a is a factor related to the nonlinear transient, k_{nl} being a dimensionless nonlinear rate constant and t_c the nonlinear transient duration period. The functions Φ are given by

$$\Phi_1 = 2\, a\, \alpha Dt - Da^2 t$$
$$\Phi_2 = (a - \alpha)\,(Dt)^{1/2}$$
$$\Phi_3 = \alpha\,(Dt)^{1/2}\,. \quad (2)$$

When Φ_3 becomes numerically equal to 2, the time dependence vanishes, and the compositionally disturbed layer approaches a limit, given by

$$\text{Area of CD} = \pm\,(C_{oi} - C_{\infty i})/2\,\alpha\,. \quad (3)$$

The additional significant factor is the limiting extent of composition disturbance given by Eq. (3). For the sheath specimen in question, $t_c << 1$, so that the nonlinear transient terms involving Φ_1 and Φ_2 vanish, and the linear corrosion rate ($2\,\alpha D\rho$) measures 167 mg/dm^2-mo. Using this value with Eq. (1), the calculated value of α is 447, and the limiting disturbed mass of Cr, for instance, is given as

$$\rho\,(\text{Area Cr CD}) = \frac{\rho\,(0.191 - 0.148)}{2 \times 447} = 385\ \text{mg/dm}^2\,,$$

where ρ = alloy phase density, 8×10^6 mg/dm^3, and 0.148 = C_{oi} for Cr, as compared with the value of 100 mg/dm^2 (Table I) obtained in the first 1044 h.

E. G. Brush
S. Leistikow
W. L. Pearl

Atomic Products Division
General Electric Company
175 Curtner Avenue
San Jose, California, 95125

BURNUP UNITS

Dear Sir:

Various units are used to express the amount of energy extracted from a given amount of reactor fuel. The useful unit for this, however, depends on the particular property in question. Traditionally, units of fission/cm^3, MWD/T, and % burnup have been used. A volumetric unit (e.g., f/cm^3) is frequently used, in that volumetric retention of volatile fission products is thought to be related to fuel swelling phenomena. Such a

TABLE I

Burnup Units Equivalent to 1 gf/cm^3 [a]

	Oxides [b]	Carbides [c]	Solid Metals [d]	Liquid Metals [e]
gf/cm^3	1.0	1.0	1.0	1.0
gf/cm^3 smeared [f]	0.90	0.95	0.80	0.95
% BU of heavy atoms	12.17	9.09	6.54	25.0
MWD/metric ton heavy atoms	114 100	85 200	61 200	234 200
MWD/long ton heavy atoms	115 900	86 600	62 200	238 000
MWD/short ton heavy atoms	103 500	77 300	55 500	212 500
MWD/metric ton fuel	100 600	81 100	55 100	100 500
MWD/long ton fuel	102 200	83 000	56 000	102 100
MWD/short ton fuel	91 300	73 600	50 000	91 200
f/cm^3	25.3×10^{20}	25.3×10^{20}	25.3×10^{20}	25.3×10^{20}
f/cm^3 smeared	22.8×10^{20}	24.0×10^{20}	20.2×10^{20}	24.0×10^{20}

[a] Based on 199 MeV/fission = 3.2×10^{-17} MWsec/fission.
= 8.1×10^4 MWsec/gf = 0.937 MWD/gf.

[b] Oxides are taken to have a density of 9.316 g/cm^3 (85% of theoretical)
smeared density of 8.384 g/cm^3 (90 vol %)

[c] Carbides are taken to have a density of 11.56 g/cm^3 (85% of theoretical)
smeared density of 10.98 g/cm^3 (95 vol %)

[d] Solid metals are taken to have a density of 17 g/cm^3 (90 wt % heavy atoms)
smeared density of 13.6 g/cm^3 (80 vol %)

[e] Liquid metals are taken to have a density of 9.32 (4 g Pu/cm^3 fuel)

[f] The "smeared density" is the ratio of fuel mass-to-total internal volume of the fuel element, including bond volume. The smeared densities used are illustrative and are not associated with specific designs.

unit has several disadvantages. The numerical magnitudes (e.g., 2×10^{21}) are inconvenient and not easily visualized and are subject to misunderstanding ($2 \times 10^{21} = 20 \times 10^{20}$). Further, the relationship of such a unit to parameters of economic or resource interest is not readily apparent in terms of other commonly used factors.

The other common units (MWD/T; % burnup) are not thought to be related to materials capability (e.g., 100 000 MWD/T in oxides is equivalent in volumetric fission-product generation to ≅ 60 000 MWD/T in metals). The MWD/T unit is also ambiguous as to whether the denominator is long, short, or metric ton; and as to whether the mass quoted is a ton of the fuel material or of heavy atoms. A unit of MWD/kg is more convenient but does not avoid all of the above problems.

It is proposed that the unit "grams fissioned/cm^3 fuel" is preferable. While this is not a perfect unit, it avoids some of the obvious difficulties referred to above. Namely, it is a volumetric unit, and thus is presumably related to burnup capability; and, the only ambiguity is whether the bond volume is included or not. In addition, the magnitude is convenient, in that a common burnup goal is 1 gf/cm^3. This is related to % burnup by means of a density which is usually available.

Table I lists conversion factors for some of the more commonly used units.

W. H. Hannum

University of California
Los Alamos Scientific Laboratory
P.O. Box 1663
Los Alamos, New Mexico