

#2

原子力と放射線の物理  
 第一歩  
 PHYSICS OF  
 NUCLEAR POWER & RADIATION  
 (FIRST STEP)

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#2-01

Structure of Atom & Nuclear  
 (原子と原子核の構造)

Crystal (結晶)

Atom (原子)  
 (nuclear & electron)  
 (原子核と電子)

Nuclear model by N.Bohr (~1915)

proton Neutron

Hydrogen  
 P : 1  
 N : 0  
 (A=1)

Helium  
 P : 2  
 N : 2  
 (A=4)

Uranium-235  
 P : 92  
 N : 143  
 (A=235)

Nuclear

#2-3

Weights & Dimensions(大きさと重さ)

	amu (atomic mass unit)	$m_e$	(gram)
nuclear of carbon	12		$9.1 \times 10^{-28}$
proton	1.0073	1836.1	
neutron	1.0087	1838.6	
electron	$5.49 \times 10^{-4}$	1	

Radius of Nuclear  
 $R = r_0 A^{1/3}$   $r_0 = 1.5 \times 10^{-13}(\text{cm})$

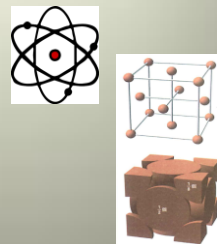
#2-04

Nuclear / Metal Crystal  
 (原子核 / 金属結晶)

Al (aluminum)

Nuclear Radius of aluminum  
 (原子核の大きさ)  
 $R = 1.5 \times 10^{-13} \times A^{1/3} (\text{cm})$   
 $= 4.5 \times 10^{-6} (\text{nm})$

lattice constant of Al metal  
 (結晶の大きさ)  
 (face centered cubic lattice)  
 $a = 0.4049 (\text{nm})$   
 atom size in crystal (Al)  
 $r = 0.143 (\text{nm})$



#2-05

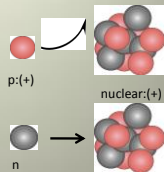
Nuclear Reaction (核反応)

reaction of radiation with nuclear(原子核と放射線の反応)  
 charged particle : electron, proton, alpha particle  
 neutron

neutron reactions(中性子の反応)  
 原子炉で重要  
 no electric charge

elastic scatter  
 in\_elastic scatter  
 absorption

capture(n, $\gamma$ )  
 (n, $\alpha$ ),(n,p),....  
 fission



#2-06

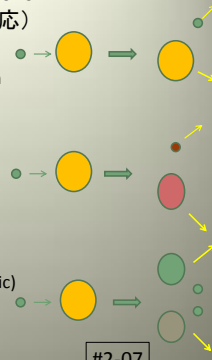
neutron reactions  
 (中性子の反応)

neutron emission (中性子放出)  
 change of neutron energy, direction

neutron capture (中性子捕獲)  
 no neutrons after reaction  
 (n, $\gamma$ )  
 (n,p),(n, $\alpha$ )


fission (核分裂)  
 multiplication of neutrons  
 neutron energy, direction(isotropic)

transport of neutron (中性子輸送)




#2-07

### Neutron Reaction Cross Section (中性子反応断面積)



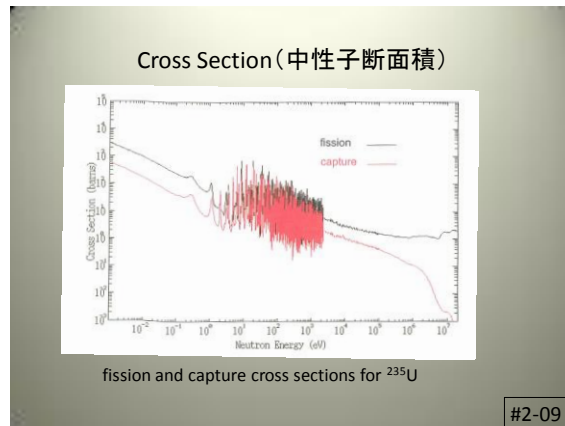
nuclear radius(simple model by experiment)  
 $R = 1.5 \times 10^{-15} \times A^{1/3} \text{ (m)}$

U-235  
 $A = 235$   
 $R \sim 9 \times 10^{-15} \text{ (m)}$   
 $S \sim 2.5 \times 10^{-28} \text{ (m}^2\text{)}$



unit of reaction cross section  
 barn :  $1 \text{ barn} = 10^{-28} \text{ m}^2$

#2-08

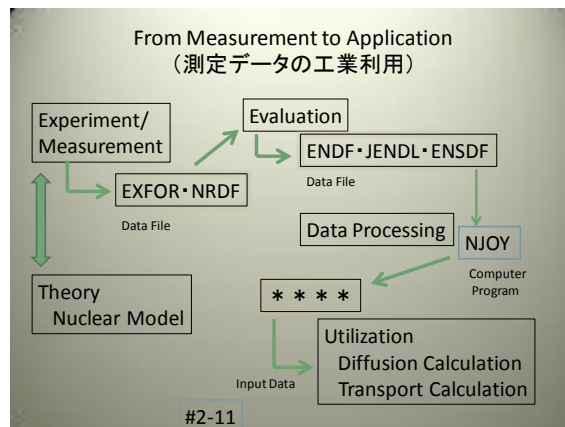


### Evaluated Nuclear Data File (評価済核データファイル)

Nuclear Data (核データ)  
 Nuclear Structure  
 Half-Life  
 Decay Scheme  
 Cross-section

Use (利用)  
 Industry : Nuclear Reactor, Fusion,  
 Nuclear Conversion  
 Nuclear Medicine, Physics

#2-10



### Evaluated Nuclear Data File (ENDF)

ENDF : Name of Format  
 : Name of U.S.A. Library

	Publish		Number of Nuclear
ENDF/B-IV.8	2001.10	U.S.A.	329
JENDL-3.3	2002.5	JAPAN	337
JEFF-3.0	2002.4	NEA	340

Data in ENDF  
 $\sigma, d\sigma/d\Omega, d\sigma/dE, d\sigma/d\Omega dE$ , Resonance Parameter  
 Fission Neutron, Fission Product,  $co\_variance$

#2-12

### ENDF (Resonance Parameter of <sup>27</sup>Al)

```

11325 0 0 0
1.302700+4 2.675000+1 0 0 1 01325 2151 1
1.302700+4 1.000000+0 0 0 1 01325 2151 2
1.000000+5 2.100000+5 1 2 0 01325 2151 3
2.500000+0 5.098000+1 0 0 3 01325 2151 4
2.676810+1 0.000000+0 0 0 42 11325 2151 5
3.479500+2 2.000000+0 3.100280+3 3.000000+3 2.300000+0 0.000000+0 0.125 2151 6
8.729500+4 5.000000+0 1.051100+4 1.052000+4 2.100000+0 0.000000+0 0.125 2151 7
1.421000+5 3.000000+0 1.749510+4 1.749000+4 5.100000+0 0.000000+0 0.125 2151 8
2.020000+5 2.000000+0 1.110600+4 1.100000+4 6.000000+0 0.000000+0 0.125 2151 9
2.816000+5 1.000000+0 1.100270+4 1.300000+4 2.700000+0 0.000000+0 0.125 2151 10
3.887000+5 2.000000+0 1.602900+3 1.600000+3 2.900000+0 0.000000+0 0.125 2151 11
4.895000+5 2.000000+0 6.646700+3 6.960000+3 8.700000+0 0.000000+0 0.125 2151 12
2.676810+1 0.000000+0 1 0 72 11325 2151 13
3.910000+1 1.000000+0 1.778000+1 1.768000+1 7.100000+3 0.000000+0 0.125 2151 14
1.375700+1 2.000000+0 2.704000+3 2.700000+3 4.900000+0 0.000000+0 0.125 2151 15
1.388000+5 4.000000+0 4.200000+3 4.200000+3 6.000000+1 0.000000+0 0.125 2151 16
2.127000+5 5.000000+0 8.898900+3 8.980000+3 9.600000+1 0.000000+0 0.125 2151 17
2.571600+5 2.000000+0 1.572000+1 1.500000+1 7.200000+1 0.000000+0 0.125 2151 18
2.156500+5 2.000000+0 2.550210+4 2.500000+4 2.200000+0 0.000000+0 0.125 2151 19
3.148000+5 1.000000+0 1.110560+4 1.100000+4 5.600000+0 0.000000+0 0.125 2151 20
3.738000+5 2.000000+0 2.503600+3 2.500000+3 3.600000+0 0.000000+0 0.125 2151 21
4.252000+5 2.000000+0 4.114800+4 4.100000+4 4.800000+1 0.000000+0 0.125 2151 22
5.283000+5 4.000000+0 1.000790+4 1.000000+4 7.900000+0 0.000000+0 0.125 2151 23
5.700000+5 3.000000+0 1.971920+4 1.970000+4 1.100000+1 0.000000+0 0.125 2151 24
5.870000+5 2.000000+0 1.963000+3 1.900000+3 3.000000+0 0.000000+0 0.125 2151 25
2.676810+1 0.000000+0 2 0 12 2125 2151 26
1.870000+5 5.000000+0 5.040700+1 5.000000+1 4.700000+0 0.000000+0 0.125 2151 27
4.780000+5 2.000000+0 4.965500+3 4.960000+3 5.500000+0 0.000000+0 0.125 2151 28
11325 2 99999
    
```

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### Fission (核分裂)

Fissile Nuclear  
 U-235  
 $\text{Pu-239} \leftarrow \text{U-238} + n$   
 $\text{U-233} \leftarrow \text{Th-232} + n$

Production of Thermal Energy  
 $\sim 200\text{MeV}(\text{FP}, \beta, \gamma, n)$   
 $\sim 2\text{MeV}/n$

Example(statistical)  
 ${}_{92}\text{U}^{235} + {}_0\text{n}^1 \rightarrow {}_{57}\text{La}^{147} + {}_{35}\text{Br}^{87} + 2{}_0\text{n}^1$

#2-14

### Fission Products(FP) & FP Decay (核分裂片と核分裂片の崩壊)

Fission Products Mass Distribution

Fission Products Decay Chain Including 135-Xe

#2-15

### Fission Neutron (核分裂で発生する中性子)

Number of Fission Neutrons ( $\nu$ ):  $2.5 \pm 0.1$   
 (核分裂ででてくる中性子の個数)  
 uranium-235 fission by slow neutrons

Fission Neutron Energy Distribution

#2-16

### Criticality (臨界)

Chain Reaction & Criticality (連鎖反応と臨界)  
 mean number of neutrons ( $\nu$ )  $\approx 2.5$

- \* absorbed in material(iron, water, control material ...)
- \* leak\_out from the system
- 1.0 absorbed U-235 introducing next fission

#2-17