

**Chapter 12**  
**Behavior of Solid Fission Products**  
**in Oxide Fuel Elements**

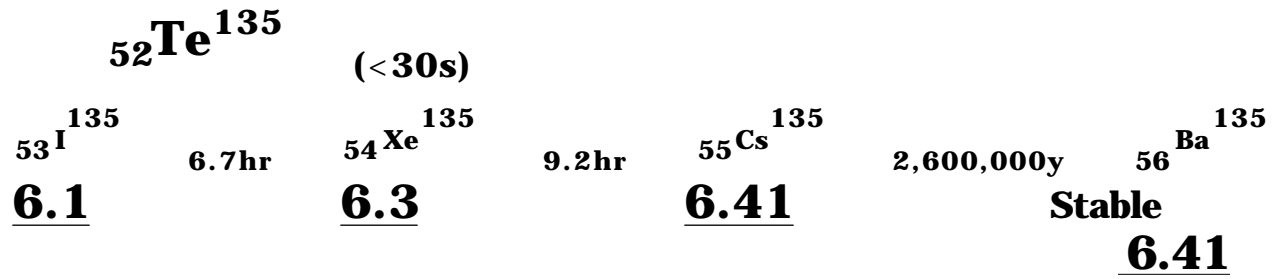
*Why are fission products so important?*

- 1.) They influence the availability of oxygen
- 2.) Their volume is different
- 3.) Fission gases like Xe and Kr escape increasing pressure in fuel
- 4.) Solid FP can change the thermal conductivity and melting point
- 5.) Gaseous FP can change the thermal conductivity of gas in gap.

-----  
*Since target burnups are 10%, we can have as much as 20% in FP in the fuel*  
-----

**12.1 Elemental Yield of Fission Products**  
**From nuclear physics;**

$$\begin{array}{ccc} & & Z \\ & & \text{(iy)}_{Z',M}^A \\ & & Z' \\ \text{(cy)}_{Z,M}^A & = & \text{Independent Yield} \end{array}$$



**Chain Yield**  $Y_A = (\text{cy})_{zMA}$

**Three Things effect the final distribution;**

- 1.) Fissile isotope (note Pu shift)
- 2.) Neutron energy
- 3.) Neutron flux (burnout)

*See figures, 12.2 and 3.16*

**Fission Product yield**

**Elemental Yield**  $Y_i = \frac{1}{F t_{\text{irr}}} N_{i,A}$

**Fission Rate**      **Concentration of element i resulting from the decay chain at mass # A**

**Note also;**

$$Y_i = 2$$

**One is not usually interested in the isotopes, but rather the elements. See Olander for a calculation of**

$$Y_{Cs} = y_{133} + y_{135} + y_{137} \quad (\text{figure 12.1})$$

$$N_{Cs^{133}} = y_{133} \dot{F} t_{irr} \left[ 1 - \frac{\{1 - \exp[-\lambda_{Xe} t_{irr}]\}}{\lambda_{Xe} t_{irr}} \right]$$

**Since  $t_{1/2} = 5.3$  d for  $Xe_{133}$**

$$N_{Cs^{133}} \approx Y_{133} \dot{F} t_{irr} \quad \text{for times} > 5 \text{ days}$$

See table 12.1

## **Importance of Various FP's**

- Zr + Nb**
  - Zr can combine with  $O_2 \rightarrow ZrO_2$
  - Zr, Nb can take C away from UC
- Y + rare earths** • High crosssections, oxides
- Ba + Sr** • Sr radioactivity, zirconates
- Mo, Ru, Tc** • Volatile oxide, oxygen buffer
- Rh, Pd** • Reprocessing
- Cs + Rb** • Volatile, corrosive
- I + Te** • I is volatile, corrosive
- Xe + Kr** • Gases, pressure on cladding, thermal conductivity of gap

**Fast <sup>235</sup>U**

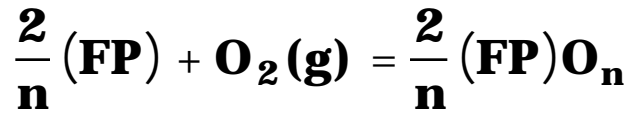
**Fast ( Mixed Oxide)**

<b>1.) Y + Rare Earths</b>	<b>Y + Rare Earths (0.493)</b>
<b>2.) Zr + Nb</b>	<b>Noble metals (0.456)</b>
<b>3.) Noble Metals</b>	<b>Xe + Kr (0.25)</b>
<b>4.) Xe + Kr</b>	<b>Zr + Nb (0.219)</b>
<b>5.) Mo</b>	<b>Cs + Rb (0.209)</b>
<b>6.) Cs + Rb</b>	<b>Mo (0.206)</b>
<b>7.) Ba + Sr</b>	<b>Ba + Sr (0.109)</b>
<b>8.) I + Te</b>	<b>I + Te (0.07)</b>

### 12.3

## Chemical State of Fission Products in Oxide Fuels

***Big question is, Do the FP's form Oxides?***



***Valence of FP Cation = 2n***

**Key is the oxygen partial pressure**

-----

**The oxygen partial pressure at which the element and oxide coexist comes from the Law of Mass Action**

$$p_{\text{O}_2} = \exp \frac{G_{\text{FP}}^\circ}{RT}$$

**where  $G_{\text{FP}}^\circ$  = Free energy of formation of FP oxide at T, per mole of oxygen**

**If G is positive or only slightly negative, it will take a high  $p_{\text{O}_2}$  from the fuel to cause an oxide to form.**

**If G is strongly negative, then even small oxygen partial pressure from the fuel will form oxide**

The oxides from  $\text{UO}_{2\pm x}$  have oxygen potentials ranging from;

-170 kJ/mole (Hyper)

[Figure 11.12]

to - 670 kJ/mole (Hypo)

---

Figure 12.6

Figure 12.7

*If the free energy of formation of the oxide is more negative than the fuel, then the oxide will form*

*If the free energy of formation of the oxide is less negative than the fuel, then the elemental form will remain.*

---

Note the case for Mo:

The  $G_{FP}$  is close to stoichiometric fuel

Hypo - Mo Metal

Hyper-  $\text{MoO}_2$

# Mo Can Buffer Oxygen Content

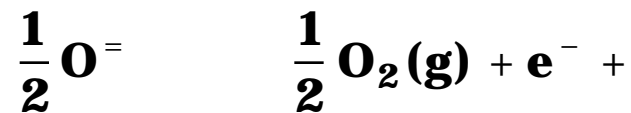
see Table 12.3

## How Do FP Oxides Actually Fit into the Oxide?

**When oxidation state = 4, no problem!**

***When sesquioxides form,  $M_2O_3$ , and charge is +3, then electric neutrality is required;***

**1.) Produce oxygen vacancy (fig. 12.8b)**



**2.) U atoms oxidize to  $U^{+5}$  or  $U^{+6}$  (fig. 12.8c)**

