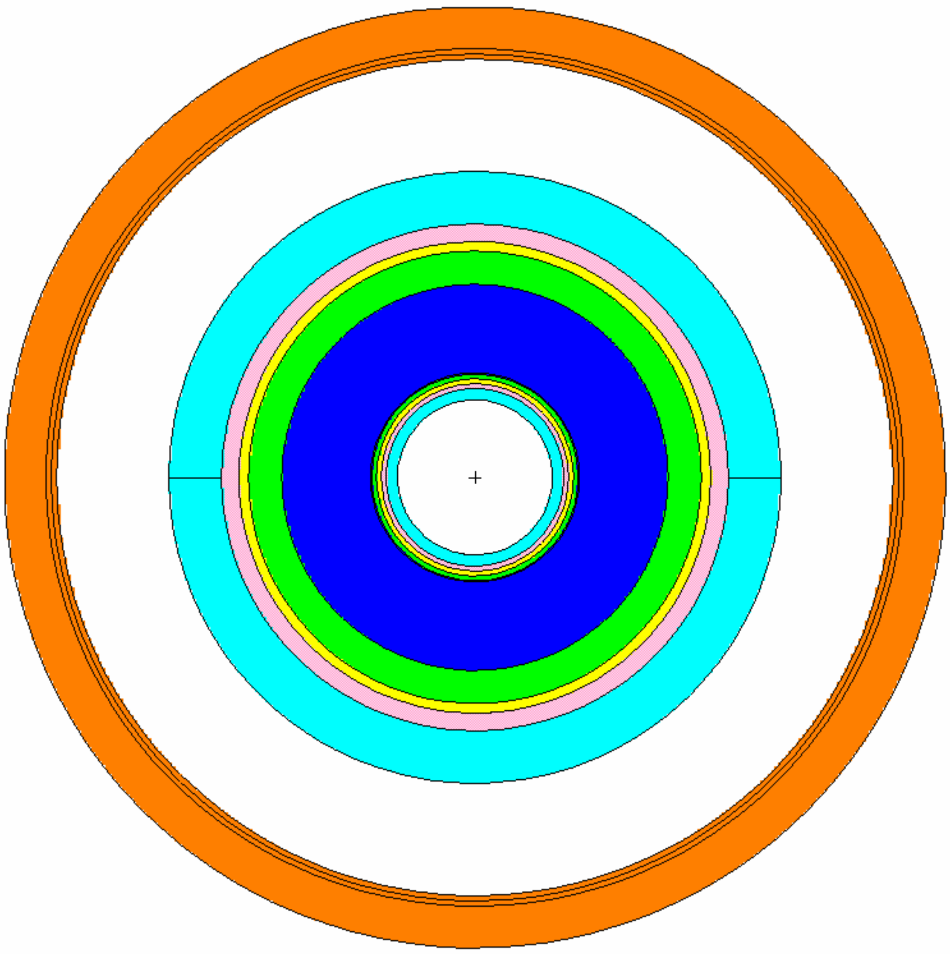


Fig. 2. Calculation model of tokamak building of ITER – view from top.

Table 1. Radial dimensions and material composition of the different layers of the computational model of the tokamak (Fig.1) according to Tables 1÷5, Table A1.1, Annex 1 [1].

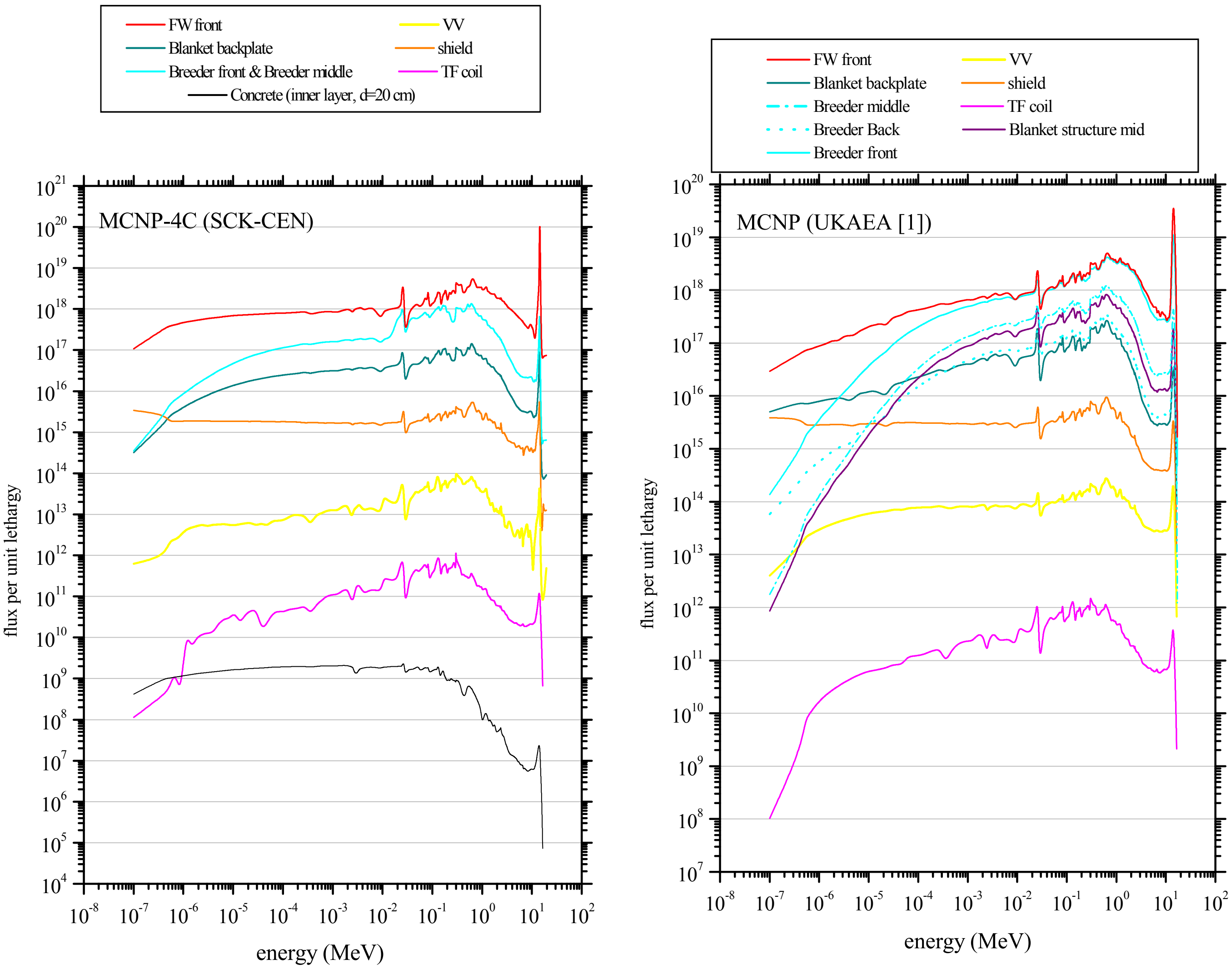
Structure	Layer N°	Component (layer description)	Radial Thickness (m)	Material Composition
Outboard	1	TF coil	2.458	SC coil
	2	VV	0.780	316SS, B, H_2O
	3	Shield	0.150	Eurofer, H_2O
	4	Manifold	0.109	Eurofer, H_2O
	5	Blanket backplane	0.060	Eurofer, H_2O
	6÷14	Blanket breeder	0.827	Eurofer, $Li_{17}Pb_{83}$, H_2O
	15÷17	FW	0.021	Eurofer, H_2O
Inboard	18	TF coil	1.370	SC coil
	19	VV	0.380	316SS, B, H_2O
	20	Shield	0.150	Eurofer, H_2O
	21	Manifold	0.091	Eurofer, H_2O
	22	Blanket backplane	0.030	Eurofer, H_2O
	23÷31	Blanket breeder	0.528	Eurofer, $Li_{17}Pb_{83}$, H_2O
	32÷34	FW	0.021	Eurofer, H_2O
Divertor	35	–	–	316SS, Water

Table 2. Main parameters of DT plasma neutron source [1].

Mean Energy	14.1 MeV
Central Ion Temperature	58.0 keV
Effective temperature	52.6 keV
Plasma minor radius	3.27 m
Plasma major radius	9.80 m
Elongation	1.7
Peaking factor	1.7

2. Comparison of neutron spectra calculated by MCNP in different parts of the tokamak with the results from UKAEA

The neutron spectra calculated by MCNP in different parts of the tokamak are compared with those calculated at UKAEA, which are given in the documentation [1]. For this purpose, a neutron source with Gaussian energy distribution of mean energy 14.1 MeV and typical spatial distribution of thermonuclear plasma was located in the poloidal field of the torus. The calculated neutron spectra (SCK) are given at Fig. 3a and the calculated at UKAEA neutron spectra are shown at Fig. 4b.

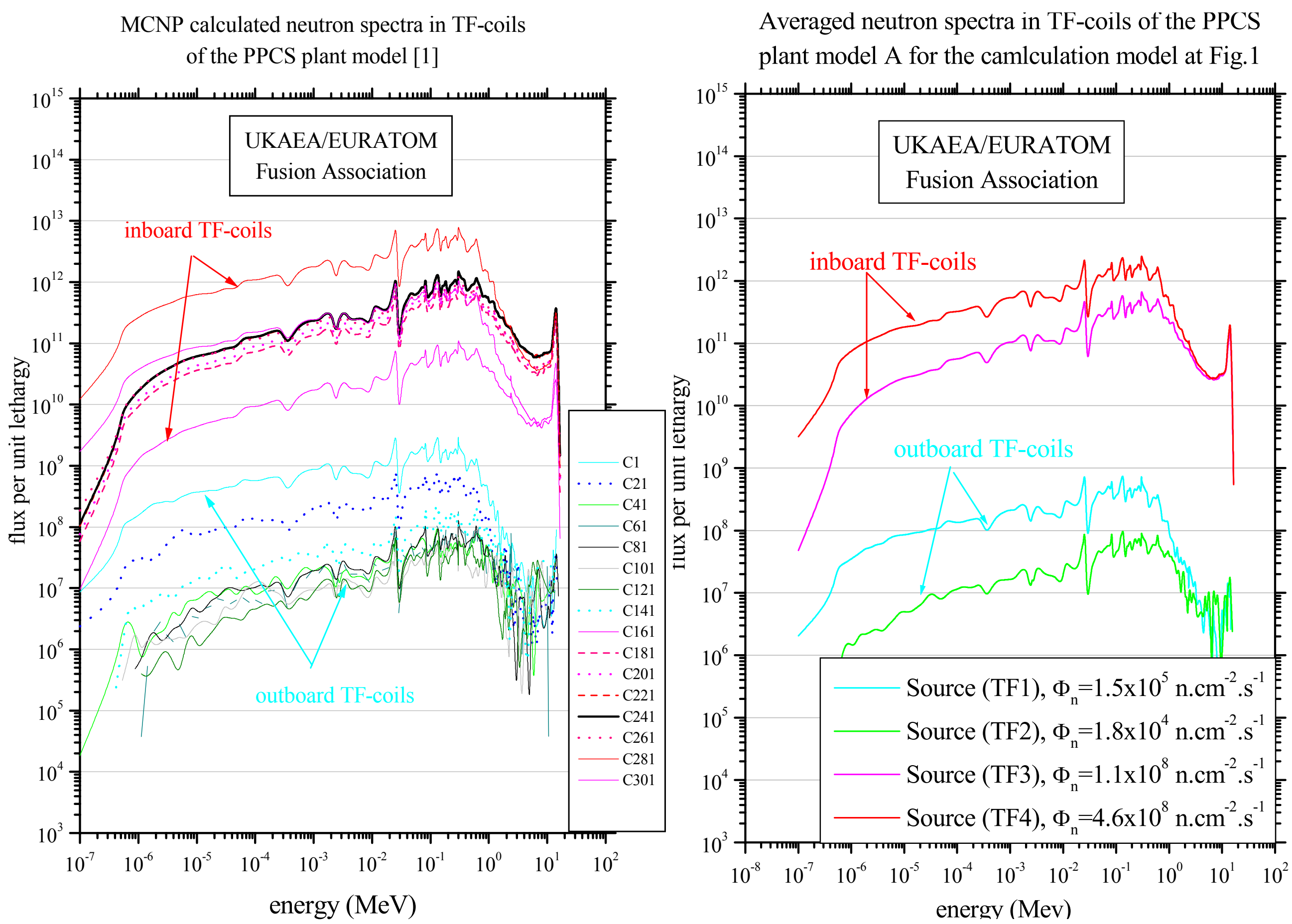


a) b)

Fig. 3. Comparison between MCNP calculations of neutron spectra in different parts of the torus: a) at SCK-CEN and b) at UKAEA [1].

3. Calculation of neutron spectra in the concrete using the calculated at UKAEA neutron spectra in TF-coils [1] as external neutron source

The comparison of the calculated neutron spectra for a few parts of the tokamak have shown an acceptable agreement with those reported in [1]. However, the calculated neutron spectra in the TF coil cells at UKAEA (Table 2 and Fig.2 in [1]) were used as an external neutron source for the presented calculations of the neutron spectra in the bio shield and of the activation of the concrete. Four volume neutron sources of outboard TF coils (1,2) and inboard TF (3,4) coils were used (see Fig. 1). The energy spectra in these 4 sources are averaged correspondingly over the poloidal angles: 0°÷77° (Source 1=C1 & C21 & C41 & C61, outboard TF coils); 99°÷165° (Source 2=C81 & C101 & C121 & C141 , outboard TF coils); 187°÷253° (Source 3=C161 & C181 & C201 & C221, inboard TF coils); 275°÷341° (Source 4=C241 & C261 & C281 & C301, inboard TF coils). The data for the group fluxes in these cells have been taken from file gr_out.doc [1]. The neutron spectra in all spatial cells of the TF-coils, calculated by UKAEA, are given at Fig. 4a. The neutron spectra and the averaged total neutron fluxes in the four sources used for the present calculations of the neutronic calculations in the bio shield, are shown at the Fig. 4b.



a) b)

Fig. 4. a) Calculated by MCNP neutron spectra in TF-coils at UKAEA [1]; b) averaged neutron spectra in TF-coils in 4 groups as shown at Fig. 1, which are used as external sources for the calculations of the neutron spectra in the bio shield in this report.

Neutron transport and activation calculations are performed for the inner concrete layer with a thickness ΔD=20 cm. The cover and the floor of the bio shield are divided into several concentric cylindrical layers (Fig.5) taking into account that the activation of the concrete below and above the tokamak hole will be maximum due to the high neutron fluxes in the inboard TF-coils. The bio shield side walls are divided in several axial rings, surrounding the outboard TF-coils (Fig. 6). The main parameters of the used in calculations spatial cells in the concrete as shown at Fig. 5 and Fig. 6 are summarized in Table 3.

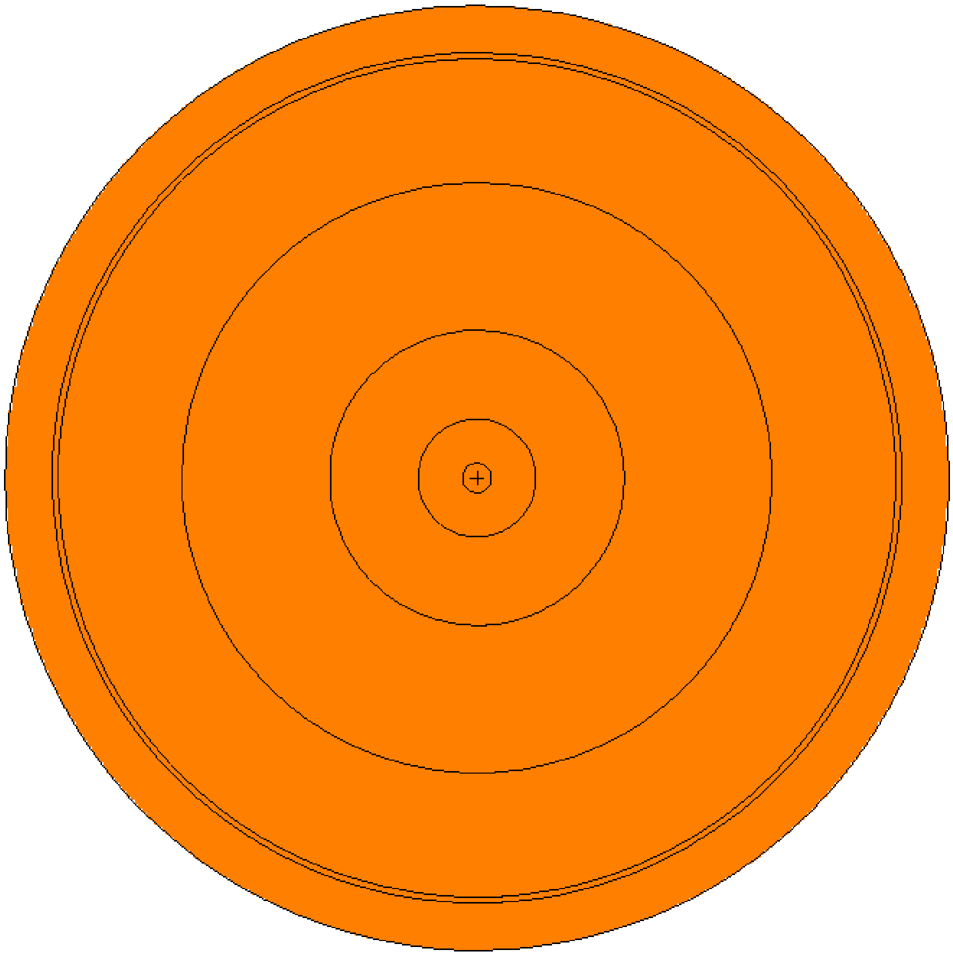


Fig. 5. Calculation model of the concrete bio shield of ITER – top cover (or floor).

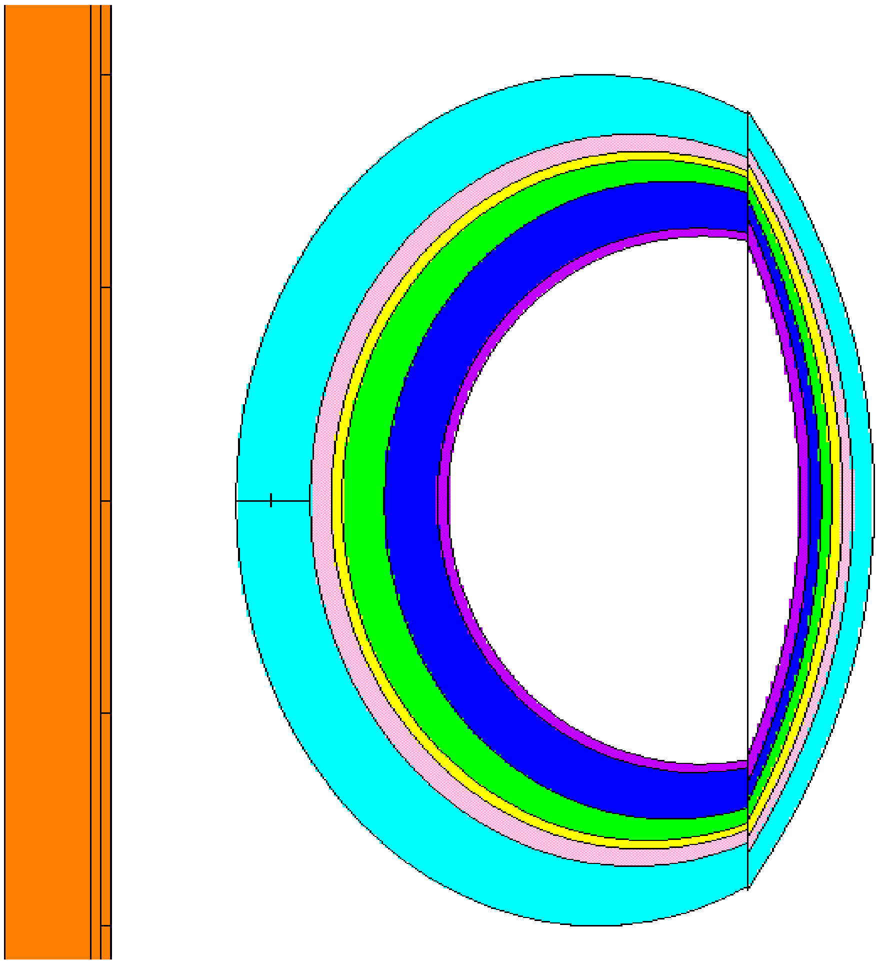


Fig. 6. Calculation model of the concrete bio shield of ITER – side walls.

Table 3. Main parameters of the concrete layers used in MCNP.

	Volume (cm^3)	Mass (kg)		Volume (cm^3)	Mass (kg)
Cell 22	8.86E+07	2.038E+05	Cell 121 (126)	1.35E+08	310500
Cell **23***)	**8.86E+07**	**2.038E+05**	Cell 221 (226)	4.71E+07	108330
Cell **24***)	**8.86E+07**	**2.038E+05**	Cell 321 **(326****)**)**	**1.32E+07**	**30478**
Cell 25	8.86E+07	2.038E+05	Cell 421 (426)	2.36E+06	5428

*) these cells are located in the side walls of the bio shield and were used for the evaluations of the minimum specific activity and minimum dose rate
**) this cell is located in the floor, below divertor and was used for the evaluation of the maximum specific activity and maximum dose rate

The transport calculations of neutron fluxes and spectra in the concrete have been performed using MCNP-4C&ENDF/B-6 [3], [4]. The detailed neutron spectra in different spatial parts of the bio shield are given at Fig. 7. The maximum neutron fluxes have been calculated in the concrete parts, located above and especially below the tokamak hole and near the divertor. The neutron fluxes in the bio shield side walls around the outboard TF-coils are minimum due to the low neutron flux, escaping from the outboard TF-coils.

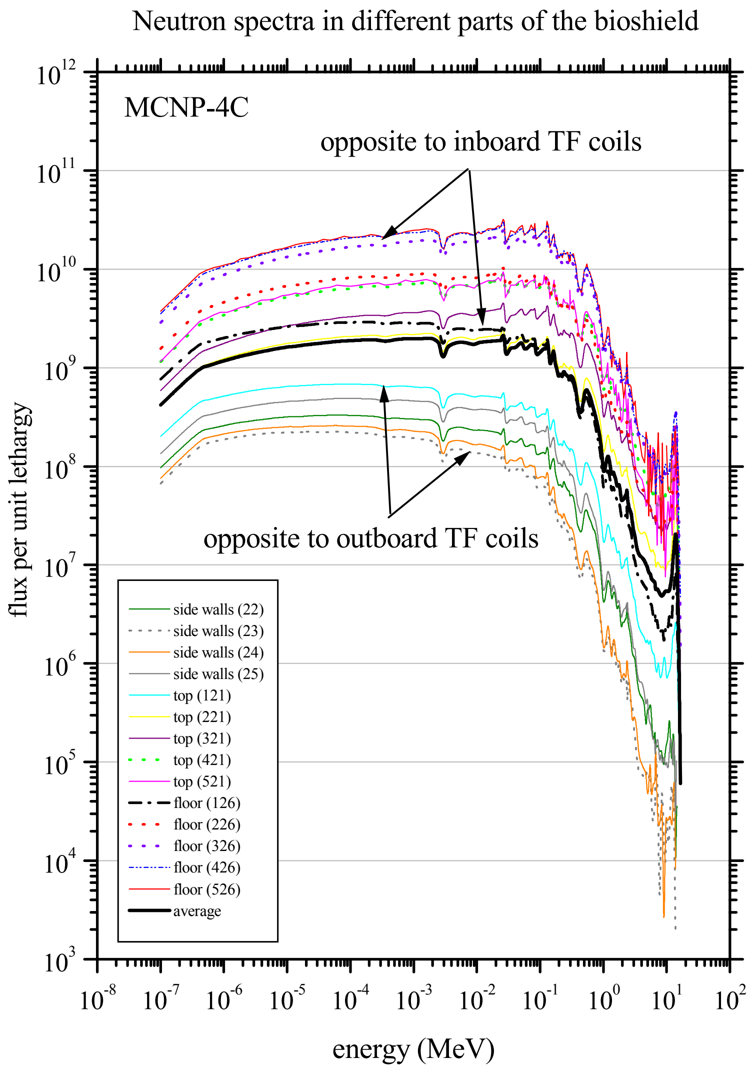


Fig. 7. Neutron spectra in different parts of the concrete in the bio shield of ITER.

4. Activation calculations for different concrete types using EASY99&FISPACT99

The activation calculations in the bio shield were performed using EASY99&FISPACT99 [5] for different concrete types: concrete used in the PWR [6] and in BR3 [7] reactors.

The time evolutions of the specific activity (Bq/kg) and the dose rate (Sv/h) of the dominant nuclides in the concrete versus the cooling time are evaluated in the floor below the divertor and in the side walls of the bio shield. The evaluations are performed assuming continuous operation of ITER during T_{oper}=25 years at total fusion power P_{fus}=5.5 GW [1].

4.1 PWR concrete composition

The isotope composition of the concrete, used in PWR reactors is given in Table 4. The time evolutions of the total specific activity and total dose rate in the concrete floor and in the side walls of the bio shield versus the cooling time are summarized in Tables 5a, 5b. The time evolutions of the dominant nuclides in the activated PWR concrete type are presented at Fig. 8,9. During the first cooling year the main dominant nuclides are H-3, Co-60,Ca-45, Fe-55, Cs-134, Eu-152, Sc-46, Rb-87, Rn-220. The dominant isotopes after 10 years cooling time are Co-60, H-3, Eu-152, Rb-87, Rn-220 and after 100 years – K-40, U-234, Th-232, Rn-220, Rb-87.

Table 4. Material composition of the bio shield (concrete) of PWR [6].

Element	wt. (%)	Element	wt. (%)	Element	wt. (%)	Element	wt. (%)
H	0.61	Cl	0.0045	Cu	0.0025	Mo	0.00103
Li	0.002	K	0.75	Zn	0.0075	Pd	0.0003
B	0.002	Ca	18.3	Ga	0.00088	Ag	0.00002
N	0.012	Sc	0.00065	As	0.00079	Cd	0.00003
O	54.2764	Ti	0.2121	Se	0.000092	Sn	0.0007
Na	0.739	V	0.0103	Br	0.00024	Sb	0.00018
Mg	0.24	Cr	0.0109	Rb	0.0035	Cs	0.00013
Al	3.1	Mn	0.0377	Sr	0.0438	Ba	0.095
Si	16.8	Fe	3.9	Y	0.00182	La	0.0013
P	0.5	Co	0.00098	Zr	0.0071	Ce	0.00243
S	0.31	Ni	0.0038	Nb	0.00043	Sm	0.000004
Eu	0.000009	Ho	0.000004	Lu	0.00006	Hf	0.00008
Ta	0.00006	W	0.0015	Th	0.00006	U	0.00009

Table 5a. Time evolution of the total **Specific Activity** (Bq/kg) in the inner concrete layer (Δd=20 cm) versus the cooling time for **PWR** concrete type. Normalization of the fluxes: total fusion power P_{fus}=5.5 GW, E(dt)=17.6 MeV, $P_{neutron}$=4.4 GW according to [1]. Duration of operation T_{oper}=25.0 years.

	Activity , EASY99&FISPACT99			
	Concrete Floor (opposite to inboard TF-coils)		Concrete Side Walls (around outboard TF-coils)	
Cooling Time	Bq	Bq/kg	Bq	Bq/kg
0	2.28E+10	7.48E+05	2.89E+09	1.42E+04
1.0 day	7.84E+09	2.57E+05	1.12E+09	5.50E+03
11.0 days	6.16E+09	2.02E+05	9.04E+08	4.44E+03
71.0 days	5.20E+09	1.71E+05	7.90E+08	3.88E+03
1.2 years	3.73E+09	1.22E+05	5.90E+08	2.90E+03
11.2 years	1.40E+09	4.59E+04	2.66E+08	1.30E+03
111.1 years	2.41E+07	7.90E+02	6.91E+07	3.40E+02

Table 5b. Time evolution of the **Dose Rate** (Sv/h) in the inner concrete layer (Δd=20 cm) versus the cooling time for **PWR** concrete type. Normalization of the fluxes: total fusion power P_{fus}=5.5 GW, E(dt)=17.6 MeV, $P_{neutron}$=4.4 GW according to [1]. Duration of operation T_{oper}=25.0 years.

	Activity , EASY99&FISPACT99	
	Concrete Floor (opposite to inboard TF-coils)	Concrete Side Walls (around outboard TF-coils)
Cooling Time	Sv/h.	Sv/h.
0	2.59E-04	5.01E-06
1.0 day	4.95E-05	9.84E-07
11.0 days	8.52E-06	1.59E-07
71.0 days	7.38E-06	1.38E-07
1.2 years	5.42E-06	1.03E-07
11.2 years	1.40E-06	3.54E-08
111.1 years	1.27E-08	1.20E-08

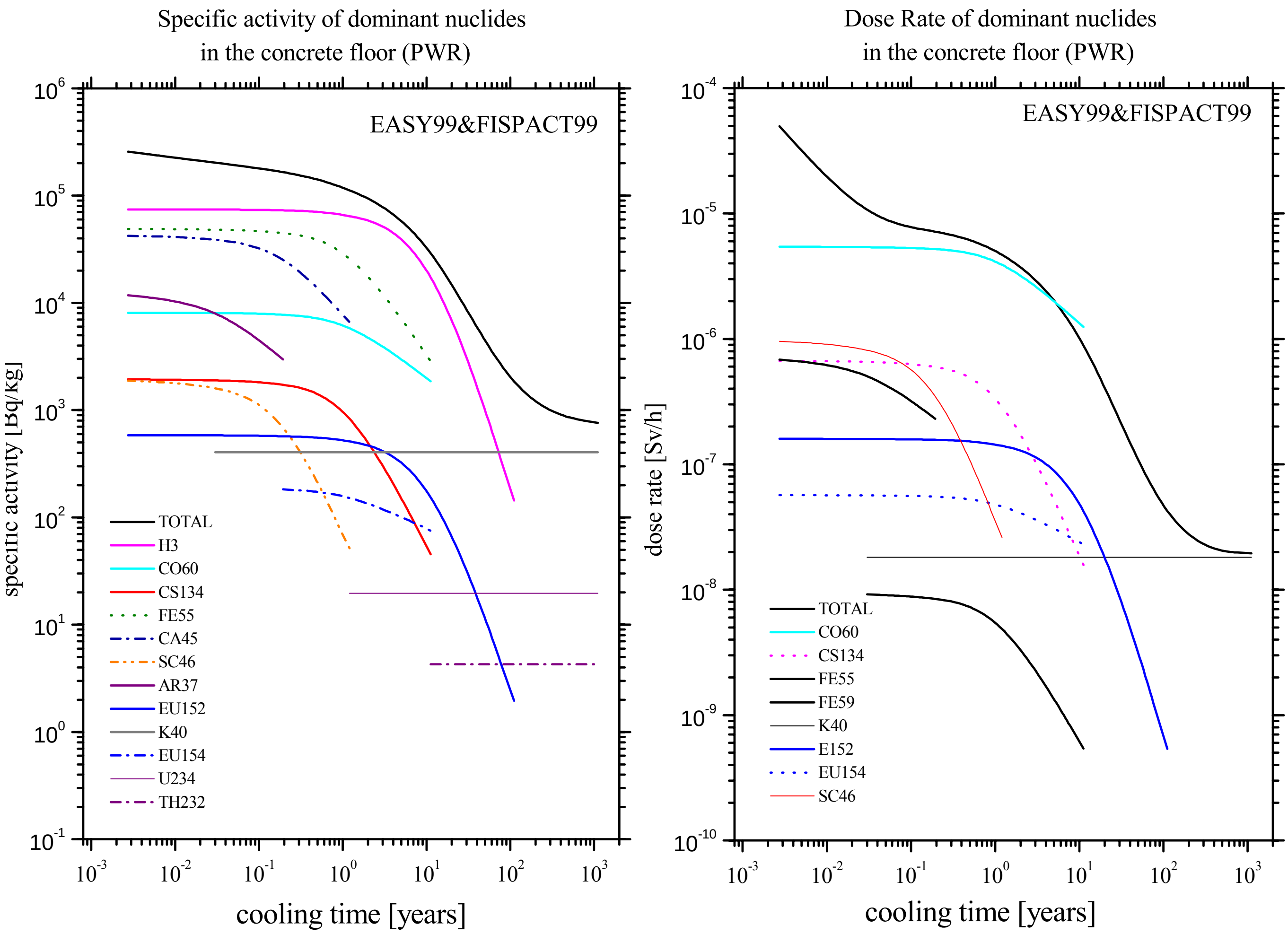


Fig. 8. Time evolution of the specific activity (Bq/kg) and the dose rate (Sv/h) of the dominant nuclides in the ***concrete floor*** of the bio shield of ITER. Composition of the concrete – ***PWR*** (Table 4).

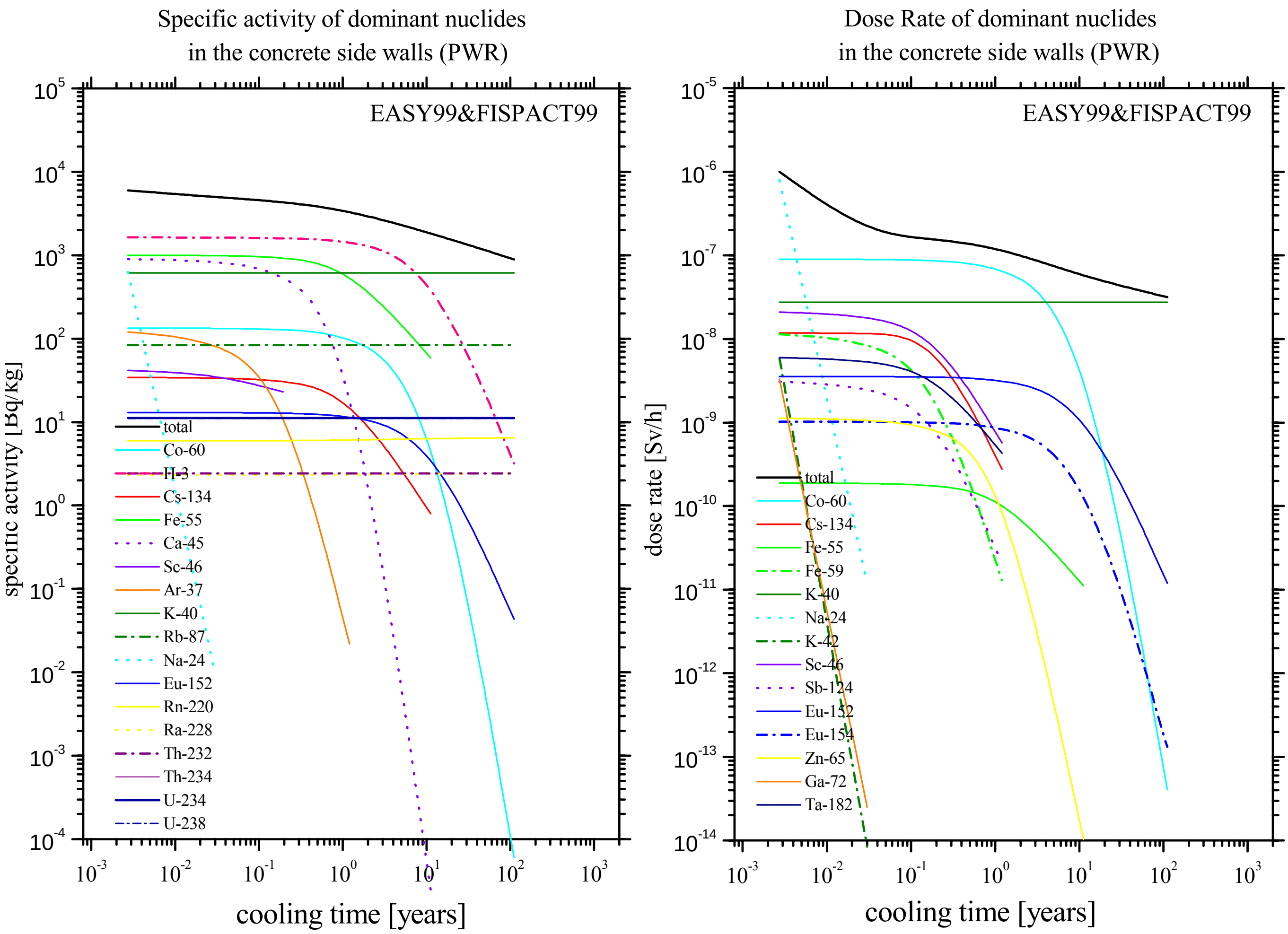


Fig. 9. Time evolution of the specific activity (Bq/kg) and the dose rate (Sv/h) of the dominant nuclides in the ***concrete side walls*** of the bio shield of ITER. Composition of the concrete – ***PWR*** (Table 4).

4.2 BR3 concrete composition

The isotope compositions of 2 different concrete samples, cut from the biological shield of the BR3 reactor, are presented in Table 6. The time evolutions of the specific activity and the dose rate in the bio shield of ITER versus the cooling time are given at Fig. 10, 11 (for sample 1 of the concrete, used in BR3 shield) and at Fig. 12, 13 (for concrete sample 2). It is seen, that the total specific activity is ≈ 2 times higher and the dose rate is ≈ 1.2÷1.3 times higher in comparison with PWR concrete type. The main dominant isotopes in the activated concrete during the 1st cooling year (after continuous operation of ITER during T_{oper}=25 years) are: Ba-133, Ba-131, Eu-152, Eu-154, S-35, Cs-134. After 10 years cooling time, the main dominant nuclides are Ba-133, Eu-152, Eu-154, Co-60 and after 100 years remain only K-40.

Table 6. Material composition of the bio shield (concrete) of BR3 [7].

Element	Sample 1	Sample 2
	wt. (%)	wt. (%)
H	0.26	0.34
O	32.0	32.9
Na	0.62	0.71
Mg	0.33	0.43
Al	1.1	1.4
Si	5.8	5.5
S	8.6	7.5
K	0.17	0.15
Ca	8.3	6.7
Mn	0.001	0.001
Fe	2.0	10.1
Co	0.0001	0.0001
Cs	0.0001	0.0001
Ba	40.8	34.3
Eu	0.0001	0.0001
Total	100.0	100.0

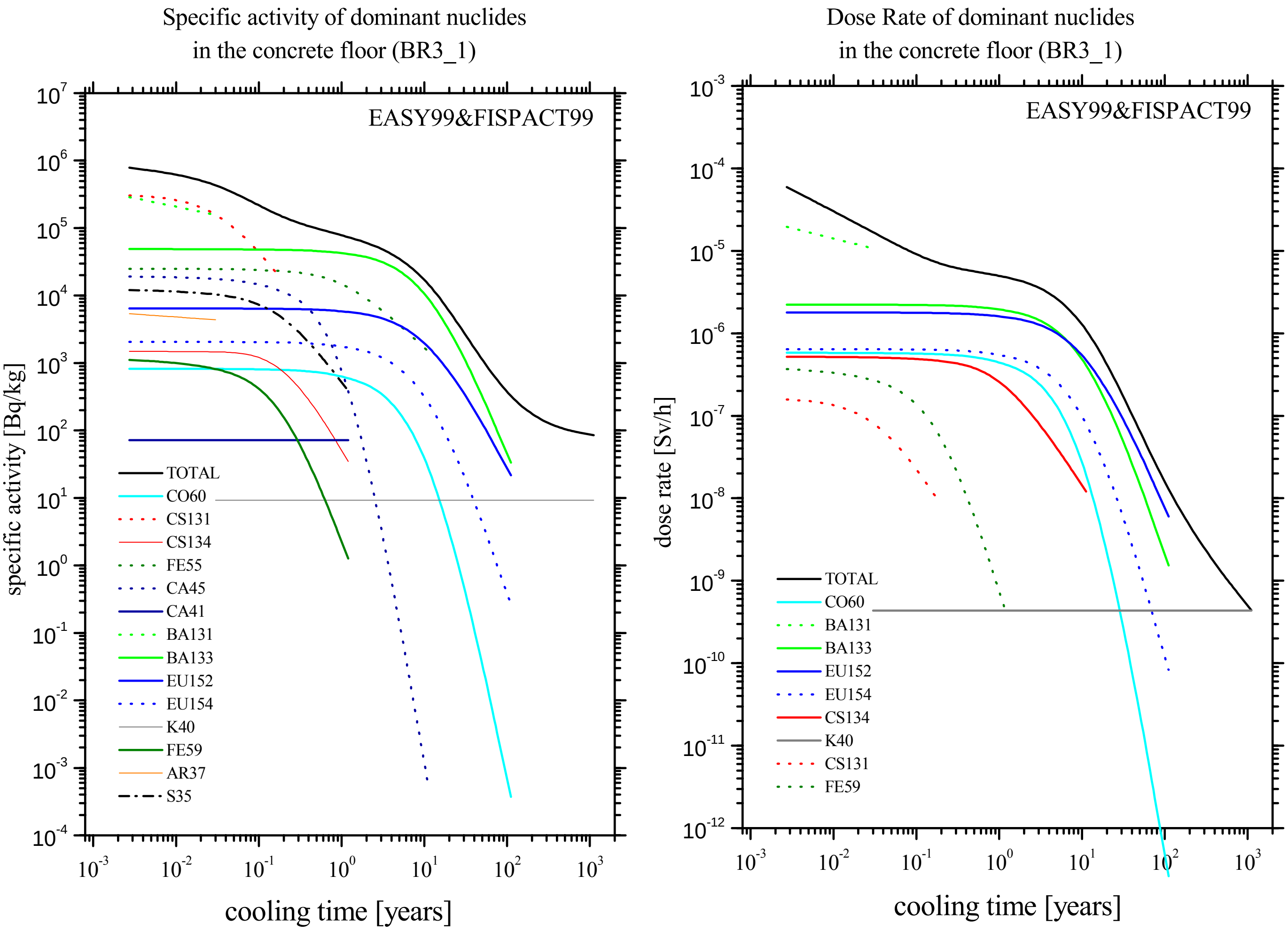


Fig. 10. Time evolution of the specific activity (Bq/kg) and the dose rate (Sv/h) of the dominant nuclides in the ***concrete floor*** of the bio shield of ITER. Composition of the concrete – ***BR3*** (Table 6, ***sample 1***).

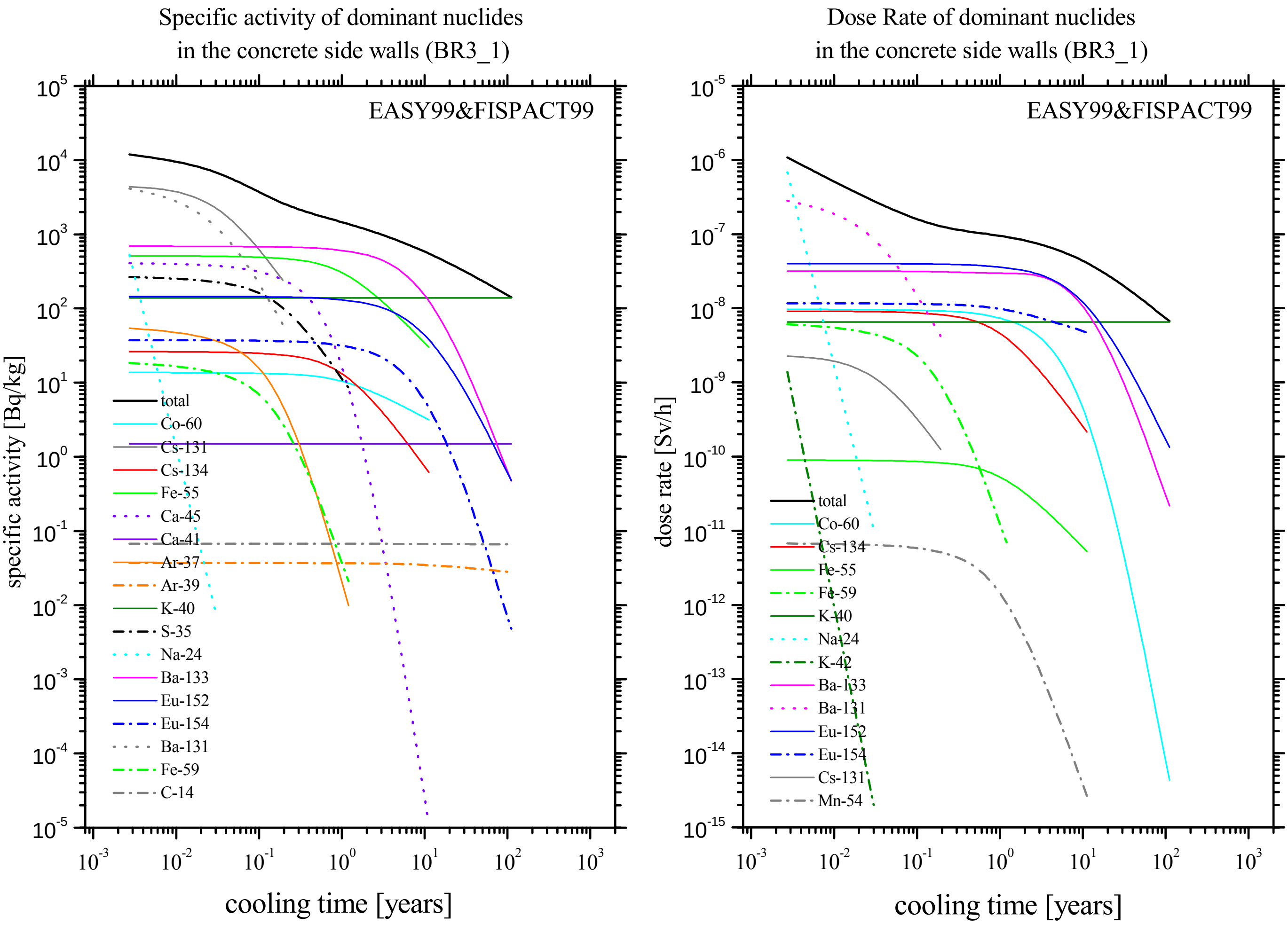


Fig. 11. Time evolution of the specific activity (Bq/kg) and the dose rate (Sv/h) of the dominant nuclides in the ***side concrete walls*** of the bio shield of ITER. Composition of the concrete – ***BR3*** (Table 6, ***sample 1***).

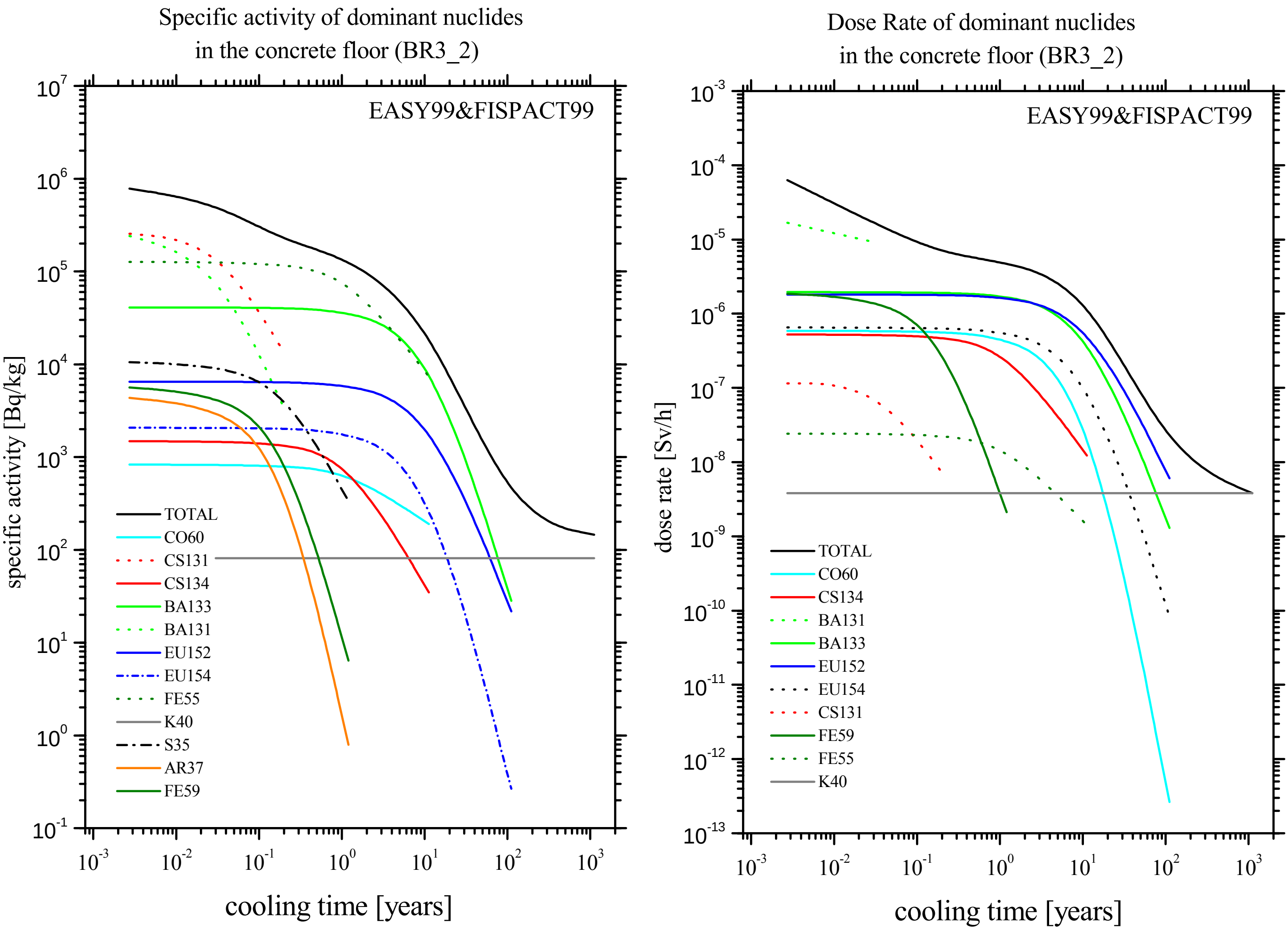


Fig. 12. Time evolution of the specific activity (Bq/kg) and the dose rate (Sv/h) of the dominant nuclides in the ***concrete floor*** of the bio shield of ITER. Composition of the concrete – ***BR3*** (Table 6, ***sample 2***).

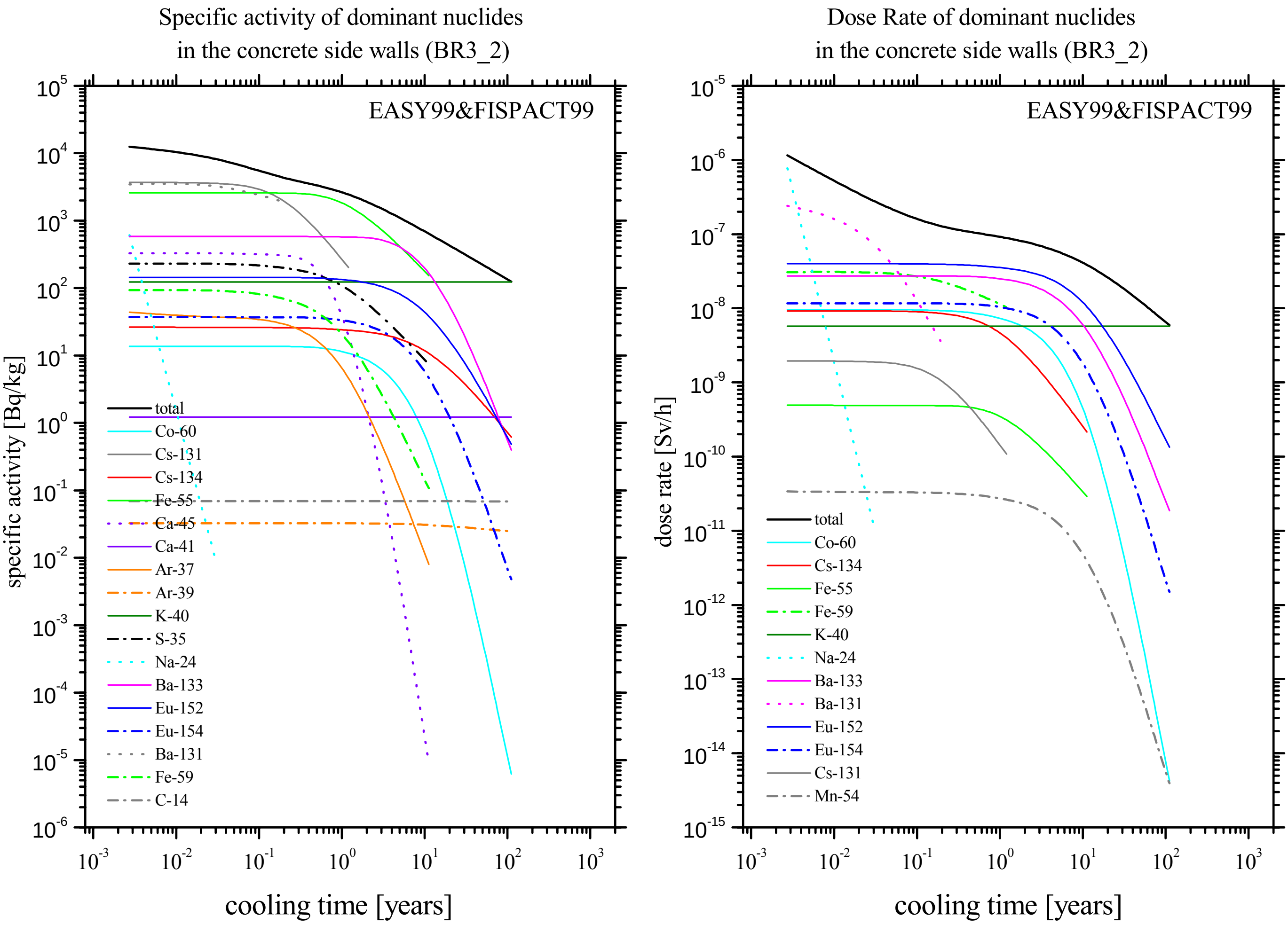


Fig. 13. Time evolution of the specific activity (Bq/kg) and the dose rate (Sv/h) of the dominant nuclides in the ***side concrete walls*** of the bio shield of ITER. Composition of the concrete – ***BR3*** (Table 6, ***sample 2***).

5. Conclusions

- A computational model of the tokamak building for PPCS plant model A [1] was prepared in SCK using MCNP-4C. The neutron spectra calculated by MCNP in different parts of the tokamak are compared with the results of UKAEA, given in [1].
- The design and the dimensions of the bio shield around the tokamak are taken from the current ITER design [2]. The neutron spectra and activation of the bio shield of ITER are evaluated, using the calculated in UKAEA neutron spectra in TF-coils [1] as external neutron sources in the MCNP model, developed at SCK.
- The evaluations of the activity (Bq), specific activity (Bq/kg) and dose rate (Sv/h.) in the bio shield have been performed by EASY99&FISPACT99 using the neutron spectra in the concrete calculated by MCNP at SCK.
- All activation calculations are performed assuming continuous operation of ITER during T_{oper}=25 years at total fusion power P_{fusion}=5.5 GW [1].
- The specific activity and the dose rate peak on the central line of the torus, on the floor of the bio shield, because this area has the largest solid angle to the source relative to any other point in the bio shield. From the other hand the location of the divertor near this area is a reason for the maximum neutron fluxes in the lower inboard TF-coils and in the concrete floor, respectively.
- The low neutron flux, escaping from the thick outboard TF-coils causes the specific activity and the dose rate to have a minimum in the concrete side walls.
- The estimated by MCNP neutron fluxes in the inner concrete layer of the bio shield with a thickness d=20 cm are as follows:

  – Φ_n^{max} = 1.3E+07 $n.cm^{-2}.s^{-1}$ (floor, below tokamak hole, opposite to the lower inboard TF-coils, near the divertor);

  – Φ_n^{min} = 1.5E+05 $n.cm^{-2}.s^{-1}$ (side walls, around outboard TF-coils).
- The estimated specific activity using EASY99 at t=0 after operation of 25 years is:

  – Q^{max} = 7.5E+05 Bq/kg (floor, below tokamak hole, opposite to inboard TF-coils, near the divertor);

  – Q^{min} = 1.4E+04 Bq/kg (side walls, around outboard TF-coils).
- The estimated dose rate using EASY99 at t=0 after operation of 25 years is:

  – q^{max} = 2.6E–04 Sv/h (floor, below tokamak hole, opposite to the lower inboard TF-coils, near the divertor);

  – q^{min} = 5.0E–06 Sv/h (side walls, around outboard TF-coils).
- The activation calculations are performed and compared for concrete types used in the biological shield of PWR and BR3 reactors, having different isotope compositions and therefore leading to a different composition of the dominant nuclides in the activated concretes.

  − the total specific activity and the total dose rate in the activated concrete, used in the biological shield of the BR3 reactor are slightly higher than in the PWR concrete type;

  − the main dominant nuclides in the PWR concrete after 25 years operation of ITER and after 10 years cooling time are: Co-60, H-3, Eu-152, Rb-87, Rn-220, U-234, Th-232.;

  − the main dominant nuclides in the BR3 concrete after 25 years operation of ITER and after 10 years cooling time are: Ba-133, Eu-152, Eu-154, Co-60.

  − the main dominant in all considered concrete types after long cooling time > 100÷1000 years remains the natural isotope K-40.

6. References

[1]. R.Pampin-Garcia and M.J.Loughlin, "Neutronic and Activation Calculations for PPCS Plant Model A". PPCS/UKAEA/PPCS4D2-3, May 2002. Euratom/UKAEA Fusion Association, Culham Science Centra, Abigdon, Oxfordshire OX14 3DB, UK. Power Plant Conceptual Study, Stage 3.

[2]. DDD 6.2 SiteLayout and Buildings – Introduction

[3] MCNP4C. Monte Carlo N-Particle Transport Code System. Oak Ridge National Laboratory, RSICC Computer Collection, CCC-700/MCNP4C.

[4] MCNPDATA. Standard Neutron, Photon, and electron Data Libraries for MCNP4C. Oak Ridge National Laboratory, RSICC Computer Collection, DLC-200/MCNPDATA.

[5]. EASY-99: OVERVIEW, RA FORREST, EURATOM/UKAEA Fusion Association, Culham Science Centre, Abingdon, Oxfordshire OX14 3DB, UK.

[6]. R. de Wouters, A. Quoidbach and Ph. Beguin, "Calculation of Activations in PWR Structures", *Tractabel Energy Engineering 7, av. Ariane B-1200 Brussels.*

[7]. M.Klein, V.Massaut, H.Ait Abderrahim, R.Mandoki, Ch.Plateau, E.Rousseau, "Contaminated and Activated Concrete: Characterization, Decontamination and Demolition Techniques", Spectrum '98, September 13-18, 1998, Ref. 052/98-11b.