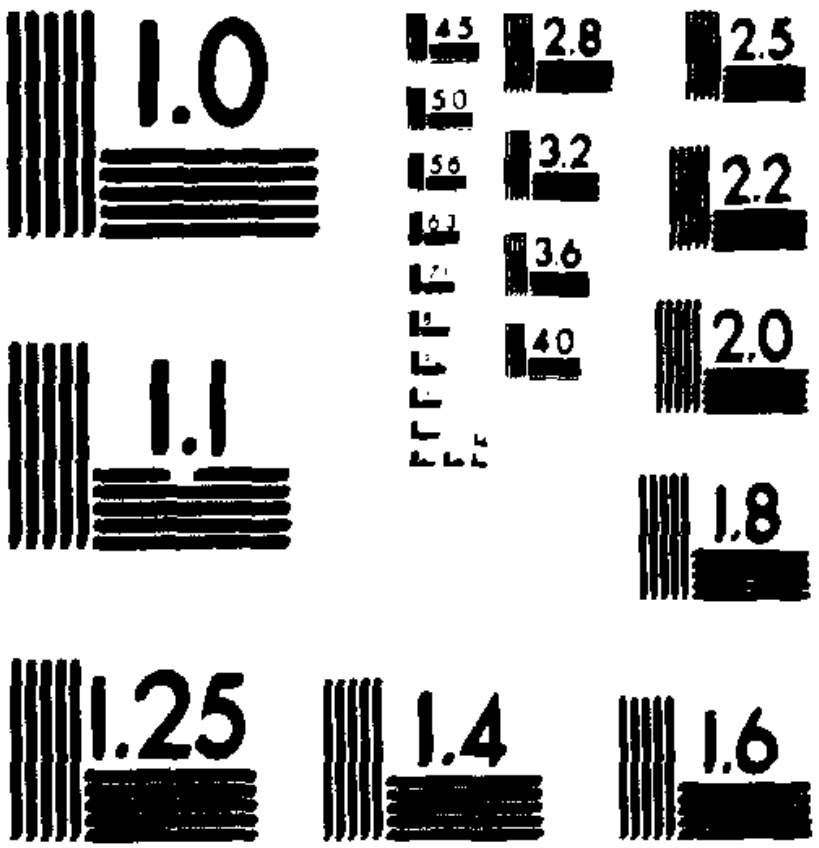

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V. VIOLANTE

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TRITIUM DYNAMICS IN FUSION REACTOR SOLID BREEDER

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RT/TIB/86/11

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SUMMARY

In the field of the "NET" research program,the chemical and diffusive processes involved in solid ceramic breeder materials have been analysed.
A mathematical model describing the phenomena has been developed to obtain a quantitative evaluation for a first design approach.
The data obtained by means of the above mentioned model are in good agreement with the data obtained by other research groups working in Europe and in United States.
The computer codes "BLANKET2","MC2","FWBC",have been developed to simulate the phenomena.

RIASSUNTO

Nell'ambito del programma di ricerca sul reattore a fusione "NET" si e' sviluppata una schematizzazione qualitativa dei processi chimici e diffusivi innescati dalle reazioni nucleari che avvengono nei breeder solidi ceramici.
Lo schema proposto viene quindi modellizzato in termini matematici al fine di ottenere una valutazione quantitativa utile in una fase preprogettuale.
I dati ottenuti,nei limiti dello schema proposto e delle approssimazioni legate al modello matematico,sono in accordo con i dati ottenuti presso altri centri di ricerca in Europa e negli Stati Uniti,e forniscono informazioni necessarie per il dimensionamento del blanket del reattore a fusione in funzione dei parametri fondamentali,ossia l'Inventory del trizio ed il Tritium Breeeding Ratio.
Per sviluppare questo lavoro sono stati elaborati tre codici di calcolo,il "BLANKET2" per il calcolo dell'inventory diffusivo,l'"MC2" per il calcolo dell'inventory di trapping, e l'"FWBC" per il calcolo del flusso di trizio dal plasma al refrigerante attraverso la prima parete.

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1) INTRODUCTION

This paper is devoted to the study of tritium production and control in the breeder material of the "IL MANTELLO" blanket/24/. The hypothetical reactions involved with tritium production in a γ-LiAlO2 blanket are:

$$n' + {}^{6}Li\,Al\,O_2 \longrightarrow AlO_2^- + \square + T^+ + He^{++} + 2e^- + ENERGY \qquad (1.1)$$

$$n + {}^{7}Li\,Al\,O_2 \longrightarrow AlO_2^- + \square + T^+ + He^{++} + 2e^- - ENERGY \qquad (1.2)$$

where n' is a low energy neutron, n is a high energy neutron and $\square$ is a vacancy.

The quickly migrating T ion can alloy an oxigen atom to form the groups AlO(OT)(T_{Li}) and LiOT(T_{Li}) in the litium alluminate lattice or in litium oxide respectively.

$$AlO_2^- + \square + T^+ \longrightarrow T_{Li}$$
$$2\,T_{Li} \longrightarrow Al_2O_3 + T_2O \qquad (1.3)$$

$$LiO^- + \square + T^+ \longrightarrow T_{Li}$$
$$2\,T_{Li} \longrightarrow Li_2O + T_2O \qquad (1.4)$$

The diffusion process can be splitted into two steps:

a) diffusion through the grains of which the breeder materiai is constituted (bulk diffusion);
b) permeation and percolation into the gas purge stream (see Figure 1).

The rate controlling step is the diffusion through the grains when the grain sizes are large.
In the model,belowe described,the tritium diffusion through the grains and the diffusion through the pores are treated separately.
The tritium concentration in the pores is used as boundary condition to calculate the concentration profile in the grains (usually,in the literature the grains boundary concentration is taken to be zero).
The influence of the radial temperature profile in each breeder tube on the diffusion coefficent is taken into account.This section includes also a discussion about the great uncertainty in the tritium diffusion coefficent value,as observed in the experiments.The tritium trapping into the reticular defects has been studied using a statistical approach,and the permeation barriers effect has been analyzed to evaluate the tritium losses into the helium coolant stream.

The "FWBC" code allows to us to obtain a simulation of the tritium implanted on the first wall internal sourface:the tritium mass transfer through the first wall and the tritium flux into the coolant helium has been evaluated by means of "FWBC"

2) TRITIUM DIFFUSION INVENTORY IN PORES AND IN GRAINS.

The breeder physical properties strongly influence the tritium diffusion.

Using γ-LiAlO2 as breeder material it is necessary to increase the material density (ρ > 80% T.D.) to obtain a good breeding performance.

Samples with 80% of theoretical density have been recently produced at the Casaccia ENEA Center /15/.

The first step to analyze the tritium inventory is to describe the tritium transport through a blanket material.

A diffusion model with proper boundary conditions is proposed for the system as shown in Fig.1 .

This is a typical breeder tube contained within the blanket module.

The He flowing in the central hole removes the tritium.

The tritium transport in pores is governed by the usual diffusion equation:

$$D \nabla^2 C + B = 0 \qquad (2.1)$$

being:

$$B = 0.5 \sum_i (1-\varepsilon)\rho \frac{P_i^{L_i}}{w_i} \int \sigma_i(E)\,\phi(E)\,dE \qquad (2.2)$$

the source term (see the symbol list).

The diffusive inventory evaluation is made considering the breeder as a two phase system:

i) grains (solid)

ii) pores (gas)

The diffusion through the grains and the diffusion (percolation) through the pores are evaluated separately.

a) Diffusion in pores

The tritium concentration in the gas phase is used as boundary (surface) condition to evaluate the tritium inventory in the grains.The tritium concentration in the pores is calculated by solving (2.1) where D(T) is the gas phase diffusion coefficent.

To solve the equation (2.1) we neglect the cylindrical effect

$$\nabla^2 C = \frac{\partial^2 C}{\partial r^2} + \frac{\partial^2 C}{\partial z^2} \qquad (2.3)$$

where r is equivalent to the radial coordinate,and z is the longitudinal coordinate along the tube.

As far as the axial boundary conditions are are concerned,we have zero tritium fluxes at the tube ends (z=0,z=L).

$$\left(\frac{\delta C}{\partial z}\right)_{z=0} = \left(\frac{\delta C}{\partial z}\right)_{z=L} = 0 \qquad (2.4)$$

At the outer edge (r=R), the diffusion flux is supposed to be equal to the permeation flux j through the barrier (HT-9 structure +glass barrier).

$$J = P^{1/2}\left(X_R^{1/2} - X_\infty^{1/2}\right) / R_{tot} \qquad (2.5)$$

$$-D\left(\frac{\delta C}{\delta z}\right)_{z=R} = J \qquad (2.6)$$

In eq.(2.5), x_∞ is the tritium molar fraction in the cooling gas (x_∞=o), and x_R is the tritium molar fraction at the inside wall. Rtot is the total permeation resistence that is obtined by adding the glass and structure resistence:

$$R_{tot} = R^{Si\,C} + R^{HT\text{-}9} \qquad (2.7)$$

$$R^{Si\,C} = \delta_i / P_i^{Si\,C} \qquad (2.8)$$

$$R^{HT-9} = \delta_2 / Pe^{HT-9} \qquad (2.9)$$

$$R_{tot} = \frac{\delta_1 Pe^{HT-9} + \delta_2 Pe^{SiC}}{Pe^{SiC} Pe^{HT-9}} \qquad (2.10)$$

Pe^{SiC} and Pe^{HT-9} are the glass and HT-9 permeabilies respectively.

Using the expression (6.1) for the tritium permeability through the SiC glass /3/,we obtain Pe^{SiC} =1e-34 (stdcm^2/sec atm^0.5) at T=773 kelvin.

Therefore,the total resistence is practically infinite and equation (2.6) reduces to:

$$\left(\frac{\delta c}{\delta r}\right)_{r=R} = 0 \qquad (2.11)$$

the last boundary condition is on the purge gas pipe sourface:

$$C(r=0,z) = C_{pg}(z) \qquad (2.12)$$

The meaning of equation (2.12) is that at steady state the tritium concentration on the purge helium pipe wall is practically the tritium concentration in purge helium.the model has been solved numerically using an over relaxation thecnique to itegrate the equation (2.1).

The source term B is a function of the breeder element position in the blanket canister and it is obtained by neutronic calculations.

In order to obtain a correlation beteween the purge gas flow-rate and the tritium concentration in the purge flow pipe,a mass balance on the purge gas stream is necessary.
From a mass baiance on a differential volume element we obtain:

$$\frac{\delta}{\partial z} C_{pg}(z) = 2\pi \cdot \frac{B \cdot V}{W \cdot S} \cdot r_i \qquad (2.13)$$

with

$$C_{pg}(z=0) = 0 \qquad (2.14)$$

as boundary condition
Integrating equation (2.13) with this boundary condition leads to:

$$C_{pg}(z) = \frac{2\pi B V r_i}{W S} z \qquad (2.15)$$

which in therms of the gas linear velocity $V=W/\pi r_i$ becomes

$$C_{Tg}(z) = \frac{2\,B\,V}{S\,V\,\varepsilon_i}\,z \qquad (2.16)$$

therefore the tritium concentration into the purge helium stream increases linearly with the axial coordinate.

The tritium diffusion coefficent for a porous system is given by the following formula /4/ :

$$\frac{1}{D} = \frac{1}{\varepsilon\,D_{AB}} + \frac{3}{4\,K_0\,V_{th}} \qquad (2.17)$$

where /5/:

$$D_{AB} = \frac{0.001\cdot[T(^oK)]^{1.75}\left(\frac{1}{M_1}+\frac{1}{M_2}\right)^{\frac{1}{2}}}{P(Kg/cm^2)\left[(\Sigma v_1)^{\frac{1}{3}}+(\Sigma v_2)^{\frac{1}{3}}\right]^2} \qquad (2.18)$$

and

$$V_{th} = \left(\frac{8\,R_0\,T(^oK)}{\pi\,\mu}\right) \qquad (2.19)$$

$$K_0 = \delta / K_1 \qquad (2.20)$$

b) Diffusion through the grains

Assuming a spherical shape for the grains, the concentration in the grains is obtained by solving the equation:

$$\frac{D'}{r'} \frac{d}{dr'} \left(r' \frac{dC'}{dr'} \right) = - \frac{B'}{A_0} \qquad (2.21)$$

with the following boundary conditions:

$$\left(\frac{dC'}{dr'} \right)_{r'=0} = 0$$

$$\left(C' \right)_{r'=R} = C(r,z) \qquad (2.22)$$

where C(r,z) is the solution of the equation (2.1).

The grain inventory, Ig, is obtained by solving (2.21) for C'(r')

$$C'(r') = \frac{B'}{4 A_0 D'} \left(R'^2 - r'^2 \right) + C(r,z) \qquad (2.23)$$

and integrating over the grain volume:

$$I_g = \frac{2\pi B'}{15 D'} R'^5 + \int_{grain} C'(r,z)\, dV \qquad (2.24)$$

The tritium diffusive inventory in the breeder volume is the sum of the inventory in the grains Ig and the inventory in the pores Igas.

$$I_{tot} = I_{gas} + I_g \qquad (2.25)$$

The temperature profile effects on the diffusion coefficent have been considered.

In this case the gas and the solid phase diffusion coefficents are both functions of the temperature inside the breeder tube;that means a variation of D and D' with the tube radius.

Using the computer model we can also take into account a bimodal grain size distribution.However,we have limited ourselves to considering grains of 0.5 μm with unimodal distribution.

This kind of breeder material is one of the best γ-LiAlO2 obtined by ENEA /15/.

The calculations lead to a tritium inventory of 360 gr using tubes with 4 cm of outer diameter,and an inventory of 114.5 gr using tubes with 2.5 of outer diameter.In both cases the critical zone for the tritium inventory seems to be the one close to the nose of the canister.

By splitting the inventory in two parts, inventory in grains (solid).and inventory in pores (gas),it results that using tubes with 4 cm of diameter the solid inventory is 357.1 gr and the gas inventory is 3.6 gr.Using a tube with 2.5 cm of diameter,the solid inventory is 112 gr and the gas inventory is 2.5 gr.
A complete summary of results is reported in table 1.

INVENTORY (gr)

(cm)	Solid Phase	Gas Phase	Total
4	357.1	3.6	360.8
2.5	112	2.5	114.5

Table 1

For these calculations we have used as tritium diffusion coefficent the values coming from the empirical expression:

$$D' = 0.012 \exp\left[-\frac{24\,900}{1.987\,T(^{\circ}K)}\right] \ (Cm^2/sec) \qquad (2.26)$$

obtained by Kudo and Okuno.

The D' values obtained using this formula seem to be an average of the very differentvalues reported in the literature.From the above numerical results,an intersting effect of the tube diameter on the tritium inventory appears.By using tubes with small diameter the average temperature in the tube is lower than in the case of large diameter tubes.Therefore,the average diffusion coefficent should be lower and the inventory should be higher: but the radial concentration difference through the large tubes is stronger and plays a fundamendals role in increasing the tritium inventory

3) TRITIUM DIFFUSION COEFFICENT IN SOLID BREEDER MATERIALS.

A wide spread (even by three orders of magnitude) of the tritium diffusion coefficent in solid breeder materials (ceramics) is found in the literature.This leads to a large degree of uncertainty in the evaluation of the tritium inventory in the blanket of a fusion reactor.

A collection of avaluable data on γ-LiAlO2 and Li2O is presented here,aiming at identifying the parameters which control the tritium coefficent.

a) Diffusion in γ-LiAlo2

Several semi-empirical formulae for the tritium diffusion coefficent in lithium alluminate can be found in the literature. In reference /11/,Bruning,Guggi,and Ihle suggest the expression

$$\ln D\,(cm^2/sec) = (-5.78 \pm 0.7) - (9.73 \pm 0.7)\cdot 10^3/T(^\circ K) \qquad (3.1)$$

which well reproduces the experimental data for spherical pellets with radii ranging from o.7 mm to 2.5 mm for temperatures ranging beteween 873-1043 K.

For the same temperature range,different values of D have been reported according to /12/.

$$\ln D\,(cm^2/sec) = (-1.52 \pm 0.41) - (5494 \pm 420)\,/T(^\circ K) \qquad (3.2)$$

and for samples with a radius of 5μm /20/,

$$\ln D\,(cm^2/sec) = (8.86 \pm 0.05) - (1503 \pm 204)/T(^\circ K) \qquad (3.3)$$

The effect of the grain size on D,as observed in the experiments,is shown in fig.2 : D increases as the grain size decreases,as expected,because the mean residence time of tritium inside the grain decreases with decreasing grain size.

In table 2,different D values at 660 C are reported as observed in different experiments:these values range from 4e-11 to 1.2e-8 cm^2/sec.

Notice that the same authors (Kudo and Okuno) have obtained three different values of D from the same kind of sample.

In the "TRIO" experiment /16/,a large amount of data have been analyzed and the following best fitting expression has been proposed:

$$\ln D\ (cm^2/sec) = (-13.7 \pm 1.8) - (35.8 \pm 3.9)/R_0 T \qquad (3.4)$$

Notice the large scattering of data at high temperature,which is ascribed to fluctuation in the source of tritium used in the experiment (see also ref /1/).

In reference /15/,three different techniques have been used for obtaining samples of γ-LiAlO2.A sample obtained through a Al2O2 + Li2O2 reaction is shown in fig.3 (90% of T.D.,grain size 0.5-5μm). For a sample obtained by sol-spray drying,the density is 83% T.D.and the grain size is 1-3μm (see fig.4).

In fig 5 a sample is shown (86% T.D.,grain size 0.1-2 μm) that has been obtained by gel supported precipitation.We may note how the sample microstructure (and hence,the mass transfer phenomena) is affected by the fabrication method.

To summarize,the observed fluctuations of the tritium diffusion coefficent may be ascrived to the following parameters and features:

i) different chemical conditions during the diffusion step,e.g. different percentages of H2 in He /23/,different O2 activities in the experimental devices /23/;

ii) different chemical sintering processes which control the grain size and geometry /15/;

iii)different diagnostic methods to analyze the tritium mass transfer.

iiii) fluctuations of the source used for in situ tritium recovery experiments.

b) Tritium diffusion in Li2O.

Fluctuations of the tritium diffusion coefficent are also reported for Li2O (see fig 6).Accordingly,the considerations made previously for -LiAlO2 apply for Li2O as well.

TRITIUM DIFFUSIVITY

Autor	D=Do*EXP(-Ea/R*T) D (Cm^2/sec) Ea (Kcal/Mol)	Sample
Tone et Al.	D=9.5 E-3*EXP(-20.1/RT)	powder
Kudo,Okuno	D=1.9 E-3*EXP(-24.3/RT)	"
"	D=1.2E-2*EXP(-24.9/RT)	"
"	D=5.1E-3*EXP(-23.9/RT)	"

TAB.2

4) TRITIUM DIFFUSIVE INVENTORY FOR Li2O BREEDER:

The same mathematical model has been applied to evaluate the diffusive inventory in Li2O breeder tubes.

The computer program is in a general form and can work well for every solid breeder material.

The tubes considered have 2.5 cm as diameter and 100 cm as length.

For this calculation the considered diffusion coefficent for Li2O is the same used by /25/.

The computer results give to us the following results reported in table 3.

	INVENTORY (gr)		
ϕ cm	Solid Phase	Gas Phase	Total
2.5	241.2	4.1	245.3

Table 3

Werner et Al. found 572 gr using tubes with about 4cm of diameter.

Considering the diameter effect on diffusive inventory in γ-LiAlO2 case, this result seem to be in good agreement with /25/.

5) TRITIUM TRAPPING.

Tritium Trapping Inventory in the Breeder Volume:
Evaluation by Montecarlo Method.

a) Introduction

Let us assume that the reactions involved with tritium production in a γ-LiAlO2 blanket are : (1.1) and (1.2)
where n' is a low energy neutron, n is a high energy neutron and is a vacancy.
The migtating T ion can alloy an oxigen atom according to the reactions (1.3), so that a tritium atom is linked to the breeder material.
Moreover, the following reaction can take place:

$$2\,T_{Li} \longrightarrow Al_2O_3 + T_2O \qquad (5.1)$$

(see appendix).

In this case,the linked tritium is removed from the grains in the form of the species T2O.

The trapping inventory is joust the inventory of souch tritium atoms that remain linked as T_2 .

To evaluate the amount of T_2 ,T and T2O ,as a function of the reactor operation time,the trapping inventory must be calculated.

To this aim,a 2D Montecarlo code has been developed.

b) Description of the "MC2" code.

The tritium diffusion coefficent,D(T),the breeder lattice constant,the grain size and the tritium generation rate are the input data.

Two random cartesian coordinates are generated to identify the point where the (termalized) tritium atom is produced inside the grain.

The atom then moves for a length that is a mean free path in the system,the direction being random in the range (0, $\pi/2$) because of the simmetry of the system.

The time that the atom needs to reach a new point far from the starting one is $\tau = \lambda^2/D(T)$. After this time,the T atom can react if it meets a vacancy.

The reaction probability increases with the reaction operation time according to:

$$P_r(t) = \frac{\int_0^t B\,dt}{N_{tot}} \qquad (5.2)$$

where B is the tritium (or vacancy) source therm (atoms/cm^3 sec), and Ntot is the total number of cells for unit of volume (i.e.

γ-LiAlO2 molecules).

If the condition:

$$P_r(t) > \rho' \qquad (5.3)$$

is satisfied,the reaction (1.3) takes place, being ρ' a pseudorandom number uniformly distributed in the system.

If the reaction (7.3) takes place,the "MC2" code stores the coordinates where the reaction occurred and checks if an other previously generated is close is close to the considered point ("MC2" takes into account the reciprocal molecular position for the reaction (5.1)).

If this condition is satisfied, a T2O molecule is formed and two tritium atoms are removed as diffusig species.

The computation is repeated for six tousand tritium atoms with increasing time.

In table 3 the results so obtained are reported for tubes close and far from the canister nose zone,respectively.

We see that,e.g. after 18 months (60 Kg of T produced) a trapping inventory of about 3.5 Kg is accumulated in the total breeder volume (1E+8 cm^3 for tube diameter of 2.5 cm)of the"IL MANTELLO" blanket;This inventory results to be much Higer,by more than an order of magnitude,than the diffusive one (0.1 Kg) .

The "MC2" code has been extended to the case :

$$Li T_{Li} + Li Al O_2 \longrightarrow Li Al_5 O_8 + 2 T_2 O \qquad (5.4)$$

being (5.4) an other termodinamically possible reaction.

(C.Ciavola,ENEA CRE CASACCIA Rome,private communication).

TABLE 4

Cold Tubes

(350°C, $B=5\times10^{11}cm^{-3}s^{-1}$)

Time (months)	% linked T	$\%T_2O$	%diffusing T^+
1	0.1	0	99.9
7	1	12	87
9	1.8	15.2	83
11	1.73	17.07	81.2
15	2	18	80
18	2	19	79

Hot Tubes

(400°C, $B=5\times10^{12}cm^{-3}s^{-1}$)

0.5	3.31	25	71.6
1	5.22	25.4	69.9
6.5	5	55.9	39.1
9	4.9	62.1	33
12	5	70	25
13	5.5	71	23.5
16	6	72	22
18	6	72.3	21.7

6) PERMEATION FLUX THROUGH THE HT-9 TUBE WALL.

To avoid the tritium passing into the main helium coolant stream,needs to have a tritium barrier on the external wall of the breeder tube.

At low temperature the tritium permeability through the metal is low.When the temperature increases,the metals are not able to avoid the tritium permeation,therefore the system needs a strong barrier souch as SiC glass or oxide film /2/.

The permeability for SiC and Al2O3 can be calculated through:

$$P_e^{SiC} = 3.36 \cdot 10^{-8} \exp\left[\frac{-93\ \text{kcal/mol}}{R_o T\ (^\circ K)}\right] \left(\text{std cm}^2/\text{sec ATM}^{1/2}\right) \qquad (6.1)$$

and

$$P_e^{Al_2O_3} = 6.6 \exp\left[\frac{-53\ \text{Kcal/mol}}{R_o T(^\circ K)}\right] \left(\text{std cm}^2/\text{sec ATM}^{1/2}\right) \qquad (6.2)$$

The siliconized SiC glass seems to be the most attractive material for tritium permeation barriers,not only for the lower permeability value,but also for the behaviour unde neutron irradiation.

However these systems need extensive experimental study to make the best choise.

The permeability of tritium in HT-9 /24/ is:

$$P_e^{HT-9} = P_e^{\circ} \exp\left[-Q_{pm}/R_o T\right] \quad \text{cm}^3/\text{cm sec ATM}^{1/2} \qquad (6.3)$$

and the tritium flux through the HT-9 wall is described with the following equation:

$$J = \frac{P_e^{HT-9}}{d} \left(P_1^{1/2} - P_2^{1/2} \right) \qquad (6.4)$$

being:

d = wall thickness

P_e^o = 4.78E-3

Qpm = 12.000 cal/mol

$P_{1,2}$ = partial T2 pressure across the wall

R = 82.05 gas constant

T = K temperature

The calculation are made by using the average tritium concentration in gas phase,iside tubes,obtained with the computer model for all the cases:
LiAlO2 breeder with 2.5 and 4 cm of diameter tubes and LiO breeder with 2.5 cm of diameter.

a)LiAlO2

$$\phi = 2.5\ cm \qquad \bar{C}^{T}_{GAS} = 5 \cdot 10^{-8}\ mol/cm^3$$

$$\phi = 4\ cm \qquad \bar{C}^{T}_{GAS} = 2.5 \cdot 10^{-8}\ mol/cm^3$$

The He concentration is obtained by the well known formula:

$$P V_q = Z n R_o T \qquad (6.5)$$

being V_q the pores volume and Z=1 the compressibility factor.

$T = 673\ ^{\circ}K$

$P = 50$ ATM

$C_{He} = 4.8 \cdot 10^{-3}\ mol/cc$

The tritium molar fraction will be:

$$\phi = 2.5\ cm \qquad X_T = 5.20 \cdot 10^{-6}$$

$$\phi = 4\ cm \qquad X_T = 1.04 \cdot 10^{-5}$$

Introducing an SiC barrier the flux expression becames:

$$J = \frac{1}{R_{tot}} S_{tube} \left(P_1^{\frac{1}{2}} - P_2^{\frac{1}{2}} \right) \tag{6.6}$$

$P_2 \simeq 0$

$$J = \frac{1}{R_{tot}} S_{tube} \left(P_1^{\frac{1}{2}} \right) \tag{6.7}$$

Stube is the HT-9 tube external surface

$$R_{tot} = R_{HT-9} + R_{SiC} = \frac{d}{P_e^{HT-9}} + \frac{d'}{P_e^{SiC}} = 4.76 \cdot 10^{-33}$$

being d'the SiC thickness

$d = 0.1\ cm$

$d' = 1.10^{-4}\ cm$

Then the tritium losses are:

$\phi = 2.5\ cm \quad 2.66 \cdot 10^{-33}\ cm^3/sec \times Tube$

$\phi = 4\ cm \quad 6.01 \cdot 10^{-33}\ cm^3/sec \times tube$

By using again the gas equation:

$$P V_c = n R_o T$$

we get: 9.42E-9 T2 mol/cc,then

2.50E-41 mol/sec*tube ($\phi = 2.5$ cm)

5.66E-41 mol/sec*tube ($\phi = 4$ cm)

These quantities are neglectible if compared with the tritium production rate for each tube

2.93E-9 mol/sec*tube

7.51E-9 mol/sec*tube

b) Li2O

Considering again,for this case,tubes with 2.5 cm of diameter it results that the tritium flux at tube wall with an SiC barrier is:

3.60E-41 mol/sec*tube (ϕ = 2.5 cm)

the tritium production rate for tube is:

1.89E-9 mol/sec*tube

and withouth the Sic barrier the tritium flux should be:

6.58E-10 mol/sec*tube

7) TRITIUM PERMEATION FROM THE PLASMA TO FIRST WALL COOLANT SYSTEM.

An analysis has been performed to evaluate the flux of the implanted tritium through the first wall.

The approach is found on the model described in/26/.

The tritium amount passing in the wall is a fraction α of the radiation flux $\psi = 10^{16}$ (atom/cm^2 sec) which can be consedered constant or changing during the reactor working time.

The tritium mass transfer is controlled by diffusion,taking into account that on both sides of the first wall a reconbinative process takes plzce.

The recombination reaction rate β is proportional to the square of the time dependent tritium concentration on the wall surfaces.

$$\beta = \Gamma k_i(T) C_T^2 \qquad (7.1)$$

Being Γ the roughness factor and k_i the release rate constant.

We assume /26/ :

$$\Gamma k_i = 1.4 \cdot 10^{-19} \exp(-8.6/k_0 T) \ (\text{molec/cm}^2/\text{mm}^2\text{sec}) \qquad (7.2)$$

Then the equation describing the mass transfer phenomena is:

$$\frac{\partial C_T(x,t)}{\partial t} = D^{HT-9} \frac{\partial^2 C_T(x,t)}{\partial x^2} \qquad (7.3)$$

Being D^{HT-9} the tritium diffusion coefficent in HT-9, and C_T the tritium concentration across the first wall thickness.

The equation (7.3) must be solved with the following moving boundary conditions.

$$\alpha \psi = 2\sigma K_i(T) C_T^2(0,t) - D^{HT-9} \left.\frac{\partial C_T}{\partial x}\right|_{x=0} \qquad (7.4)$$

and

$$0 = 2\sigma k_i(T) C_T^2(X_L,t) + D^{HT-9} \left.\frac{\partial C_T}{\partial x}\right|_{x=\Delta} \qquad (7.5)$$

The model has been solved numerically by means of the following scheme:

$$C_T(i,j+1) = C(i,j) + D^{HT-9}\frac{\Delta t}{\Delta x^2}\left(C_T(i+1,j) - 2C_T(i,j) + C_T(i-1,j)\right) \qquad (7.6)$$

$$C_T(1,j) = \left(1 - \sqrt{1 + \frac{4A(i)\Delta x}{D^{HT-9}}\left[C_T(2,j) + \frac{F\Delta x}{D^{HT-9}}\right]}\right) \Big/ \left(2A(i)\Delta x / D^{HT-9}\right) \qquad (7.7)$$

$$C_T(M,J) = \left(-1 + \sqrt{1 + \frac{4\,A(M)\,\Delta x}{D^{MT-9}}\left[C_T(M-1,J)\right]}\right) \Big/ \left(2\,A(M)\,\Delta x / D^{MT-9}\right) \qquad (7.8)$$

Being $A(I) = 2\pi K_i$

The equations (7.7) and (7.8) can be easly derived from the boundary conditions (7.4) and (7.5).

The calculation results are reported in table 5.

TIME (sec)	TRITIUM FLUX (gr/cm^2 sec)
100	4.699e-26
200	1.359e-23
300	3.46 e-22
400	3.33 e-21
500	1.89 e-20
600	7.71 e-20
700	2.498e-19
800	6.849e-19
900	1.65 e-18
1000	3.61 e-18

TABLE 5

APPENDIX

Under neutron irradiation conditions,vacancies and poin defect are produced.In this approach both vacancies and defect arre assumed to be produced uniformly in time and homogeneously in space. Diffusion of point defect in irradiated materials is governed by the continuity equation /27/ :

$$\frac{\delta c_v}{\delta t} = S(a,t)_v - \alpha C_v C_d - div J_v$$

(1.a)

$$\frac{\delta c_d}{\delta t} = S(a,t)_d - \alpha C_v C_d - div J_v$$

Being d and v defects and vacancies respectively,S the production rate, a the position vector,t the time, J the flux, and $\alpha C_v C_d$ the mutual recombination term.

In this paper the trapping de-trapping phenomena are analized by means of the montecarlo method.

This approach allow us to obtain a trapping inventory evaluation without solving the eqations (1.a) .

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LIST OF SYMBOLS

A_o	Avogadro number
c	tritium concentration (moles/cm^3)
B/A_o	tritium generation rate (moles/cm^{3}s)
P_i	isotopic ratio
$\mathcal{W}$	molar weight of the breeder (e.g. γ-$LiAlO_2$)
r	radial coordinate (cm)
z	axial coordinate (cm)
D	diffusion coefficient (cm^2/s)
X	tritium molar fraction
T	temperature (°K)
E	energy (eV)
p	pressure (Kg/cm^2)
P_e	permeability (STD cm^3/s cm^2 atm$^{1/2}$)
R_o	gas constant
$\delta_{1,2,3}$	thickness (cm)
R	breeder tube radius (cm)
r_i	purge flow pipe radius (cm)
W	purge flow rate cm^3/s
V	tube volume (cm^3)
S	purge flow pipe surface (cm^2)
σ_i	cross-section (cm^2)
ϕ	neutron flux (cm^{-2}s-1)
ε	porosity of the solid breeder
ρ	density of the solid breeder (g/cm^3)
$D_{breeder}$	breeder diffusion coefficient*
q	tortuosity ratio
D_{AB}	T_2 diffusion coefficient into He
$\mu_{1,2}$	molecular weights

ζ/K_2 form factor for non-circular capillary

m interstitial average hydraulic radius

v_{th} average molecular velocity

c' tritium concentration in grains

R' grain radius

I_{gas} inventory into the pores

I_g inventory into the grains

D' solid grains diffusion coefficient

r' grain radial coordinate

$B' =$ $B/(1 - \varepsilon)$ nuclear tritium production rate in grains

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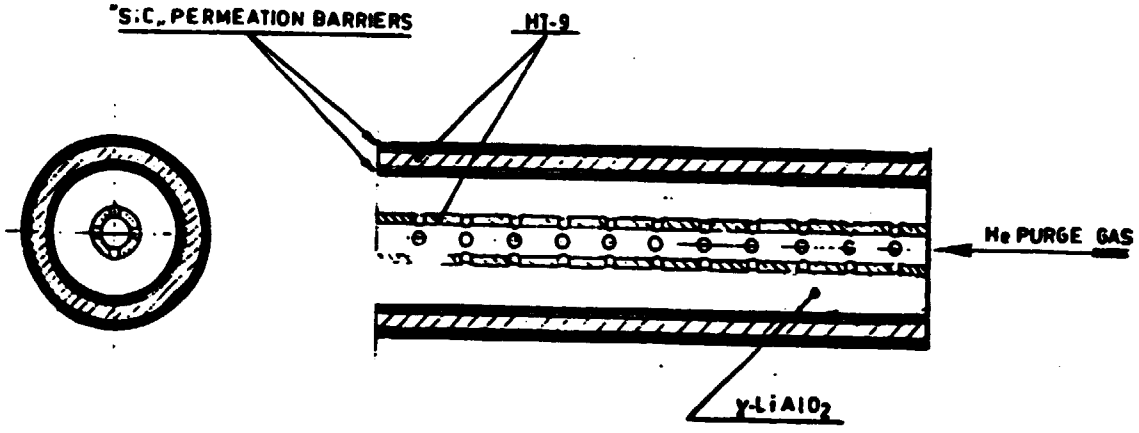


Cross section of a typical breeder element tube

FIG. 1

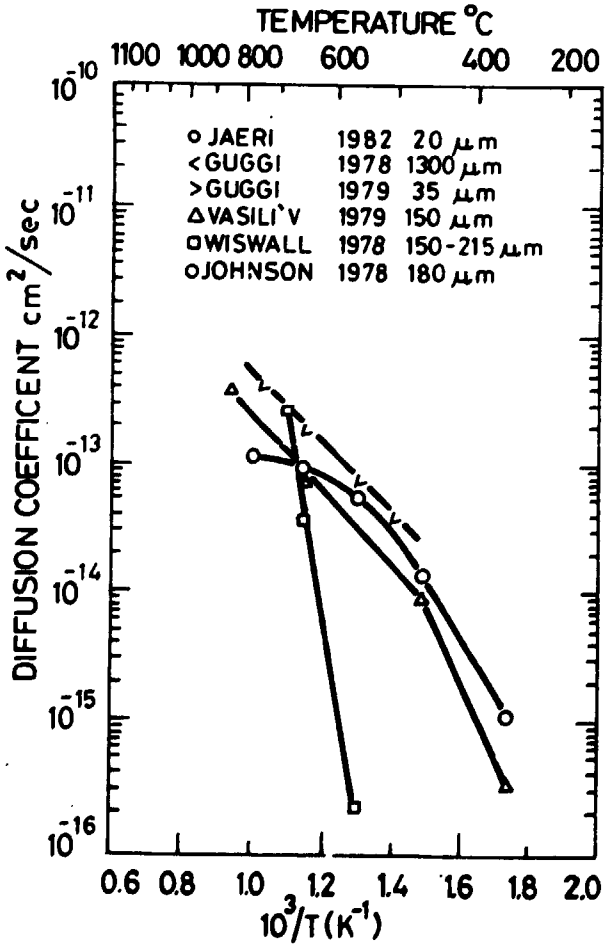
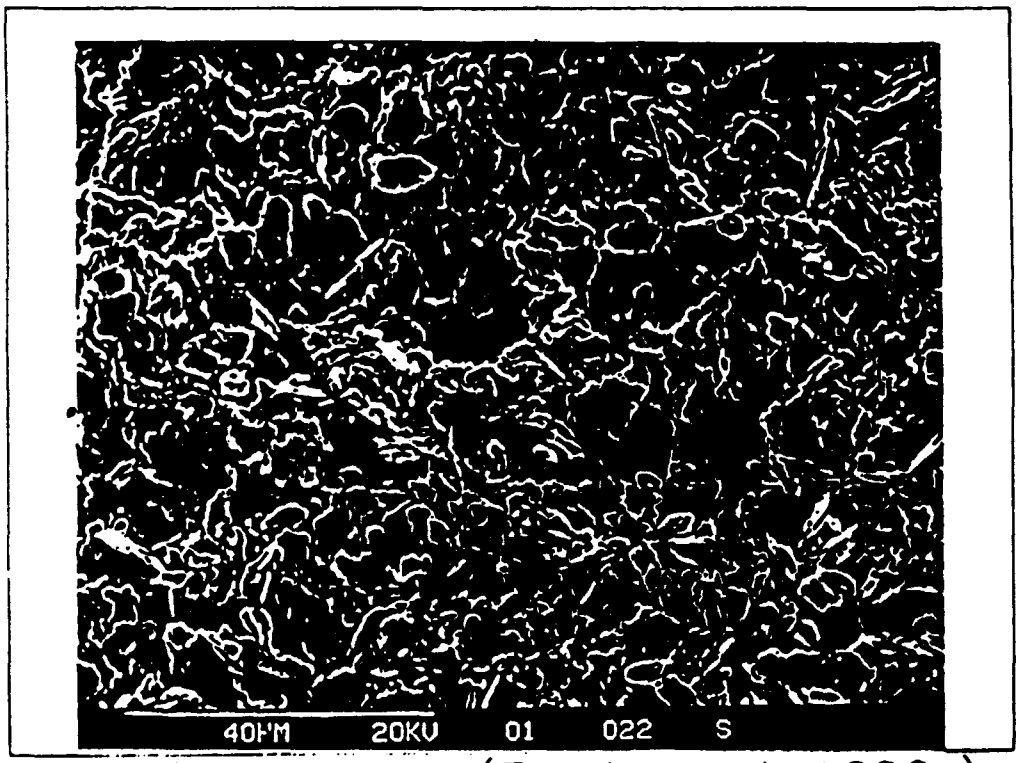


FIG. 2

ENEA C.R.E.-Casaccia
TIB-CHI

FIG.3

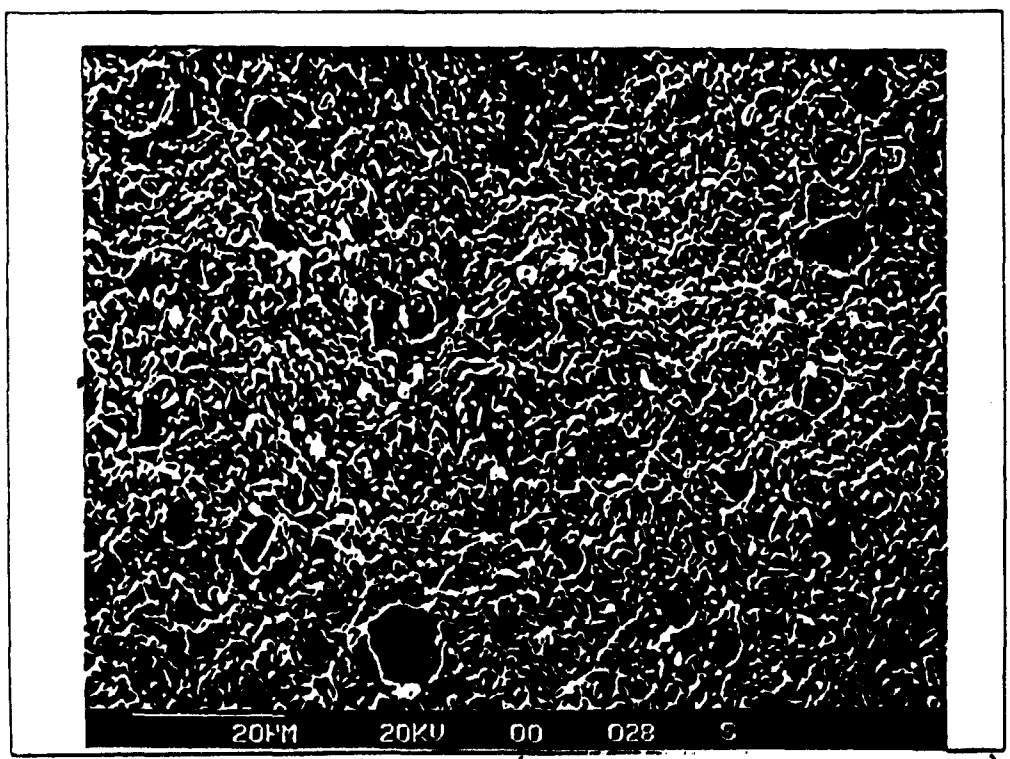


SAMPLE : P-1 (Fractograph 1000x)

90% of T.D.- Grain size 0.5-5 microns

ENEA C.R.E.-Casaccia
TIB-CHI

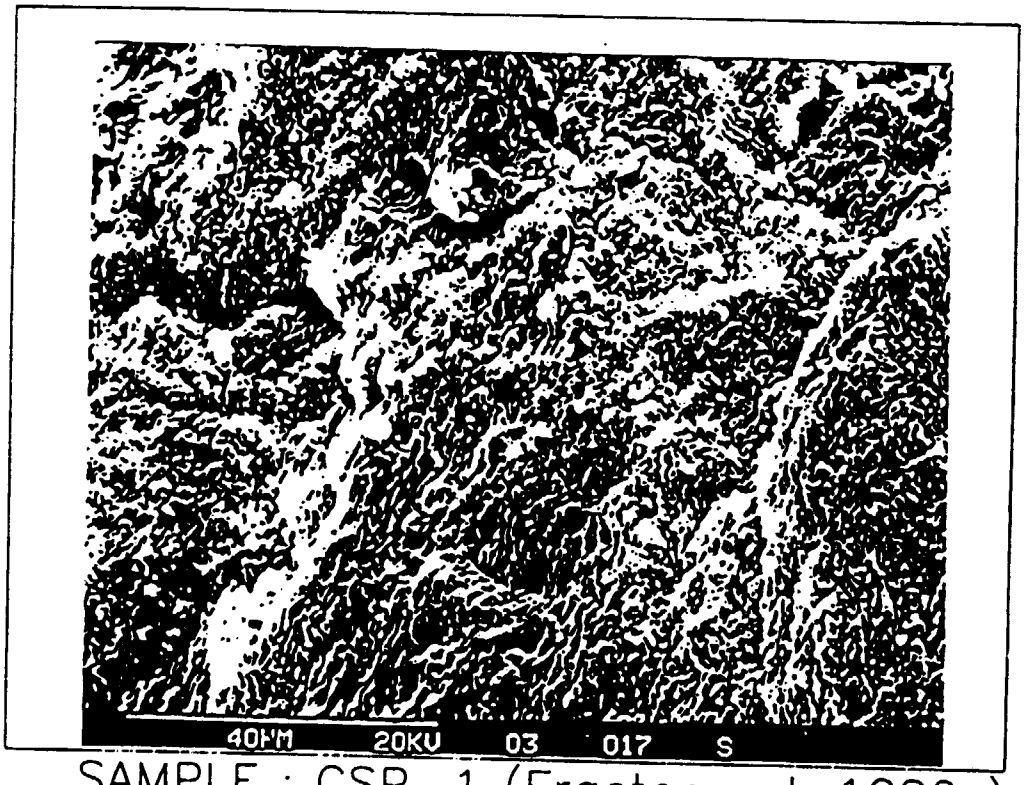
FIG.4



SAMPLE : SSD-1 (Fractograph 1000x)

83% of T.D.- Grain size 1-3 microns

FIG.5



SAMPLE : GSP-1 (Fractograph 1000x)

86% of T.D.- Grain size 0.1-2 microns

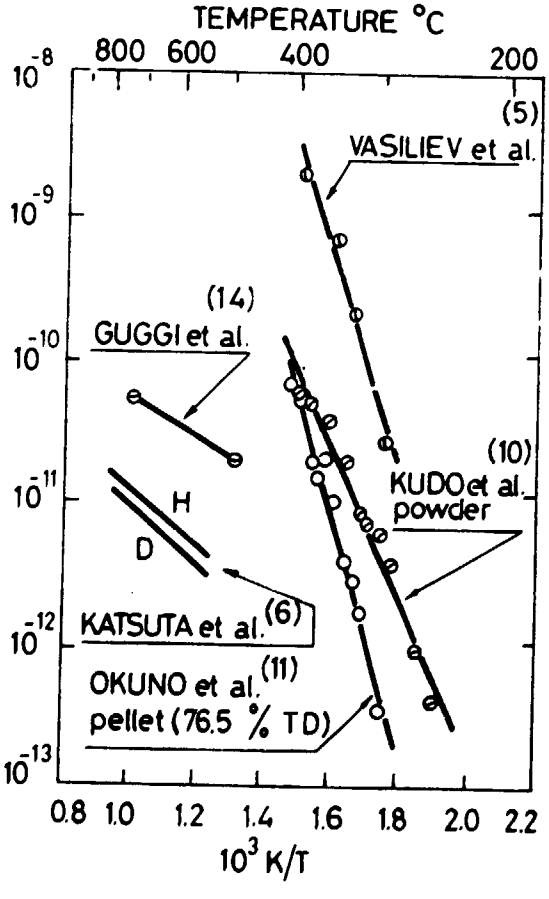


FIG. 6

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