FUSION AND FISSION NUCLEAR POWER REACTORS: AN ATTEMPT TO COMPARE THE RADIOACTIVE WASTE ENVIRONMENTAL IMPACT

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ABSTRACT

The environmental impact of radioactive wastes from the present nuclear fission (PWR) and the future nuclear fusion commercial power plants (STARFIRE) has been evaluated in terms of Ingestion Toxic Potential (IT). Using literature data, the total amount of radioactivity, the radioactivity of each radionuclide in wastes produced in the whole production cycle, and the corresponding IT have been calculated up to 10^6 years. There is a large difference between the characteristics of fission and fusion reactor wastes as far as radionuclides are concerned. The lack of transuranic elements in fusion reactor wastes on the one hand keeps fusion IT values below those of fission reactors, and on the other allows the attainment of significant reductions of IT by means of the development and utilization of low-activation materials. The target of this IT reduction could be the IT values of thermal power plants, which could be taken as reference for the establishment of IT acceptability limits for nuclear fusion.

INTRODUCTION

Up to a few years ago it was common opinion that electricity production by future nuclear fusion power reactors would be substantially without effects as regards the environmental impact. This belief was supported primarily by the absence of fission products and transuranic elements in the reactors, the activation products being considered much less important.

More recently, on the basis of fusion power plant conceptual designs (1,2), it was evaluated that the environmental impact due to activation products could be in some circumstances comparable to the impact of LMFBRs in terms of radioactivity, and a lot of effort should be put into developing material shaving low-activation properties (3-6).

However, to our knowledge, no comprehensive evaluations have so far been made that compare the environmental impact due to the radioactive wastes produced during the entire nuclear plant production cycle of present commercial light-water reactors (PWR) and future commercial fusion reactors.

In this paper an attempt to make such an evaluation is reported.

The environmental impact of radioactive wastes has been calculated in terms of Ingestion Toxic Potential (IT) for the public, and is defined as the volume of water into which a certain radionuclide has to be completely dispersed for the water to be considered safe to drink. The ALI (Annual Limit of Intake) values published by ICRP and reported in the European Community Regulations (7) have been used for the calculations.

Both the total amount of radioactivity and the radioactivity of each radionuclide in different types of wastes up to 10E6 years' decay time in terms of Bq per kWh(t) produced have been calculated. For each type, data taken from the published literature have been used.

The calculations have been carried out using the Microsoft Corporation Excel Software Program, on an Apple MacIntosh IISI PC.

RADIOACTIVE WASTES FROM NUCLEAR FISSION POWER REACTORS

The reference power reactor is a 1200-MWe pressurized water reactor, operating for 30 years and producing the following radioactive wastes during its entire life cycle:

- solid and liquid radioactive wastes produced during the reactor operation;
- radioactive wastes produced during the fuel cycle;
- radioactive wastes produced during the plant decommissioning.

Radioactive Wastes from Power Reactor Operation

Data published by the European Community in 1980 have been used (8) to evaluated the radioactivity and its decay in time of effluents produced by PWR nuclear power plants during their normal operation. The wastes from 11 plants were averaged as regards their radioactivity, while the isotopic composition of the Chooz French plant was taken as reference for IT calculations.

The waste radioactivity produced per kWh(t) and its decay in time is shown in Fig. 1. Figure 2 gives the corresponding IT in terms of cubic meters of water.

In the case of solid wastes, the sources of major radioactivity (more than 90%of the total) are the exhausted bead-resin ion exchangers (9,10), whose radioactivity comes mainly from the isotopes ^{60}Co, ^{137}Cs, and ^{14}C.

This explains why the IT of the effluents is much lower than that of the solid wastes, while the corresponding radioactivities per kWh(t) are comparable.

Radioactive Wastes from the Fuel Cycle

The most important radioactive-waste types produced during the fuel cycle, in terms of radioactivity and environmental impact, are those resulting from spent-fuel reprocessing: hulls, vitrified high-level wastes (HLW), liquid and solid wastes produced during reprocessing plant operation. The radwastes produced during the fuel-element fabrication or in uranium mines, in fact, can be considered negligible in comparison. Vitrified high-level wastes are the major radioactivity source in the fuel cycle. They incorporate the radioactive isotopes shown in Tables I and II (11), where the radioactivity

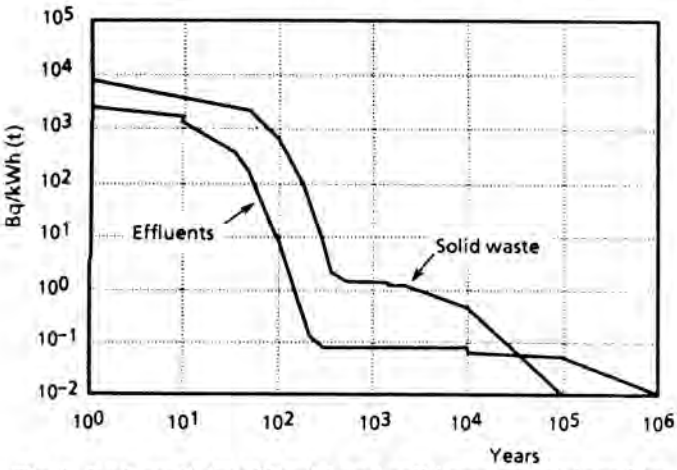

Fig. 1. Radioactivity of liquid and solid wastes produced by 1200-MWe PWR nuclear power plant operation.

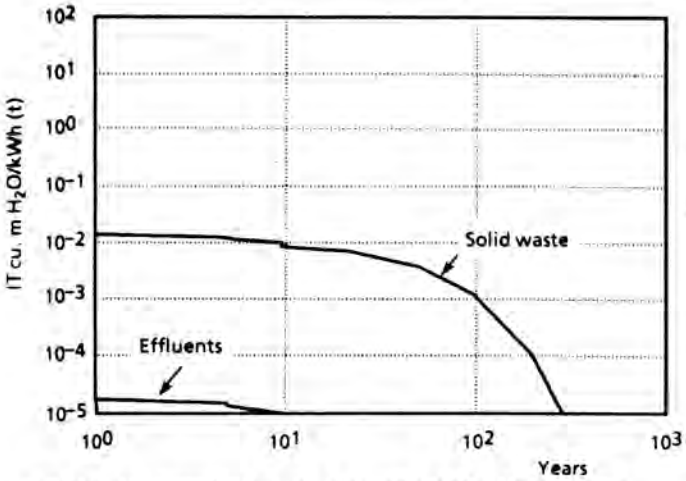

Fig. 2. The Ingestion Toxic Potential (IT) of liquid and solid radwastes produced by 1200-MWe PWR nuclear power plant operation.

(Bq) and the IT (cubic meters of H_2O) at different times after the fuel discharge for each kWh(t) produced are reported, respectively.

The data concerning reprocessing plant effluents refer to the Windscale Plant(8).

The solid wastes generated in fuel reprocessing include several streams. Hulls and fuel assembly hardware from head-end operations are the most important in terms of radioactivity. Although a lot of information has been published on such wastes in the literature, it is not simple to correlate their radioactivity either with the corresponding kWh(t) or with the radioisotope spectra concerned. The most exhaustive source of information is Ref. (9), from which the data for the present work have been taken.

In Figs. 3 and 4, the radioactivity and the IT per kWh(t) of fuel reprocessing wastes are reported. The contribution of hulls and reprocessing hardware to the environmental impact after some thousands of years appears to be of the same order as that of vitrified HLW, due to the transuranics contained.

Radioactive Wastes from Plant Decommissioning

The contribution to the environmental impact of decommissioning of fission nuclear power plants should take into account both the decommissioning of electricity production plants themselves and the decommissioning of related plants, such as fuel reprocessing plants and fuel fabrication plants.

A good deal of information has been published on reprocessing plant decommissioning (12-14). Unfortunately, it cannot be used for our purposes, since it is impossible to correlate the radioactivity with the corresponding kWh(t) produced. On the other hand, the contribution of fuel fabrication plant decommissioning to the environmental impact is negligible if compared to that of other decommissioning wastes.

Only pressurized water-reactor power station decommissioning is therefore taken into account as a waste source in this paper. The waste radioactivity produced totals from 2.7×10^4 Bq/kWh(t) (15) to 2×10^5 Bq/kWh(t) (16). The biggest (more than 99%) contribution to waste radioactivity is from reactor-component neutron activation.

Using the information reported in Ref. (16), the radioactivity and the IT in time have been calculated for neutron-activated reactor components (see Tables III and IV).

Figures 5 and 6 show the contribution of decommissioning waste to the radioactivity of the entire nuclear production cycle. It appears to be relatively small and comparable to reactor operation radwastes. On the contrary, as well known, the fuel reprocessing waste contribution is the maximum, with the contribution from the hulls comparable, in the long term (more than 10^4 years), to vitrified HLW, as already reported.

RADIOACTIVE WASTES FROM NUCLEAR FUSION POWER STATIONS

To our knowledge the only available reference for comparing the overall environmental impact of future fusion power stations with present fission power stations is the STARFIRE study of a commercial tokamak fusion power plant (1). The STARFIRE design, in fact, takes into account the use of commercially available materials for construction. However, it estimated the safety and environmental impact as a result of the design itself, rather than fully integrating these constraints and goals into the study from the beginning.

On the other hand, more recent studies, such as ARIES-1, a fusion reactor design based on conventional physics but advanced technology (high magnetic field, advanced materials), consider safety and environmental requirements primary objectives and take into account the use of low-activation materials, such as SiC/SiC composites, at present not yet fully developed, as structural materials for this type of machine (2, 17-19).

The STARFIRE plant characteristics are summarized in Table V.

The average annual solid radwaste removed from the STARFIRE reactor is estimated to be about 250 MT, 48% of which is due to the $LiAlO_2$ breeder, 11% to the graphite reflector, 19% to the neutron multiplier Zr_5Pb_3, and 30% to the PCA (primary candidate alloy) structural material, which is an austenitic titanium-modified stainless steel.

The radioactivity associated with effluents is due almost entirely to tritium, whose maximum release is assumed to be 5000 Ci/y. The contribution of radioactive corrosion products represents only a small fraction of this figure.

Figure 7 reports the waste radioactivity corresponding to 1 kWh(t) produced for each different waste source; and Fig. 8, the ingestion toxic potentials.

TABLE I

The Radioactivity of Vitrified HLW Produced in PWR Fuel Reprocessing [Bq/kWh(t)]

RADIONUCLIDES	HALF-LIFE Y	5 Y	100 Y	1000 Y	10E4 Y	10E5 Y	10E6 Y
Se 79	6.50E+04	1.38E+01	1.38E+01	1.37E+01	1.24E+01	4.76E+00	3.24E-04
Sr 90	2.91E+01	2.75E+06	2.61E+05	1.28E-04	0.00E+00	0.00E+00	0.00E+00
Zr 93	1.53E+06	1.14E+01	1.14E+01	1.14E+01	1.14E+01	1.09E+01	7.26E+00
Tc 99	2.13E+05	5.71E+02	5.71E+02	5.69E+02	5.53E+02	4.12E+02	2.21E+01
Ru 106	1.01E+00	1.01E+06	3.19E-24	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Rh 106	9.51E-07	9.53E-01	3.01E-30	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Sn 126	1.00E+05	2.43E+01	2.43E+01	2.41E+01	2.27E+01	1.22E+01	2.38E-02
Sb 116m	1.00E+05	2.43E+01	2.43E+01	2.41E+01	2.27E+01	1.22E+01	2.38E-02
Cs 134	2.06E+00	1.08E+06	3.70E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Cs 135	2.30E+06	6.79E+01	6.79E+01	6.79E+01	6.77E+01	6.59E+01	5.03E+01
Cs 137	3.00E+01	3.95E+06	4.01E+05	3.75E-04	0.00E+00	0.00E+00	0.00E+00
Pm 147	2.62E+00	1.98E+06	8.40E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Sm 151	9.00E+01	1.70E+01	7.93E+00	7.75E-03	0.00E+00	0.00E+00	0.00E+00
U 233	1.59E+05	7.18E-02	7.18E-02	7.15E-02	6.87E-02	4.64E-02	9.19E-04
U 234	2.45E+05	7.01E-02	7.01E-02	6.99E-02	6.81E-02	5.28E-02	4.14E-03
U 236	2.34E+07	1.95E-02	1.95E-02	1.95E-02	1.95E-02	1.95E-02	1.90E-02
Np 237	2.14E+06	1.29E+01	1.29E+01	1.29E+01	1.29E+01	1.25E+01	9.33E+00
Pu 238	8.77E+01	4.73E+02	2.17E+02	1.77E-01	0.00E+00	0.00E+00	0.00E+00
Pu 239	2.41E+04	4.57E+01	4.55E+01	4.44E+01	3.43E+01	2.57E+00	1.48E-11
Pu 240	6.54E+03	7.62E+01	7.55E+01	6.86E+01	2.64E+01	1.91E-03	0.00E+00
Pu 241	1.44E+01	5.27E+05	4.49E+03	6.95E-16	0.00E+00	0.00E+00	0.00E+00
Pu 242	3.76E+05	2.51E-01	2.51E-01	2.51E-01	2.47E-01	2.09E-01	3.98E-02
Am 241	4.32E+02	3.08E+04	2.63E+04	6.20E+03	3.33E-03	0.00E+00	0.00E+00
Am 243	7.38E+03	8.45E+02	8.37E+02	7.69E+02	3.30E+02	7.06E-02	0.00E+00
Cm 244	1.80E+01	7.58E+04	1.68E+03	1.50E-12	0.00E+00	0.00E+00	0.00E+00
Cm 245	8.50E+03	9.09E+00	9.01E+00	8.38E+00	4.02E+00	2.62E-03	0.00E+00
Cm 246	4.73E+03	2.35E+00	2.32E+00	2.03E+00	5.43E-01	1.02E-06	0.00E+00
TOTAL		1.14E+07	6.96E+05	7.81E+03	1.10E+03	5.34E+02	8.90E+01

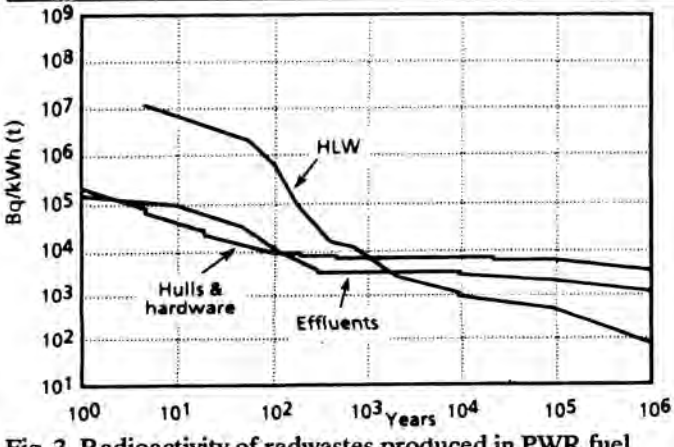

Fig. 3. Radioactivity of radwastes produced in PWR fuel reprocessing.

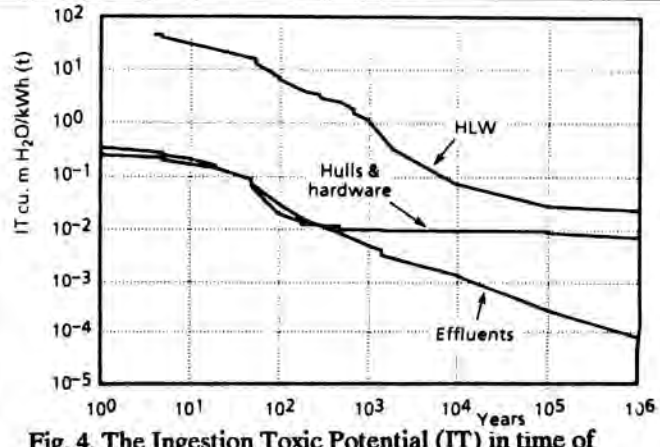

Fig. 4. The Ingestion Toxic Potential (IT) in time of radwastes produced in PWR fuel reprocessing.

In the short term both the radioactivity and the IT per kWh(t) are due almost completely to the neutron-activated structural material, discharged during both plant operation and the decommissioning stage, while in the long term (say more than 10^4 years), the contribution of the neutron multiplier and of the breeder becomes significant.

This is due to the presence of long-lived isotopes ^{93}Zr and ^{205}Pb in the neutron multiplier (Zr_5Pb_3) and of ^{26}Al in the breeder ($LiAlO_2$). The long-lived isotopes in structural materials that contribute the most are, in the long term, ^{59}Ni, ^{93}Mo, and ^{14}C.

TABLE II

The Ingestion Toxic Potential (IT) of Vitrified HLW Produced in PWR Fuel Reprocessing
[$m^3H_2O/kWh(t)$]

ISOTOPES	ALI CEE	MCA	5 Y	100 Y	1000 Y	10E4 Y	10E5 Y	10E6 Y
	Pubbl.Bq	Bq/cu.m.H_2O						
Se 79	2.00E+06	2.88E+06	4.79E-06	4.78E-06	4.74E-06	4.31E-06	1.65E-06	1.12E-10
Sr 90	1.00E+05	1.44E+05	1.96E+01	1.81E+00	8.89E-10	0.00E+00	0.00E+00	0.00E+00
Zr 93	5.00E+06	7.21E+06	1.58E-06	1.58E-06	1.58E-06	1.58E-06	1.51E-06	1.01E-06
Tc 99	1.00E+07	1.44E+07	3.96E-05	3.96E-05	3.95E-05	3.83E-05	2.86E-05	1.53E-06
Ru 106	7.00E+05	1.01E+06	1.99E+00	3.16E-30	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Rh 106	3.00E+07	4.33E+07	4.64E-02	6.96E-38	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Sn 126	1.00E+06	1.44E+06	1.69E-05	1.69E-05	1.67E-05	1.57E-05	8.43E-06	1.65E-08
Sb 116m	8.00E+07	1.15E+08	2.11E-07	2.11E-07	2.09E-07	1.97E-07	1.05E-07	2.06E-10
Cs 134	3.00E+05	4.33E+05	3.48E+00	8.55E-15	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Cs 135	3.00E+06	4.33E+06	1.57E-05	1.57E-05	1.57E-05	1.57E-05	1.52E-05	1.16E-05
Cs 137	4.00E+05	5.77E+05	7.01E+00	6.95E-01	6.51E-10	0.00E+00	0.00E+00	0.00E+00
Pm 147	2.00E+07	2.88E+07	8.95E-02	2.91E-13	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Sm 151	5.00E+07	7.21E+07	2.38E-07	1.10E-07	1.08E-10	0.00E+00	0.00E+00	0.00E+00
U 233	7.00E+05	1.01E+06	7.11E-08	7.11E-08	7.08E-08	6.81E-08	4.60E-08	9.10E-10
U 234	7.00E+05	1.01E+06	6.94E-08	6.94E-08	6.92E-08	6.75E-08	5.23E-08	4.10E-09
U 236	8.00E+05	1.15E+06	1.69E-08	1.69E-08	1.69E-08	1.69E-08	1.69E-08	1.64E-08
Np 237	3.00E+02	4.33E+02	2.98E-02	2.98E-02	2.98E-02	2.97E-02	2.89E-02	2.16E-02
Pu 238	3.00E+05	4.33E+05	1.10E-03	5.01E-04	4.08E-07	5.31E-38	0.00E+00	0.00E+00
Pu 239	2.00E+05	2.88E+05	1.58E-04	1.58E-04	1.54E-04	1.19E-04	8.93E-06	5.14E-17
Pu 240	2.00E+05	2.88E+05	2.64E-04	2.62E-04	2.38E-04	9.16E-05	6.61E-09	0.00E+00
Pu 241	1.00E+07	1.44E+07	3.83E-02	3.11E-04	4.82E-23	0.00E+00	0.00E+00	0.00E+00
Pu 242	3.00E+05	4.33E+05	5.81E-07	5.80E-07	5.79E-07	5.70E-07	4.83E-07	9.19E-08
Am 241	5.00E+03	7.21E+03	4.28E+00	3.64E+00	8.60E-01	4.61E-07	9.18E-70	0.00E+00
Am 243	5.00E+03	7.21E+03	1.17E-01	1.16E-01	1.07E-01	4.58E-02	9.79E-06	0.00E+00
Cm 244	9.00E+03	1.30E+04	6.07E+00	1.29E-01	1.16E-16	0.00E+00	0.00E+00	0.00E+00
Cm 245	5.00E+03	7.21E+03	1.26E-03	1.25E-03	1.16E-03	5.58E-04	3.63E-07	0.00E+00
Cm 246	5.00E+03	7.21E+03	3.26E-04	3.21E-04	2.82E-04	7.54E-05	1.41E-10	0.00E+00
TOTAL			4.27E+01	6.42E+00	9.98E-01	7.65E-02	2.89E-02	2.16E-02

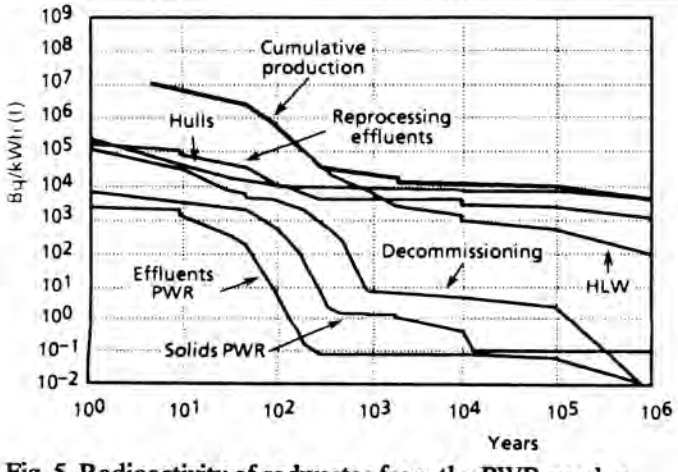

Fig. 5. Radioactivity of radwastes from the PWR production cycle.

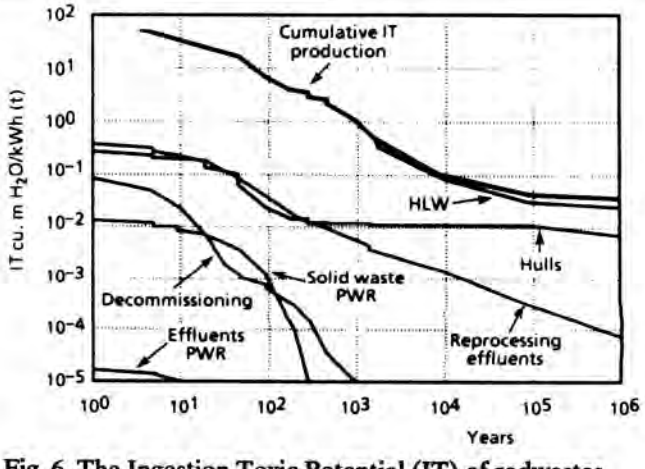

Fig. 6. The Ingestion Toxic Potential (IT) of radwastes from the PWR production cycle.

TABLE III

The Radioactivity of Radwastes Produced in the Decommissioning of a PWR Nuclear Power Plant [Bq/kWh(t)]

ISOTOPES	HALF-LIFE	1 Y	100 Y	1000 Y	10E4 Y	10E5 Y	10E6 Y
Nb 95	9.59E-02	8.92E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Fe 59	1.25E-01	7.20E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Co 58	1.95E-01	8.64E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Zn 65	6.71E-01	3.44E+00	1.00E-44	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Mn 54	8.22E-01	2.37E+03	1.01E-33	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Fe 55	2.70E+00	7.25E+04	6.14E-07	2.93E-107	0.00E+00	0.00E+00	0.00E+00
Co 60	5.20E+00	7.62E+04	1.36E-01	1.10E-53	0.00E+00	0.00E+00	0.00E+00
Ni 63	9.20E+01	8.00E+03	3.79E+03	4.31E+00	1.56E-29	0.00E+00	0.00E+00
Mo 93	1.00E+02	2.48E-02	1.24E-02	2.43E-05	1.99E-32	2.69E-303	0.00E+00
C 14	5.73E+03	1.00E+01	9.89E+00	8.87E+00	2.99E+00	5.60E-05	2.99E-52
Nb 94	2.00E+04	3.28E-01	3.27E-01	3.17E-01	2.32E-01	1.03E-02	2.94E-16
Ni 59	8.00E+04	5.23E+01	5.23E+01	5.18E+01	4.80E+01	2.20E+01	9.04E-03
TOTAL		1.60E+05	3.85E+03	6.53E+01	5.12E+01	2.20E+01	9.04E-03

TABLE IV

The Ingestion Toxic Potential of Radwastes Produced in the Decommissioning of PWR Nuclear Power Plants [m^3H_20/kWh(t)]

ISOTOPES	ALI CEE Pubbl. Bq	1 Y	10 Y	100 Y	1000 Y	10E4 Y	10E5 Y	10E6 Y
Nb 95	8.00E+06	7.73E-08	4.09E-37	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Fe 59	3.00E+06	1.66E-05	5.76E-28	1.16E-244	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Co 58	5.00E+06	1.20E-04	5.08E-19	1.10E-157	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Zn 65	1.00E+06	2.39E-06	1.57E-10	6.94E-51	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Mn 54	7.00E+06	2.35E-04	9.01E-08	1.01E-40	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Fe 55	3.00E+07	1.68E-03	1.53E-04	1.42E-14	6.76E-115	0.00E+00	0.00E+00	0.00E+00
Co 60	7.00E+05	7.55E-02	2.18E-02	1.34E-07	1.09E-59	0.00E+00	0.00E+00	0.00E+00
Ni 63	4.00E+06	1.39E-03	1.29E-03	6.57E-04	7.47E-07	2.70E-36	0.00E+00	0.00E+00
Mo 93	4.00E+06	4.29E-09	4.02E-09	2.16E-09	4.22E-12	3.45E-39	0.00E+00	0.00E+00
C 14	9.00E+06	7.71E-07	7.71E-07	7.62E-07	6.84E-07	2.30E-07	4.31E-12	2.31E-59
Nb 94	4.00E+06	5.69E-08	5.69E-08	5.67E-08	5.49E-08	4.02E-08	1.78E-09	5.09E-23
Ni 59	9.00E+07	4.03E-07	4.03E-07	4.03E-07	4.00E-07	3.70E-07	1.69E-07	6.97E-11
TOTAL		7.89E-02	2.32E-02	6.58E-04	1.88E-06	6.40E-07	1.71E-07	6.97E-11

COMPARISON BETWEEN FISSION AND FUSION REACTOR WASTES

Considering the radwaste analysis shown in Figs. 6 and 8, it is immediately clear that there is a large difference between fusion and fission reactors in the contribution of various waste sources to the IT. In fission reactors the maximum contribution is from radwastes produced during fuel reprocessing operations or from isotopes present in the spent fuel in general, whereas in fusion reactors the maximum contribution will be from neutron activation of the structural material used in the construction of the inner reactor components (first wall, breeder, etc.).

This means that, while actinides and long-lived isotopes are in general intrinsic to nuclear fission reactions and it is not possible therefore to avoid them, in the case of nuclear fusion, room does exist for significant improvement as regards neutron activation, by means of a careful choice of materials.

From the radioactivity point of view, the STARFIRE fusion reactor wastes are about one order of magnitude higher than the fission radwastes for about $5x10^5$ years' decay time. Fission waste radioactivity then becomes higher, as shown in Fig. 9.

Of course, the very different characteristics of the radioactive isotopes concerned, expressed in terms of ALI, produce significantly different results when the ITs are calculated, as shown in Fig. 10.

The IT of fusion reactor radioactive wastes is about one order of magnitude lower than fission radwastes at short decay

TABLE V

The STARFIRE Major Design Parameters

Net electrical power, MW	1200
Gross electrical power, MW	1440
Fusion power, MW	3510
Thermal power, MW	4000
Gross turbine cycle efficiency, %	36
Overal availability, %	75
Average neutron wall load, MW/sq.m	3.6
Major radius, m	7.0
Plasma half-width, m	1.94
Plasma current, MA	10.1
Average toroidal β	0.067
Toroidal field on axis, T	11.1
No. of TF coils	12
Plasma burn mode	continuous
Blanket structural material	austenitic SS
Tritium breeding medium	α-LiA10$_2$
Plasma impurity control	Limiter, low-z coating

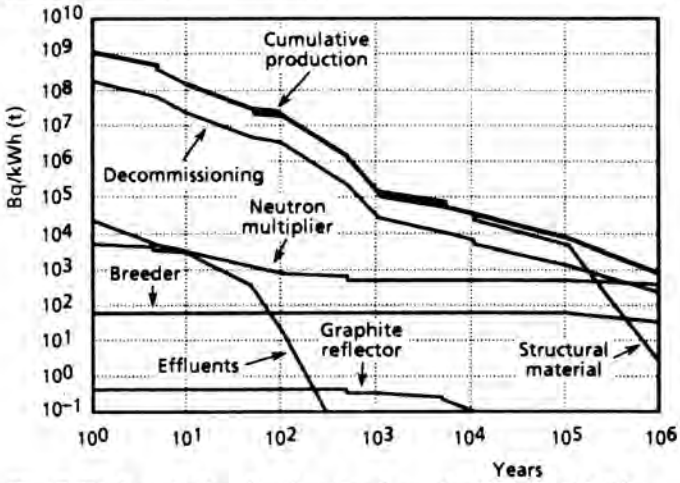

Fig. 7. Radioactivity of radwastes from the STARFIRE fusion power plant.

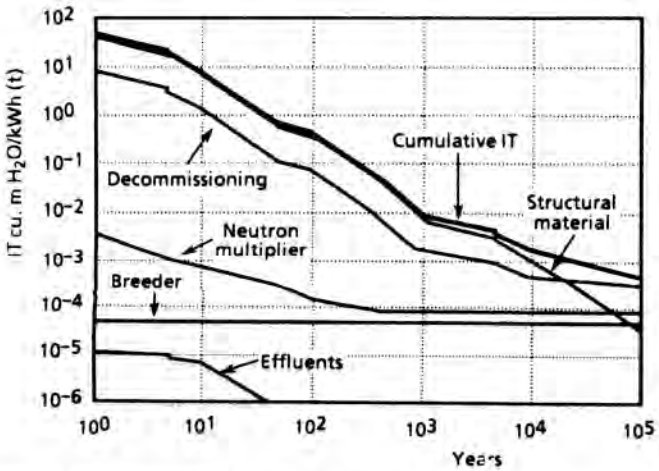

Fig. 8. The Ingestion Toxic Potential (IT) of radwastes produced by the STARFIRE fusion power plant.

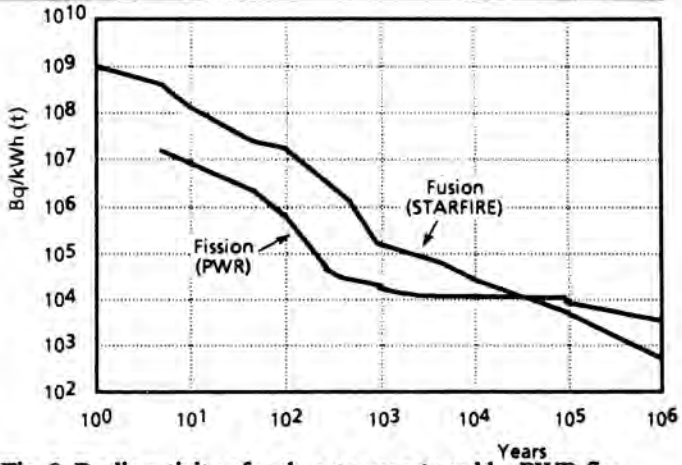

Fig. 9. Radioactivity of radwastes produced by PWR fission and STARFIRE fusion power plants.

times, becoming about two orders of magnitude lower after 1000 years approximately.

Just for reference, Fig. 10 also reports the IT values of wastes produced by thermal power plants, calculated with the same methodology.

In this case the chemical toxicity of metals released by fired coal or fuel oil is taken into account, with reference to their maximum concentration in potable water, according to the Italian Regulations. The ITs correspond in this case also to 1 kWh(t) produced, in order to make comparison possible.

The chemical toxicity of thermal power wastes of course does not decay in time, as in the case of radioactivity. The IT of coal thermal power plant waste is about ten times higher than the IT of fuel oil wastes.

As shown in Fig. 10, the fusion radwaste IT equals that of coal wastes after about 50 years, and that of fuel oil wastes after about 130 years, after which it becomes lower than both.

In the case of fission radioactive wastes, the decay times required are about 1100 years and 10000 years, respectively.

CONCLUSIONS

The environmental impact of future nuclear fusion power reactors will be largely determined by long-lived radionuclides produced by neutron activation in structural materials. Although the nuclear fusion Ingestion Toxic Potential (IT) is considerably lower than the nuclear fission IT, a big effort should be made to reduce it below or to the same levels as those of thermal power plants, which could be taken as reference for the establishment of IT acceptability limits. Reduction of the IT could be obtained by means of the development and utilization of low-activation materials (LAM), whose selection should be based on environmental impact evaluation criteria as well as engineering and operational constraints.

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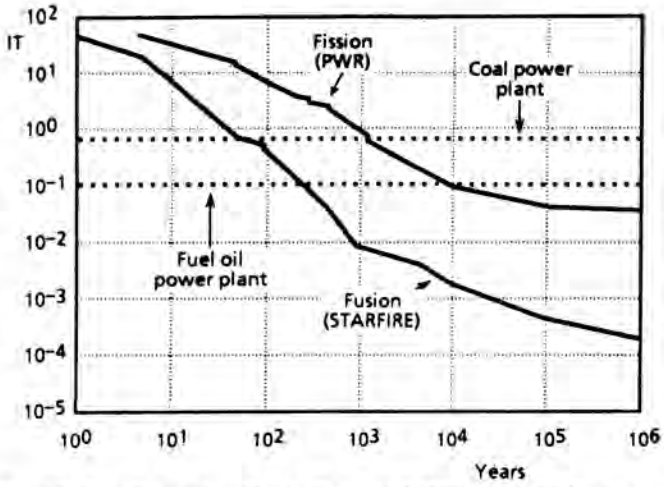

Fig. 10. The Ingestion Toxic Potential (IT) of PWR fission and STARFIRE fusion power-plant radwastes as compared with IT of thermal power-plant wastes.

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