THE MANHATTAN PROJECT

Cynthia C. Kelly, President of the Atomic Heritage Foundation (AHF)

On the occasion of the seventy-fifth anniversary of the bombing of Hiroshima, AHF published an expanded edition of its 2007 report.

CYNTHIA “CINDY” KELLY

- Baccalaureate in history at Wellesley, Masters in history at Yale.
- Brief positions teaching history.
- 1972-1974 Congressional aide.
- 1974-1993 Civil Service position at the Environmental Protection Agency. ”..learned to deal with technical people..”
- 1993-2000 Senior Executive Service at the Department of Energy’s Office of Public Accountability. Clinton administration.
- 2002 founded and assumed presidency of the Atomic Heritage Foundation (AHF). (her model, “Saving Private Ryan” 1998) First action was to thwart President G. W. Bush’s plans to freeze and diminish national parks and to get national parks at Manhattan Project sites funded. Note that AHF, like the Heritage Foundation, the Federalist Society, and other right-wing organizations is funded largely by the Koch Brothers, Philip Morris tobacco, and other similar organizations and individuals.

COURSE OUTLINE

- Ten sections of Kelly, approximately one for each OLLI meeting:
- 1.) A review of the subject of nuclear physics as available to the American and British in the 1930s to 1941. Pp 5-56=51 {12}
- 2.) The US and UK combined response to fission. Pp 57-96=39 {12}
- 3.) Groves and Oppenheimer. Pp 97-142=45 {18}
- 4.) The “secret cities” Oak Ridge, TN, Los Alamos, NM, and Hanford, WA., and also places within Dayton, OH. Pp 143-218=75 {29}
- 5.) Keeping it all secret with 150,000 Americans on the payroll and expenditures approaching 1% of the Gross Domestic Product. Pp 219-264=45 {16}
- 6.) Trinity, Alamogordo, NM, July 16, 1945. pp 265-304=39 {11}

COURSE OUTLINE CONTINUED

- 7.) “Little Boy” and “Fat Man” by air or the USS Indianapolis to Tinian, then on to Japan by B29, July and August 1945. pp 305-350=45 {12}
- 8.) The public response. 351-408=57 {13}
- 9.) Living with the bomb. Pp 409-450=41 {8}
- 10.) Seventy-five years later. Pp 451-488=37 {20}
- Chronology pp 491-495
- Biographies pp 496-505
- NOTE: Preface includes invitations to three websites that permit access to hundreds of interviews and the ability to locate the roles of particular MED personnel, over 350 interviews with scientists and SED personnel and hundreds of few-minute-long videos. (www.atomicheritage.org, www.mahattanprojectvoioces.org , www.RangerInYourPocket.org) There is also a plea by Kelly for preservation of MED relics and an historical commentary by Richard Rhodes (1937-). C-SPAN’s site has seven interviews with Kelly over the years. Kelly served as an advisor to the studio that Filmed “Oppenheimer” and some scenes in her book and the film match.

KELLY'S EARLY CHRONOLOGY

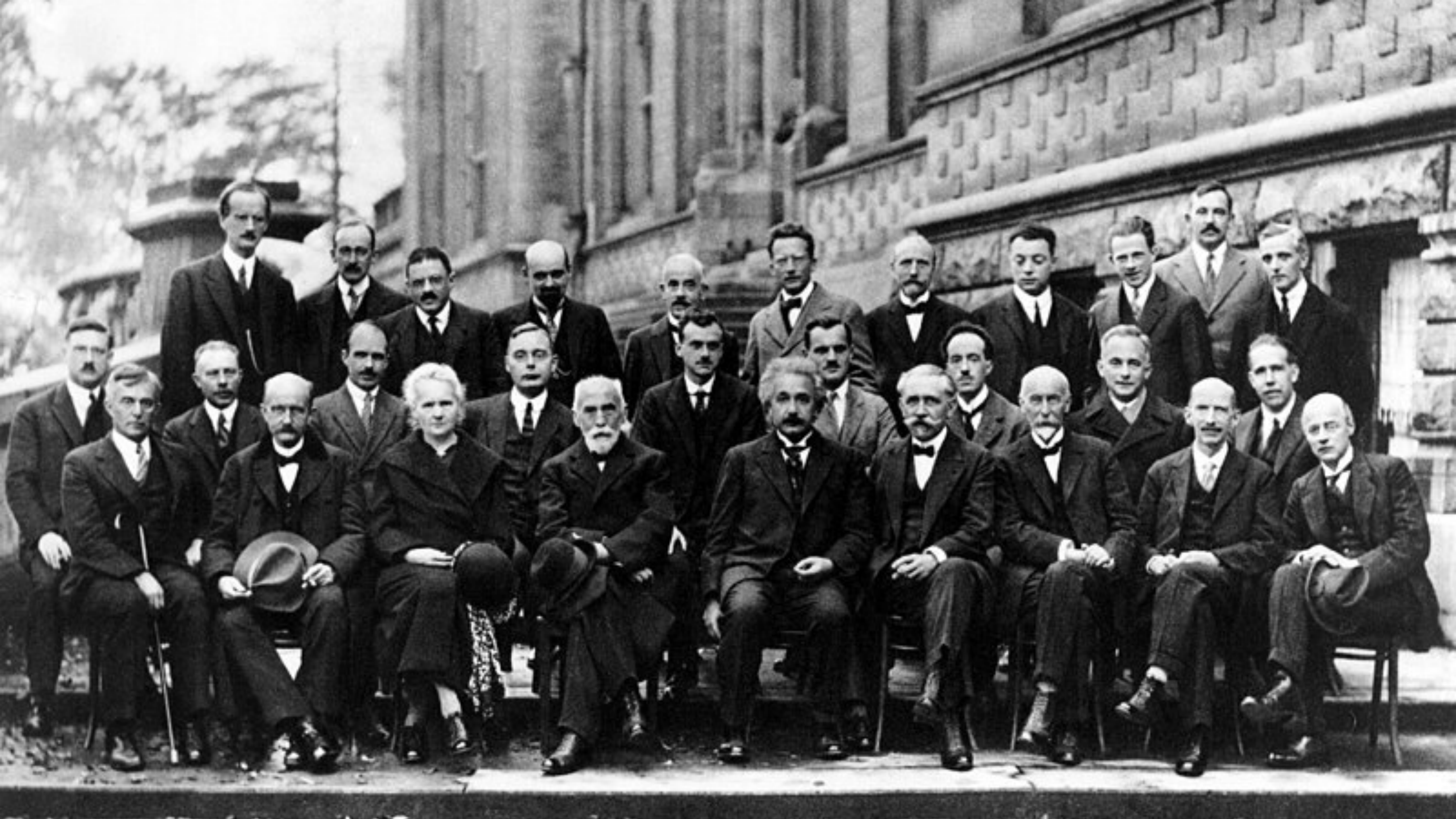
- 1899: Rutherford identifies two different types of radioactivity (i.e., radiation emitted by atomic nuclei): ALPHA (helium nuclei) and BETA (originally only electrons, later to include positrons and neutrinos).
- 1900: Villard identifies a third type, GAMMA (very high energy photons) as being different from X-RAY photons which had been known for years as being emitted by the transitions of atomic electrons.
- 1907: In 1905 (Einstein's "miracle year") he publishes a paper deriving the equation $m=E/c^2$ and showing that subatomic particles changed mass when their kinetic energy changed. In 1907 he further elaborated the equivalence between mass and energy.

CHEMISTRY AND QUANTUM MECHANICS

- December 14, 1900: Max Planck in delivering a paper in Berlin uses the Latin word for amount, QUANTUM, to describe his discovery that electro-magnetic radiation (PHOTON) can occur only with certain amounts of energy, depending on its frequency.
- 1911: Ernest Solvay, the owner of a huge chemical company in Belgium, invites European scientists to annual meetings of a "chemistry council". Postponed during WW1, the council invents a new branch of physics that explains the PERIODIC TABLE and atomic emission and absorption spectra during meetings during the 1920s and early 1930s. The new QUANTUM MECHANICS is mutually contradictory with Newtonian Physics.
- 1915: Einstein publishes a GENERAL THEORY OF RELATIVITY which extends his 1905 theory of relativity. It is also mutually contradictory with Newtonian Physics, and also quantum mechanics.

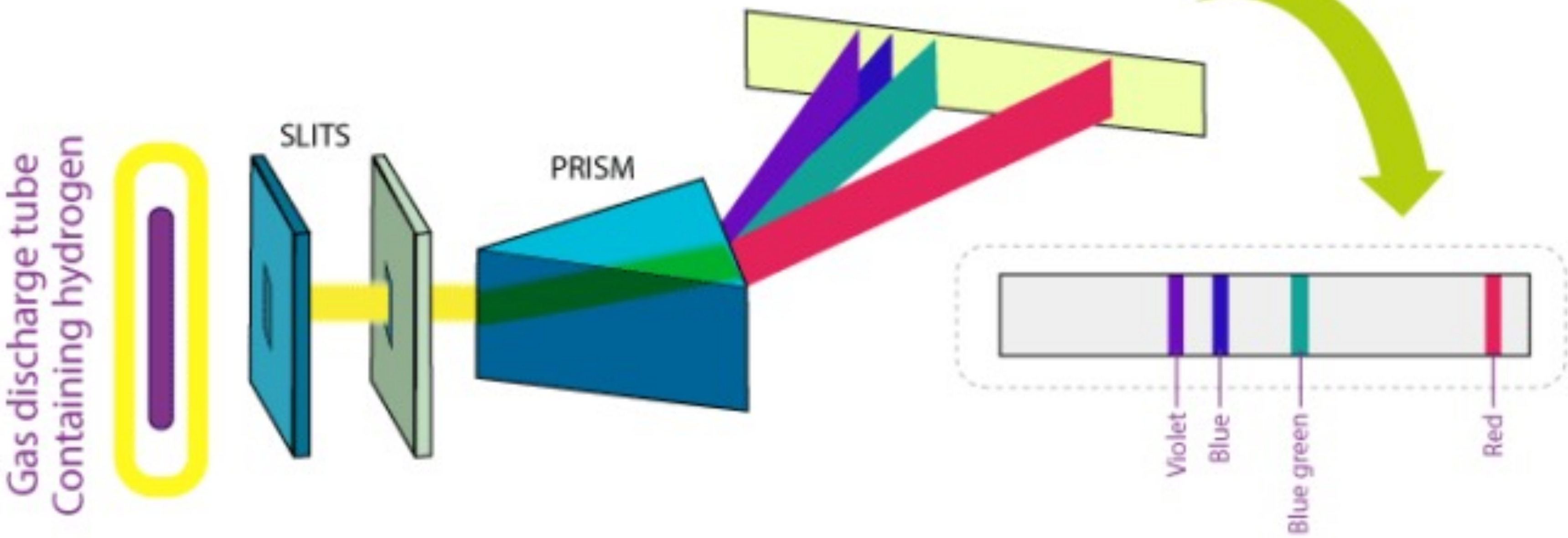
1911 ATTEDANCE

- *Seated* (L–R): W. Nernst, M. Brillouin, E. Solvay, H. Lorentz, E. Warburg, J. Perrin, W. Wien, M. Curie, and H. Poincaré. *Standing* (L–R): R. Goldschmidt, M. Planck, H. Rubens, A. Sommerfeld, F. Lindemann, M. de Broglie, M. Knudsen, F. Hasenöhrl, G. Hostelet, E. Herzen, J. H. Jeans, E. Rutherford, H. Kamerlingh Onnes, Albert Einstein and P. Langevin.

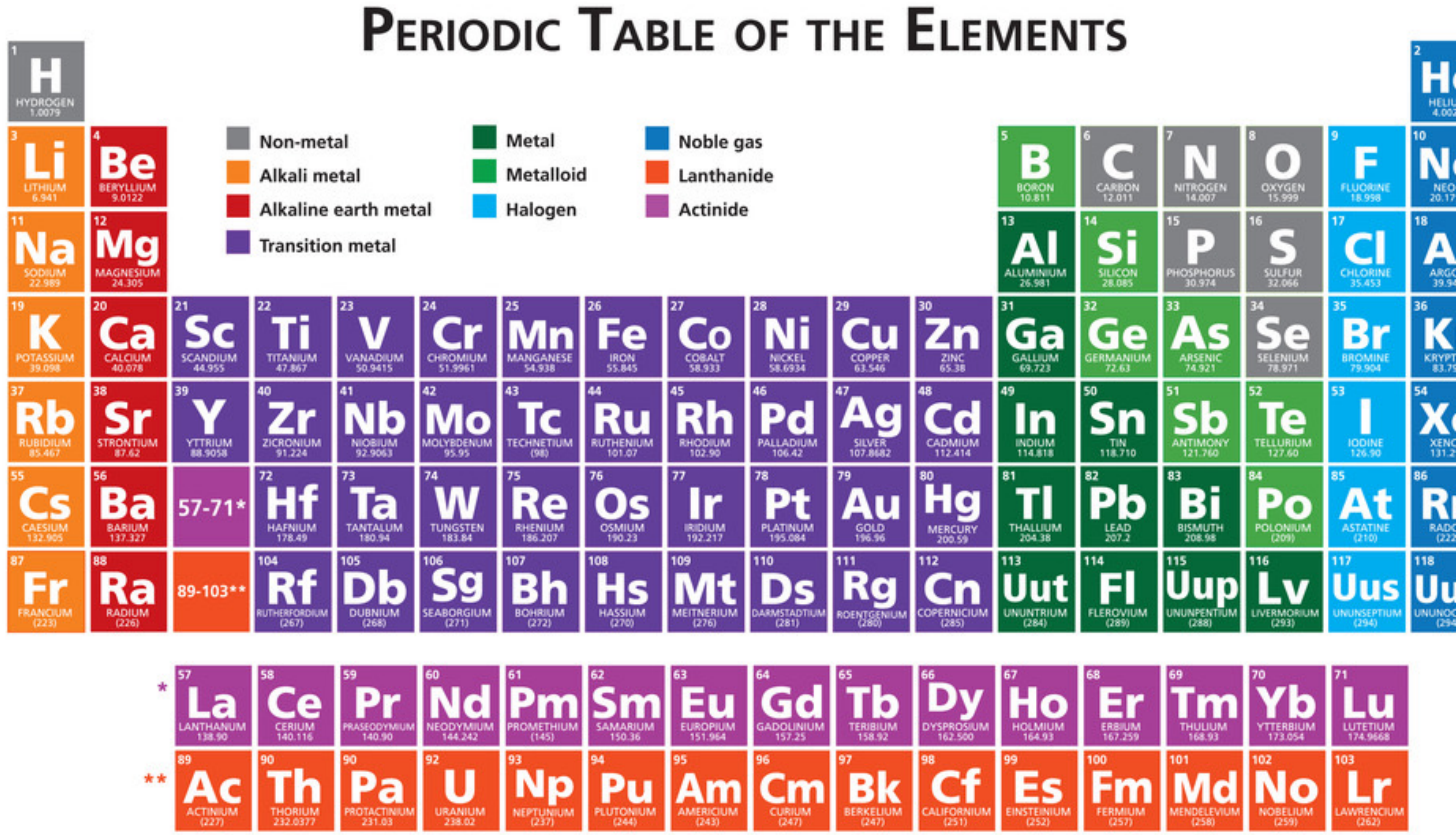


SOLVAY CHEMISTRY CONFERENCES

- Only certain amounts of energy are available to electrons in atoms. SOLUTION: mathematicians have solved the EIGENVALUE PROBLEM.
- To use eigenvalues they have to find OPERATORS for every observable, ERWIN SHRÖDINGER (1887-1961) uses version of HAMILTONIAN (1833) to solve problem. Results agree with PERIODIC TABLE OF THE ELEMENTS.
- The LAWS OF QUANTUM MECHANICS ARE LAWS OF MATHEMATICS!
- DAVID RITTENHOUSE (1732-1796) invents DIFFRACTION GRATING, which is manufactured during the 19th Century.



Hydrogen emission spectrum

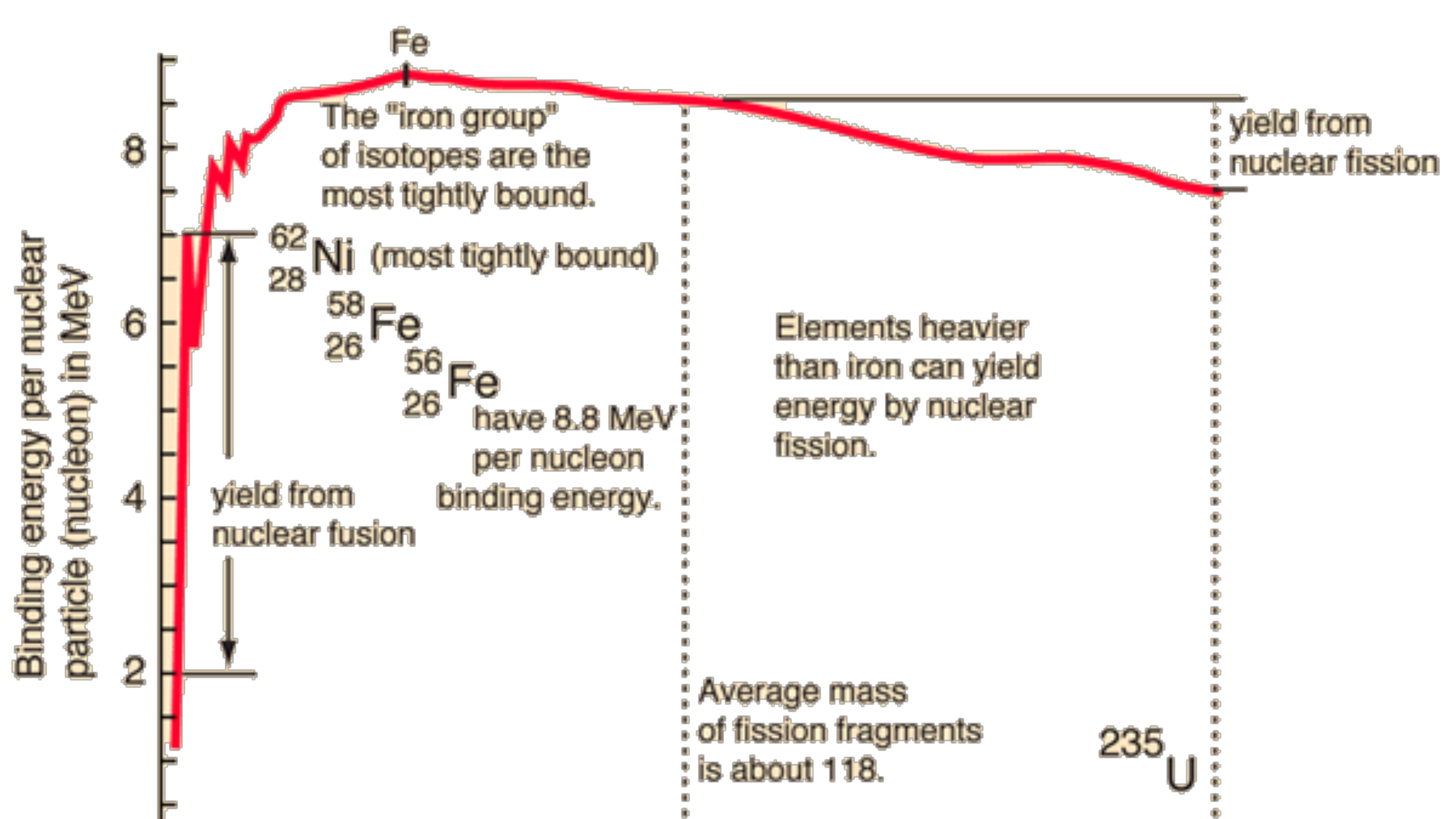

PERIODIC TABLE OF THE ELEMENTS
Non-metal
Alkali metal
Alkaline earth metal
Transition metal
Metal
Metalloid
Halogen
Noble gas
Lanthanide
Actinide
1 H HYDROGEN 1.0079
2
3 Li LITHIUM 6.941
4 Be BERYLLIUM 9.0122
5 B BORON 10.811
6 C CARBON 12.011
7 N NITROGEN 14.007
8 O OXYGEN 15.999
9 F FLUORINE 18.998
10
11 Na SODIUM 22.989
12 Mg MAGNESIUM 24.305
13 Al ALUMINIUM 26.981
14 Si SILICON 28.085
15 P PHOSPHORUS 30.974
16 S SULFUR 32.066
17 Cl CHLORINE 35.453
18
19 K POTASSIUM 39.098
20 Ca CALCIUM 40.078
21 Sc SCANDIUM 44.955
22 Ti TITANIUM 47.867
23 V VANADIUM 50.9415
24 Cr CHROMIUM 51.9961
25 Mn MANGANESE 54.938
26 Fe IRON 55.845
27 Co COBALT 58.933
28 Ni NICKEL 58.6934
29 Cu COPPER 63.546
30 Zn ZINC 65.38
31 Ga GALLIUM 69.723
32 Ge GERMANIUM 72.63
33 As ARSENIC 74.921
34 Se SELENIUM 78.971
35 Br BROMINE 79.904
36
37 Rb RUBIDIUM 85.467
38 Sr STRONTIUM 87.62
39 Y YTTRIUM 88.9058
40 Zr ZICRONIUM 91.224
41 Nb NIOBIUM 92.9063
42 Mo MOLYBDENUM 95.95
43 Tc TECHNETIUM (98)
44 Ru RUTHENIUM 101.07
45 Rh RHODIUM 102.90
46 Pd PALLADIUM 106.42
47 Ag SILVER 107.8682
48 Cd CADMIUM 112.414
49 In INDIUM 114.818
50 Sn TIN 118.710
51 Sb ANTIMONY 121.760
52 Te TELLURIUM 127.60
53 I IODINE 126.90
54
55 Cs CAESIUM 132.905
56 Ba BARIUM 137.327
57-71*
72 Hf HAFNIUM 178.49
73 Ta TANTALUM 180.94
74 W TUNGSTEN 183.84
75 Re RHENIUM 186.207
76 Os OSMIUM 190.23
77 Ir IRIDIUM 192.217
78 Pt PLATINUM 195.084
79 Au GOLD 196.96
80 Hg MERCURY 200.59
81 Tl THALLIUM 204.38
82 Pb LEAD 207.2
83 Bi BISMUTH 208.98
84 Po POLONIUM (209)
85 At ASTATINE (210)
86
87 Fr FRANCIUM (223)
88 Ra RADIUM (226)
89-103**
104 Rf RUTHERFORDIUM (267)
105 Db DUBNIUM (268)
106 Sg SEABORGIUM (271)
107 Bh BOHRIUM (272)
108 Hs HASSIUM (270)
109 Mt MEITNERIUM (276)
110 Ds DARMSTADTIUM (281)
111 Rg ROENTGENIUM (280)
112 Cn COPERNICIUM (285)
113 Uut UNUNTRIUM (284)
114 Fl FLEROVIUM (289)
115 Uup UNUNPENTIUM (288)
116 Lv LIVERMORIUM (293)
117 Uus UNUNSEPTIUM (294)
118
*
57 La LANTHANUM 138.90
58 Ce CERIUM 140.116
59 Pr PRASEODYMIUM 140.90
60 Nd NEODYMIUM 144.242
61 Pm PROMETHIUM (145)
62 Sm SAMARIUM 150.36
63 Eu EUROPIUM 151.964
64 Gd GADOLINIUM 157.25
65 Tb TERBIUM 158.92
66 Dy DYSPROSIUM 162.500
67 Ho HOLMIUM 164.93
68 Er ERBIUM 167.259
69 Tm THULIUM 168.93
70 Yb YTTERBIUM 173.054
71 Lu LUTETIUM 174.9668
**
89 Ac ACTINIUM (227)
90 Th THORIUM 232.0377
90 Pa PROTACTINIUM 231.03
92 U URANIUM 238.02
93 Np NEPTUNIUM (237)
94 Pu PLUTONIUM (244)
95 Am AMERICIUM (243)
96 Cm CURIUM (247)
97 Bk BERKELIUM (247)
98 Cf CALIFORNIUM (251)
99 Es EINSTEINIUM (252)
100 Fm FERMIUM (257)
101 Md MENDELEVIUM (258)
102 No NOBELIUM (259)
103 Lr LAWRENCIUM (262)

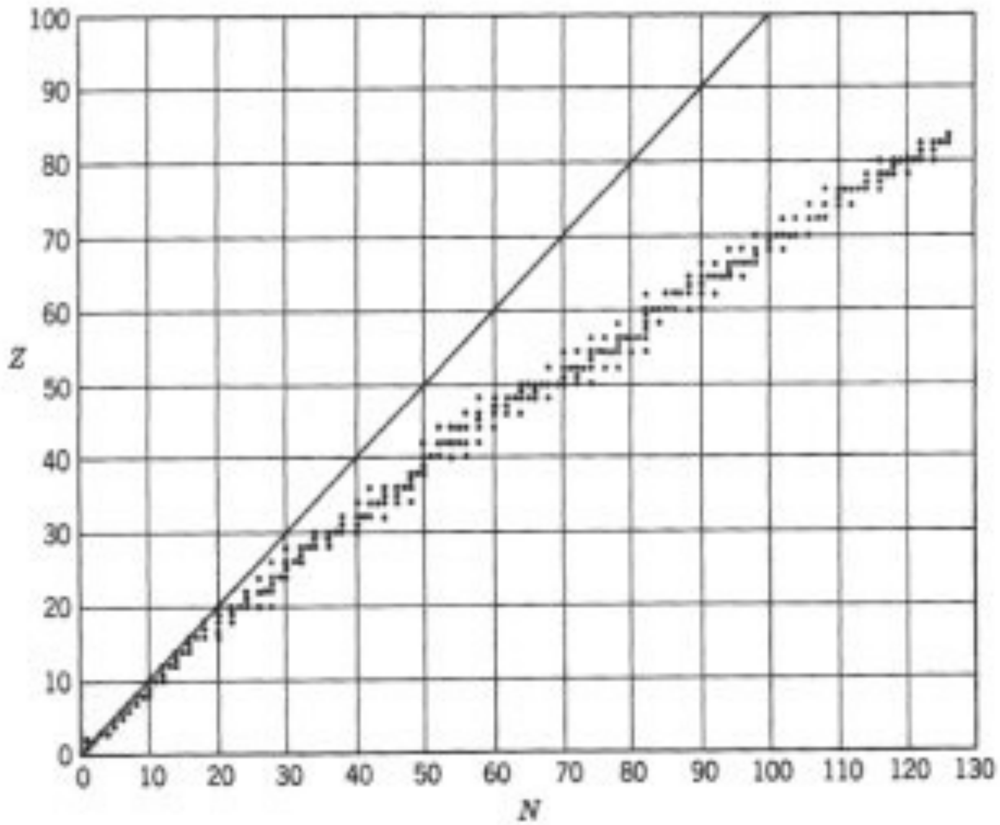
ATOM FACTS

- The nuclei of atoms contain 99.9% of the mass of those atoms yet occupy barely 0.0001% of the volume. (Similarity to solar system.)
- The vast bulk of the volume of atoms contains a thin cloud of electrons. An electron can be in a linear combination of quantum states at once.
- The hardness of substances depends upon the quantum states of the outer shells of the atom's electrons.
- If those electrons are in stable orbits with no great connection to the electrons in adjacent atoms, then the substance can be a gas.
- If those electrons are intimately related to their comparable electrons in adjacent atoms, then the substance might be steel or diamond.

WEIRD THINGS ABOUT QUANTUM PHYSICS

- There is NO CAUSE AND EFFECT!
- It is impossible to measure some things, and the uncertainty of a measurement depends upon other properties you may want to know about at the same time.
- The “wave functions” that QM pretends to describe particles are complex, i.e., they involve the square roots of negative numbers.
- Some of the fundamental particles cannot exist all by themselves but must always be combined as part of a pair or a triplet.
- Particles that are created as a new pair of separate particles are “entangled” and communicate between themselves instantaneously.
- And from General Relativity: Time does not really exist and is a “local property” depending upon relative velocities of nearby objects and the gravitational field at each location.

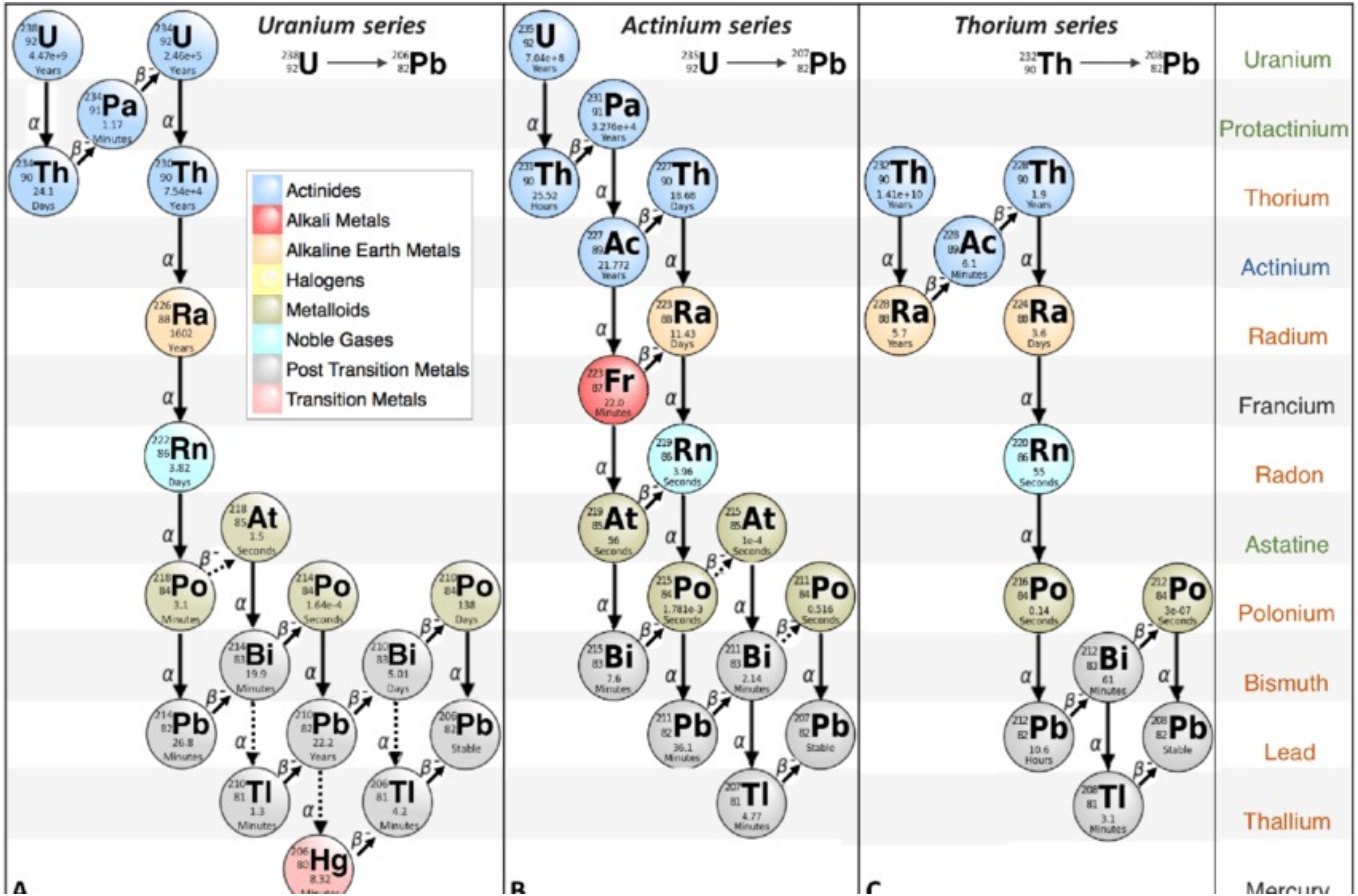

Fe
The "iron group" of isotopes are the most tightly bound.
yield from nuclear fission
8
6
4
2
Binding energy per nuclear particle (nucleon) in MeV
$^{62}_{28}Ni$ (most tightly bound)
$^{58}_{26}Fe$
$^{56}_{26}Fe$
have 8.8 MeV per nucleon binding energy.
Elements heavier than iron can yield energy by nuclear fission.
yield from nuclear fusion
Average mass of fission fragments is about 118.
^{235}U


100
90
80
70
60
50
40
30
20
10
0
Z
0 10 20 30 40 50 60 70 80 90 100 110 120 130
N

Z \ N	137	138	139	140	141	142	143	144	145	146
97		**Bk** berkelium			**Bk238** 2.4 m ε E 4.9	**Bk239** E 3.1 239.0583	**Bk240** 5 m ε, β^+ 2.1,… (SF) ω E 3.9	**Bk241** 4.6 m ε γ 152.4, 262.3, 210.7 E 2.4	**Bk242** 7 m ε, β^+ E 2.9	**Bk243** (3/−) 4.5 h ε γ 87.4D (e−),… α 6.577 ω, 6.545,… γ 187 ω,… E 1.508
96		**Cm** curium	**Cm235** E 3.2 235.0514	**Cm236** α ? ε ? E 1.7 236.0514	**Cm237** α 6.66 ε ? E 2.7 237.0529	**Cm238** 2.3 h ε α 6.56 E 1.0	**Cm239** (7/−) ~3 h ε γ 187,… α ? E 1.8	**Cm240** 27 d α 6.291, 6.248,… γ 44.6 ω SF νω 240.055530	**Cm241** 1/+ 32.8 d ε, γ 471.8,… α 5.939 (ω), 5.929, 5.884,… γ 145.6D (ω),… E 0.767	**Cm242** 162.8 d α 6.1127, 6.0694,… γ 44.1 ω (e−),… SF νω σ_γ 2E1, 12E1 σ_f < 5 242.058836
95	**Am232** 79 s ε α (SF) ? ω E 5.0	**Am233** 3 m ε α 6.78 E 3.1 233.0463	**Am234** 2.3 m ε α 6.46 ? E 4.2	**Am235** 5/− 10. m ε γ 290.6,… α 6.46 E 2.5	(1−) **Am236** (5−) 2.9 m: ε, γ 582.8, …, α 6.2 ω 3.6 m: ε, γ 319.5, …, α 6.4 ω E 3.3	**Am237** 5/(−) 1.22 h ε γ 280.2,… α 6.04 ω E 1.5	**Am238** 1+ 1.63 h ε β^+ ω γ 962.8, 918.7, 561.0,… α 5.94 νω E 2.3	**Am239** (5/)− 11.9 h ε γ 277.6, 228.2,… α 5.774 (ω), 5.734,… γ 49.3 ω E 0.802	**Am240** (3−) 2.12 d ε γ 987.7, 888.8,… α 5.378 νω,… E 1.38	**Am241** 5− 432.7 a α 5.4857, 5.4430,… γ 59.5409, 26.3 – 955 SF νω σ_γ (5E1 + 63E1), (19E1 + 35E2) σ_f 3.2, 14 241.056829
94	**Pu231** 8.6 m ε α 6.72 E 2.7 231.04110	**Pu232** 34 m ε α 6.60, 6.54 E 1.0 232.04119	**Pu233** 20.9 m ε γ 235.3, 534.7,… α 6.30 ω E 2.1	**Pu234** 8.8 h ε α 6.200, 6.149,… E 0.39	**Pu235** (5/+) 25.3 m ε γ 49.2, 756.4,… α 5.85 ω E 1.14	**Pu236** 2.87 a α 5.7675, 5.7209,… γ 47.6 – 643.7 ω SF ννω σ_f 16E1, 1E3 236.046058	**Pu237** 7/− 0.18 s: IT 145.54 45.64 d: ε, γ 59.5,…; α 5.344(ω),… γ 280.4(νω), 289.9, 320.8,… σ_f 24E2 E 0.220	**Pu238** 87.7 a α 5.4992, 5.4565,… γ 43.5 ω (e−), 99.9 (e−),… SF νω σ_γ 54E1, 20E1 σ_f 18, ~33 238.049560	**Pu239** 1/+ 2.410E4 a α 5.156, 5.144, 5.105,… γ 51.6 e−, 30.1 – 1057.3ω SF ννω σ_γ 271, 20E1 σ_f 750, 30E1 σ_α < 0.4 mb 239.052163	**Pu240** 6.56E3 a α 5.1685, 5.1241,… γ 45.2ω (e−), 104.2 (e−),… SF νω σ_γ 290, 81E2 σ_f 0.05, 2.4 240.053814
93	**Np230** 4.6 m ε α 6.66 E 3.6	**Np231** (5/) 48.8 m ε γ 370.3, 347.5, 262.9,… α 6.26 E 1.8	**Np232** (4+) 14.7 m ε γ 326.8, 819.2, 866.8, 864.3,… E 2.8	**Np233** (5/+) 36.2 m ε γ 312.0, 298.9, 546.5,… α 5.53 ? ω E 1.0	**Np234** (0+) 4.4 d ε β^+ 0.79 ω γ 1558.7, 1527.2, 1602.2,… σ_f 9E2 E 1.81	**Np235** 5/+ 1.085 a ε α 5.021 (νω), 5.004,… γ 25.6 – 188.8 νω σ_γ (15E1 + ?) E 0.124	1(−) **Np236** (6−) 22.5 h: ε, β^- 0.54,…; γ 642.3, 687.6,…; σ_f 2.7E3, 7E2; E^+ 0.9 1.55E5 a: ε, γ 160.3,…; β^-, γ 44.6 e−,…; σ_f 2.5E3, 1E3; E^- 0.5	**Np237** 5/+ 2.14E6 a α 4.788, 4.771,… γ 29.4, 86.5,… σ_γ 169, 65E1 σ_f 0.02, 7 237.048173	**Np238** 2+ 2.103 d β^- 0.263, 1.248,… γ 984.5, 1028.5,… σ_γ 48E1 σ_f 21E2, 9E2 E 1.2915	**Np239** 5/+ 2.356 d β^- 0.438, 0.341,… γ 106.1, 277.6, 228.2,… σ_γ (3E1 + 3E1) σ_f < 1 E 0.723
92	**U229** (3/+) 58 m ε γ 122.5,… α 6.360, 6.332, 6.297,… E 1.31 229.03351	**U230** 20.8 d α 5.888, 5.818,… γ 72.2 ω (e−), 154.2, 230.4,… σ_f 2E1 230.03394	**U231** (5/−) 4.2 d ε γ 25.65, 84.2,… α 5.456 ω,… γ 68.33, 53.23,… σ_f 3E2 E 0.382	**U232** 69.8 a α 5.3203, 5.2635,… γ 57.8 ω(e−),129.1,… SF ω σ_γ 73, 28E1 σ_f 75, 38E1 232.037156	**U233** 5/+ 1.592E5 a α 4.824, 4.783,… γ 42.5 ω, 97.03, 54.65,… SF νω σ_γ 46, 14E1 σ_f 531, 76E1 σ_α < 0.3 mb 233.039635	**U234** UII 0.0054 2.46E5 a α 4.776, 4.725,… γ 53.2 (e−), 120.9,… SF νω σ_γ 106, 7E2 σ_f 67 mb, 7 234.040952	1/+ **U235** 7/− 26 m: IT ~76.8 eV (ω) e− AcU 0.7204, 7.04E8 a α 4.398, 4.366,… γ 185.72, 143.76,… SF νω σ_γ 98, 14E1 σ_f 585, ~275 σ_α < 0.1 mb 235.043930	**U236** 2.342E7 a α 4.494, 4.445,… γ 49.4 ω (e−), 112.8,… SF νω σ_γ 5.1, 36E1 σ_f 0.04, 4 236.045568	**U237** 1/+ 6.752 d β^- 0.24, 0.25,… γ 59.5, 208.0,… σ_γ 4E2, 12E2 σ_f < 0.35 E 0.519	**U238** UI 99.2742 4.468E9 a α 4.197, 4.147,… γ 49.6 ω (e−),… SF νω σ_γ 2.68, 277 σ_f ~5μb, 1.3mb σ_α 1μb 238.050788
91	**Pa228** (3+) 22 h ε γ 911.20, 463.02, 968.98,… α 5.71 – 6.12 ω γ 95 – 345 ω E 2.152	**Pa229** (5/+) 1.5 d ε γ 42.4 e− α 5.41 – 5.693 ω γ 24.8 – 180.2 ω E 0.311	**Pa230** 2− 17.4 d ε, γ 952.0,… β^- 0.51,… γ 314.8 ω,… α 4.766 – 5.345 νω σ_f 15E2 E^+ 1.311 E^- 0.560	**Pa231** 3/− Pa 100 3.28E4 a α 5.013, 4.950, 5.029,… γ 27.4, 300.1,… σ_γ 20E1, 5E2 σ_f 0.020, 0.05 231.035884	**Pa232** (2−) 1.32 d β^- 0.31, 0.29,… γ 969.3, 894.3,… ε ? σ_γ 5E2, 3E2 σ_f 7E2 E^+ 0.50 E^- 1.34	**Pa233** 3/− 26.967 d β^- 0.256, 0.15,… γ 311.90,… σ_γ (21 + 38), (46E1 + 44E1) σ_f < 0.1 E 0.570	(0−) **Pa234** 4+ UX2 1.17 m: β^- 2.29,…; γ 1001.0, 766.4,… ω; IT < 10; γ 73.9 ω e− UZ 6.69 h: β^- 0.48, 0.65,…; γ 131.3, 34 – 1938 E 2.195	**Pa235** (3/−) 24.4 m β^- 1.41,… γ 30.1 – 658.9 E 1.41	**Pa236** 1− 9.1 m β^- 2.0, 3.1,… γ 642.3, 687.5, 1762.7,… SF νω E 2.9	**Pa237** (1/−) 8.7 m β^- 1.2, 1.5, 2.25,… γ 853.6, 865.0, 529.3, 540.7,… E 2.3
90	**Th227** (3/+) RdAc 18.68 d α 6.038, 5.978, 5.757,… γ 236.0, 50.2,… σ_f 20E1 227.027704	**Th228** RdTh 1.912 a α 5.423, 5.340,… γ 84.4 e−, 216.0, 131.6, 166.4,… σ_γ 1.2E2, 1.0E3 σ_f < 0.3 228.028741	**Th229** 5/+ 7.4E3 a α 4.845, 4.901, 4.814,… γ 193.6, 86.4, 210.9, 31.5,… σ_γ 6E1, 1.0E3 σ_f 31, 5E2 229.031762	**Th230** Io 7.56E4 a α 4.688, 4.621,… γ 67.7 e−, 110.0–620. σ_γ ~23.0, 101E1 σ_f < 0.5 mb 230.033134	**Th231** 5/(+) UY 1.063 d β^- 0.305,… γ 25.64, 84.21,… E 0.392	**Th232** Th 100 1.40E10 a α 4.012, 3.947,… γ 63.81 ω (e−), 140.88 SF (ννω) σ_γ 7.34, 85 σ_f < 1 μb 232.038055	**Th233** (1/+) 21.83 m β^- 1.245,… γ 86.5, 29.4, 459.3,… σ_γ 15E2, 4E2 σ_f 15 E 1.243	**Th234** UX1 24.10 d β^- 0.198,… γ 63.3, 92.4, 92.8,… σ_γ 2 σ_f < 0.01 E 0.273	**Th235** 1/+ 7.2 m β^- γ 417.0, 727.2, 696.1, 644.9,… E 1.9	**Th236** 37.5 m β^- γ 110.8,… E 1.1
89	**Ac226** (1) 1.224 d β^- 0.89, 1.11,… γ 230.3, 158.1,… ε, γ 253.7, 186.0 α 5.40 ω E^- 1.113 E^+ 0.641	**Ac227** 3/− Ac 21.772 a β^- 0.045,… γ 15.2 ω (e−),… α 4.9534, 4.941 ω,… γ 100. ω,… σ_γ 9E2, 15E2 σ_f < 0.4 mb E 0.045	**Ac228** 3(+) MsTh2 6.15 h β^- 1.158, 1.731,… γ 911.204, 968.97, 338.320,… α 4.27 νω ? E 2.124	**Ac229** (3/+) 1.04 h β^- 1.17,… γ 164.524, 569.3,… E 1.17	**Ac230** (1+) 2.03 m β^- γ 454.9, 508.2, 1243.9,… E 2.9	**Ac231** (1/+) 7.5 m β^- 1.6,… γ 282.5, 307.0, 221.4, 185.7, 368.9,… E 2.1	**Ac232** (1+) 2.0 m β^- γ 665.0, 1899,… E 3.7	**Ac233** (1/+) 2.4 m β^- γ 523, 540. E 2.8	**Ac234** (1+) 40 s β^- γ 1847, 1912, 668, 1954,… E 4.5	**Ac235** E 3.5
		138		**140**		**142**		**144**		**146**

OH, YES, AND ALSO

- There are three entirely different physics, each with its own branch of mathematics and with different and mutually contradictory sets of laws.
- One governs very small things and is quantized and very strange.
- Another works on things that are big enough to see with the naked eye up to things that NASA sends rockets to and obeys Newton's 17^{th} Century laws --- mostly but sometimes needs minor corrections.
- The last works only for universes and, unlike the first two, deals with bending space, peculiar ways to measure distances and local times.



Uranium series
238U → 206Pb
Actinium series
235U → 207Pb
Thorium series
232Th → 208Pb
Actinides
Alkali Metals
Alkaline Earth Metals
Halogens
Metalloids
Noble Gases
Post Transition Metals
Transition Metals
Uranium
Protactinium
Thorium
Actinium
Radium
Francium
Radon
Astatine
Polonium
Bismuth
Lead
Thallium

DISCOVERY OF FISSION

- Kelly gives a few authors the chance to explain how they could have discovered fission if they had paid attention. Lise Meitner (1878-1968) and her nephew Otto Frisch (1904-1979) during a walk in the snow in a Swedish forest during December 1938 discussed the fission of uranium as a solution to the radioactivity generated by experiments trying to discover the element just above uranium in the periodic table. They devised an experiment to prove their theory and discussed this with Niels Bohr (1885-1962) just before he left to conferences in New York and Washington. On January 6, 1939 at the Fifth Washington Conference on Theoretical Physics at George Washington University, he and Enrico Fermi reported the discovery of fission by Meitner, Hahn, Strassmann and Frisch.

HERBERT GEORGE WELLS (1866 – 1946)

- Wells was an English writer. Prolific in many genres, he wrote more than fifty novels and dozens of short stories. His non-fiction output included works of social commentary, politics, history, popular science, satire, biography, and autobiography. In his science fiction, he took the ideas and fears that haunted the mind of his age and gave them symbolic expression as brilliantly conceived fantasy made credible by the quiet realism of its setting. (Britanica)
- Kelly sees Wells' bomb designer as an early Oppenheimer: "It is not for me to reach out to consequences I cannot foresee. I am just a part, not a whole; I am a little instrument in the armory of Change. If I were to burn all these papers, before a score of years have passed, some other man would be doing this….."

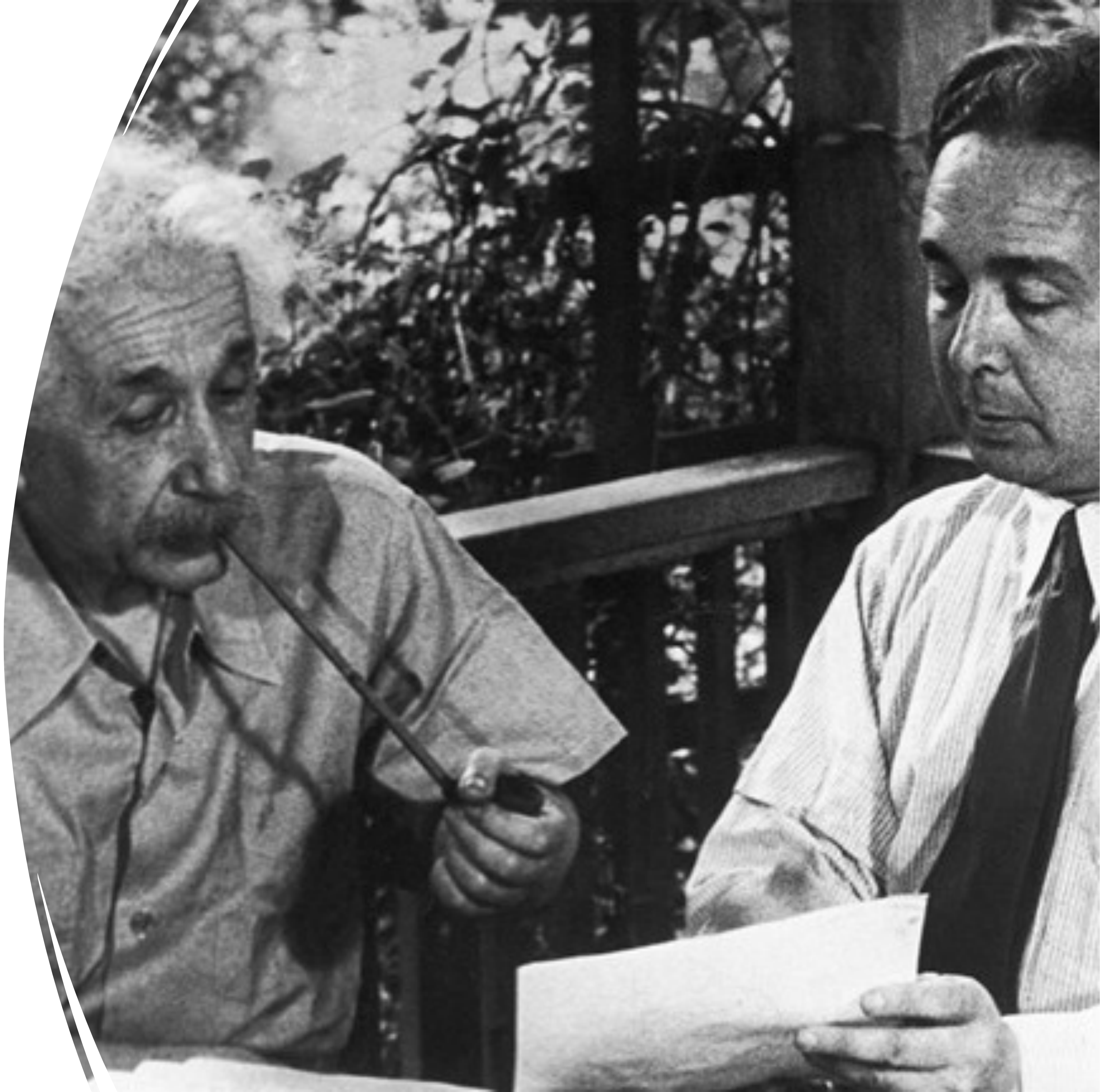
LEONA MARSHALL LIBBY (1919 – 1986)

- Libby was a child protege and received her PhD in chemistry from Chicago She made major contributions to the development of the Chicago 1 pile, including the boron trifluoride neutron counter, and at Hanford B reactor she was instrumental in the discovery of the neutron poison effects of Xe^{133} , and in getting around the Pu^{240} problem. She married John Marshall, a fellow MED scientist in 1943, producing a son, and divorced him in 1966 to marry Nobel laureate Willard Libby.
- Libby’s account of Lise Meitner and her young nephew, Otto Frish, describes Meitner’s conception of fission using Bohr’s Liquid Drop Model of nuclei in Stockholm, where she had been forced to flee, leaving her research collaborators behind in Berlin.

August 2, 1939 Einstein’s Letter

- Leo Szillard (1898-1962) and Eugene Wigner (1902-1995) consulted with Dr. Alexander Sachs (1893-1973) and decided to warn only FDR concerning the possibility of a super-bomb.
- Szillard dictated the letter and Wigner wrote it down and had it typed, they then called Einstein, who was on vacation in Patchogue, Long Island, and he agreed to sign it. Kelly pages 28-30.
- Wigner drove drove them to Patchogue, where Einstein (1879-1955) signed it. They then returned to New York City to give the letter to Sachs who then gave it to Roosevelt by hand.

- Albert Einstein and Leo Szilard review their letter warning FDR about potential to build atomic bombs.



Pitchblende Mines

- Although uranium is present in most soils in parts-per-million concentrations, only three uranium mines supplied radium for medicinal purposes in 1939. One in Nazi-controlled Czechoslovakia and the Shinkolobwe mine in Katanga, Belgian Congo. The Eldorado mine of Northern Canada had a much lower concentration and was not accessible during the winter. Also, trivial amounts of uranium were available in the tailings of a vanadium mine in Colorado.
- Edgar Sengier (1897-1963) was a director of the Belgian company that owned the Shinkolobwe mine. When Germany invaded Belgium in May of 1940, he placed 1250 of uranium oxide in 2,006 oil drums and transported them to a warehouse in Staten Island.

WORLD WAR TWO TIMELINE

- September 18, 1931 Japan invades Manchuria.
- October 2, 1935–May 1936 Fascist Italy invades, conquers, and annexes Ethiopia.
- October 25–November 1, 1936 Nazi Germany and Fascist Italy sign a treaty of cooperation on October 25. On November 1, the Rome-Berlin Axis is announced.
- November 25, 1936 Nazi Germany and Imperial Japan sign the Anti-Comintern Pact. The pact is directed against the Soviet Union and the international Communist movement.
- July 7, 1937 Japan invades China.
- November 26, 1937 Italy joins Germany and Japan in the Anti-Comintern Pact.
- March 11–13, 1938 Germany incorporates Austria in the *Anschluss*

WAR DECLARED

- September 29, 1938 Germany, Italy, Great Britain, and France sign the Munich agreement which forces the Czechoslovak Republic to cede the Sudetenland, including key Czechoslovak military defense positions, to Nazi Germany.
- March 14–15, 1939 Under German pressure, the Slovaks declare their independence and form a Slovak Republic. The Germans occupy the dismantled Czech lands in violation of the Munich agreement and form the Protectorate of Bohemia and Moravia.
- March 31, 1939 France and Great Britain guarantee the integrity of the borders of the Polish state.
- April 7–15, 1939 Fascist Italy invades and annexes Albania.
- August 23, 1939 Nazi Germany and the Soviet Union sign a non-aggression agreement and a secret protocol dividing eastern Europe into spheres of influence.
- September 1, 1939 Germany invades Poland, initiating World War II in Europe.

IT GETS SERIOUS

- September 3, 1939 Honoring their guarantee of Poland's borders, Great Britain and France declare war on Germany.
- September 17, 1939 The Soviet Union invades Poland from the east. The Polish government flees into exile via Romania, first to France and then later to Great Britain.
- September 27–29, 1939 Warsaw surrenders on September 27. Germany and the Soviet Union divide Poland between them.
- November 30, 1939–March 12, 1940 The Soviet Union invades Finland, initiating the so-called Winter War. The Finns sue for an armistice and cede the northern shores of Lake Ladoga to the Soviet Union. They also cede the small Finnish coastline on the Arctic Sea.
- April 9, 1940–June 9, 1940 Germany invades Denmark and Norway. Denmark surrenders on the day of the attack. Norway holds out until June 9. **Allied forces escape at Dunkirk.**
- On June 22, France signs an armistice agreement by which the Germans occupy the northern half of the country and the entire Atlantic coastline. In southern France, a collaborationist regime with its capital in Vichy is established.

- September 13, 1940 The Italians invade British-controlled Egypt from Italian-controlled Libya.
- September 27, 1940 Germany, Italy, and Japan sign the Tripartite Pact (the Axis).
- October 28, 1940 Italy invades Greece from Albania.
- November 1940 Hungary (November 20), Romania (November 23), and Slovakia (November 24) join the Axis.
- February 1941 The Germans send the Afrika Korps to North Africa to reinforce the faltering Italians.
- March 1, 1941 Bulgaria joins the Axis.
- April 6, 1941–June 1941 Germany, Italy, and Hungary invade Yugoslavia and, together with Bulgaria, dismember it. Yugoslavia surrenders on April 17. Germany and Bulgaria invade Greece in support of the Italians. Resistance in Greece ceases in early June 1941.

•June 22, 1941–November 1941 Nazi Germany and its Axis partners (except Bulgaria) invade the Soviet Union. Finland, seeking redress for the territorial losses in the armistice concluding the so-called Winter War, agrees to participate in the invasion. The Germans quickly overrun the Baltic states and, joined by the Finns, lay siege to Leningrad (St. Petersburg) by September. In the center, the Germans capture Smolensk in early August and drive on Moscow by October. In the south, German and Romanian troops capture Kiev (Kyiv) in September and capture Rostov on the Don River in November.

•December 6, 1941 A Soviet counteroffensive drives the Germans from the Moscow suburbs in chaotic retreat.

•December 7, 1941 Japan bombs Pearl Harbor, but its invasion is not consummated.

•December 8, 1941 The United States declares war on Japan, entering World War II. Japanese troops land in the Philippines, French Indochina (Vietnam, Laos, Cambodia), and British Singapore. The Japanese occupy the Philippines, Indochina, and Singapore by April 1942 and take control of Burma in May.

PEARL HARBOR

- During the attack on Pearl Harbor on December 7, 1941, a total of three U.S. ships were destroyed beyond repair, and a further 16 were damaged in some degree. This was in addition to more than 120 damaged or destroyed Navy Aircraft, and over 2,000 Navy personnel deaths. Two battleships, Arizona and Oklahoma, were manned and self-powered and were sunk while engaging the enemy.
- All US carriers and destroyers were still at sea performing training missions well South of the islands. The Japanese fleet was North of the islands and retired before they could be engaged. They had come with troops to invade but were dissuaded by not seeing any carriers.
- The Salvage Division righted and refloated the capsized battleship Oklahoma, partially righted the capsized Utah and recovered materiel from the wreck of the battleship Arizona. However, these three ships were not returned to service, and the hulls of the last two remain in Pearl Harbor to this day.

GENERAL “JIMMY” DOOLITTLE

- In April 1942, amid public unrest (the German U-boats virtually eliminated coastal shipping along the Atlantic seaboard) it was decided that some action was necessary against our enemies.
- General Doolittle and 79 volunteers devised a plan to bomb Tokyo. Sixteen B25 bombers were loaded with bombs and fuel and lifted onto the wooden flightdeck of the USS Hornet in San Francisco harbor, preventing its use by the aircraft below deck. They sailed from California and joined the carrier USS Enterprise and its escorts and preceded towards Japan. Using an aerodynamic trick all were able to take off several hundred miles off the coast of Japan, flew to Tokyo and released their bombs and attempted landings in occupied China. President Roosevelt, in announcing the attack, claimed they had flown from our secret airbase in Shangri-la.

OTTO FRISH (1904 -- 1979) and RUDOLF PEIERLS (1907 – 1995)

- Meitner and Frisch's paper, dated 16 January 1939, explained the physics behind the phenomenon
- **The Frisch–Peierls memorandum** (March 1940) was the first technical exposition of a practical nuclear weapon. It was written by expatriate German-Jewish physicists Otto Frisch and Rudolf Peierls while they were both working for Mark Oliphant at the University of Birminghamin Britain.
- The memorandum contained the first calculations about the size of the critical mass of fissile material needed for an atomic bomb. It revealed that the amount required might be small enough to incorporate into a bomb that could be delivered by air. It also anticipated the strategic and moral implications of nuclear weapons.
- It helped send both Britain and America down a path which led to the MAUD Committee, the Tube Alloys project, and ultimately the Manhattan Project.

Frisch later recalled that:

“In all this excitement we had missed the most important point: the chain reaction. It was Christian Møller, a Danish colleague, who first suggested to me that the fission fragments (the two freshly formed nuclei) might contain enough surplus energy each to eject a neutron or two; each of these might cause another fission and generate more neutrons... from Møller's remark the exciting vision arose that by assembling enough pure uranium (with appropriate care!) one might start a controlled chain reaction and liberate nuclear energy on a scale that really mattered”

The news of the discovery of fission was brought to America by Bohr in January 1939. Bohr and John A. Wheeler set to work applying the liquid drop model developed by Bohr and Fritz Kalckar to explain the mechanism of nuclear fission. George Placzek, who was skeptical about the whole idea of fission, challenged Bohr to explain why uranium seemed to fission with both very fast and very slow neutrons. Bohr had an epiphany that the fission at low energies was due to the uranium-235 isotope, while at high energies it was due mainly to the more abundant uranium-238 isotope. The former makes up just 0.7% of natural uranium; while the latter accounts for 99.3%. On 16 April 1939, Bohr, Placzek, Wheeler, Eugene Wigner and Leon Rosenfeld discussed whether it would be possible to use a nuclear chain reaction to make an atomic bomb, and concluded that it was not. Bohr observed that "It would take the entire efforts of a country to make a bomb."[

US MED = UK MAUD COMMITTEE

- Just as Einstein's letter to FDR started our national government to form a committee to investigate the possibility of an atomic bomb, so did a telegram in 1940 from Niels Bohr in Nazi-occupied Denmark to Otto Frisch in England. This telegram ended with instructions to pass along his message to "Cockcroft and Maud Ray, Kent". Cockcroft was obviously Sir John Cockcroft (1897-1967) a noted British physicist and Maud was thought to be some sort of code to be used to activate some secret organization. Maud Ray had been a beloved governess for Bohr's children who, when the children grew of an age no longer needing a governess, retired to spend her days in Kent, England. When passed to the White House, the Maud Committee caused a previously inactive US effort to move. There is no record of Ms. Ray having been informed.
- Building upon theoretical work on atomic bombs performed by refugee physicists Rudolf Peierls and Otto Frisch in 1940 and 1941, the MAUD report estimated that a critical mass of ten kilograms would be large enough to produce an enormous explosion. In order to rapidly assemble a super-critical mass of uranium quickly, the MAUD committee postulated a one-ton cannon would be sufficient A bomb this size could be loaded on existing aircraft and be ready in approximately two years. The same day in July 1941 that British scientists completed the Maud report, the NKVD agent in London informed Moscow of its contents.

VANNEVAR BUSH (1890 – 1974)

- **The Office of Scientific Research and Development** (**OSRD**) was an agency of the United States federal government created to coordinate scientific research for military purposes during World War II. Arrangements were made for its creation during May 1941, and it was created formally by Executive Order 8807 on June 28, 1941. It superseded the work of the National Defense Research Committee (NDRC), was given almost unlimited access to funding and resources, and was directed by Vannevar Bush, who reported only to President Franklin Delano Roosevelt.
- The research was widely varied, and included projects devoted to new and more accurate bombs, reliable detonators, work on the proximity fuze, guided missiles, radar and early-warning systems, more effective medical treatments (including work to make penicillin at scale, and sulfa drugs), more versatile vehicles, and the most secret of all, the S-1 Section, which later became the Manhattan Project.

ANDREW BROWN

- Brown was a RADIATION ONCOLOGIST practicing medicine in New Hampshire who authored biographies of James Chadwick and Joseph Rotblat and a popular history of the early days of nuclear science.
- Brown's biography of Chadwick (1891 – 1974) in 1997, *The Neutron and the Bomb*, is the definitive work on role of the discoverer of the neutron *(1932)* and as leader of the British mission to Los Alamos and later to Washington.

SIR JAMES CHADWICK (1891 – 1974)

- Kelly includes over six pages of excerpts from Andrew Brown's biography of Chadwick. Chadwick, CH*, FRS was awarded the 1935 Nobel Prize in Physics for his discovery of the neutron in 1932, which he did by letting alpha rays bombard berrylium. In July 1941, he wrote the final draft of the MAUD Report, which inspired the U.S. government to begin serious atom bomb research efforts.
- In October 1941 Roosevelt wrote to Churchill proposing the combining of bomb efforts. Meanwhile the British had formed a company, Tube Alloys, to attack the problem of separating U^{235} which supplanted the MAUD Committee. Also in October 1941, two members of the Columbia faculty (Pegram and Urey) came to Liverpool to meet Chadwick.
- Sir Mark Oliphant (1901-2000) was an Australian physicist who is known for his work in nuclear physics and radar, and, later, for becoming governor of South Australia. During the Second World War, Oliphant worked on the development of a more sophisticated radiolocation system—known today as 'radar'. Oliphant flew in a British bomber to the U.S. and worked with Bush to further the pursuit of the bomb by a joint US-UK effort, and even to Berkeley to meet Ernest Lawrence. By early 1942, the US was at war, and Lawrence had sold the possibility of Pu^{239} as a substitute for U^{235} substituting the reactor production of it for the difficulties of separating uranium isotopes.
- * Companions of Honor, only 65 British citizens may hold this title at the same time

SECTION TWO – an unprecedented alliance

- OK, fission worked in the laboratory with natural uranium, now all we needed is to separate uranium's isotopes and/or make much more than a few trillion atoms of plutonium which was an order of magnitude more fissionable than uranium.
- Briton sends its nuclear scientists to America (unfortunately with a Soviet agent included). Over a hundred European nuclear scientists were in New York City. Groves was to commandeer any companies that had technical capabilities, with headquarters in the New York Army Engineer Office, use the assets available around Columbia University, complete the science needed to design the bomb, and then build as many as possible. To differentiate the normal activities of the New York Office, a portion of the office space at 270 Broadway was established on August 13, 1942, as the Manhattan Engineer District. It was abolished in August 1945 when it was deemed to have completed its mission.
- Groves needed scientists who could actually invent the bomb, and the scientists were just then deciding which of four means of separating uranium isotopes would actually work. Differing from Britain, MED would be in charge and contracting commercial interests would be subordinate. Everybody was to work for the army engineers.

RICHARD RHODES (1937 - ?)

- Rhodes received the Pulitzer Prize in Nonfiction for his 1986 *The Making of the Atomic Bomb*. He has over two hours of lectures on YouTube. In Kelly's excerpt from his book he recounts that the 1942 view of those in charge of bomb research was that millions would be required and the work should be done within easy commuting distance of Columbia University's Morningside Heights location. Compton decided on Chicago instead, while Fermi was busy making fuel rods and Szillard was collecting graphite.

THREE UNIVERSITIES AND THE ARMY CORPS OF ENGINEERS

- At the “Rad Lab” (Radiation Laboratory) at the University of California at Berkeley, research was underway under the direction of Ernest Lawrence. Lawrence’s most significant discovery came with his invention of the cyclotron, popularly known as an “atom smasher,” which could accelerate atoms through a vacuum and use electromagnets to induce collisions at speeds up to 25,000 miles per second. Lawrence believed a version of his machine could separate Uranium-235 by electromagnetic separation.
- Meanwhile, at Columbia University, a team of scientists, including Enrico Fermi, Leo Szilard, Walter Zinn, and Herbert Anderson, conducted experiments using chain-reacting nuclear “piles” to measure the neutron emission from fission.
- The work at Columbia was moved to the Metallurgical Laboratory at the University of Chicago in February 1942. At the time German submarines were decimating shipping along the Atlantic coast and a Nazi invasion was considered possible. On December 2, 1942, Chicago Pile-1 went critical, creating the world’s first self-sustaining chain reaction. The experiment not only proved that nuclear energy could generate power, but also showed a viable method to produce plutonium.

JAMES B. CONANT (1893 – 1978)

- Conant received both undergraduate and graduate degrees in chemistry at Harvard.
- During WW1 Conant worked for the U.S. Army to develop poison gases. After the war he taught at Harvard and researched the functioning of hemoglobin and chlorophyll and toured various universities in Germany. In 1933 he became the President of Harvard, which position he held until 1953.
- Before WW2 he was prominent in pushing the U.S. to pursue an atomic bomb. And was appointed by FDR to advise and then to chair the National Defense Research Committee (NDRC). As Chairman he travelled to Britain in February 1941 to facilitate the US-UK collaboration.

James G. Hershberg (1960 - ?)

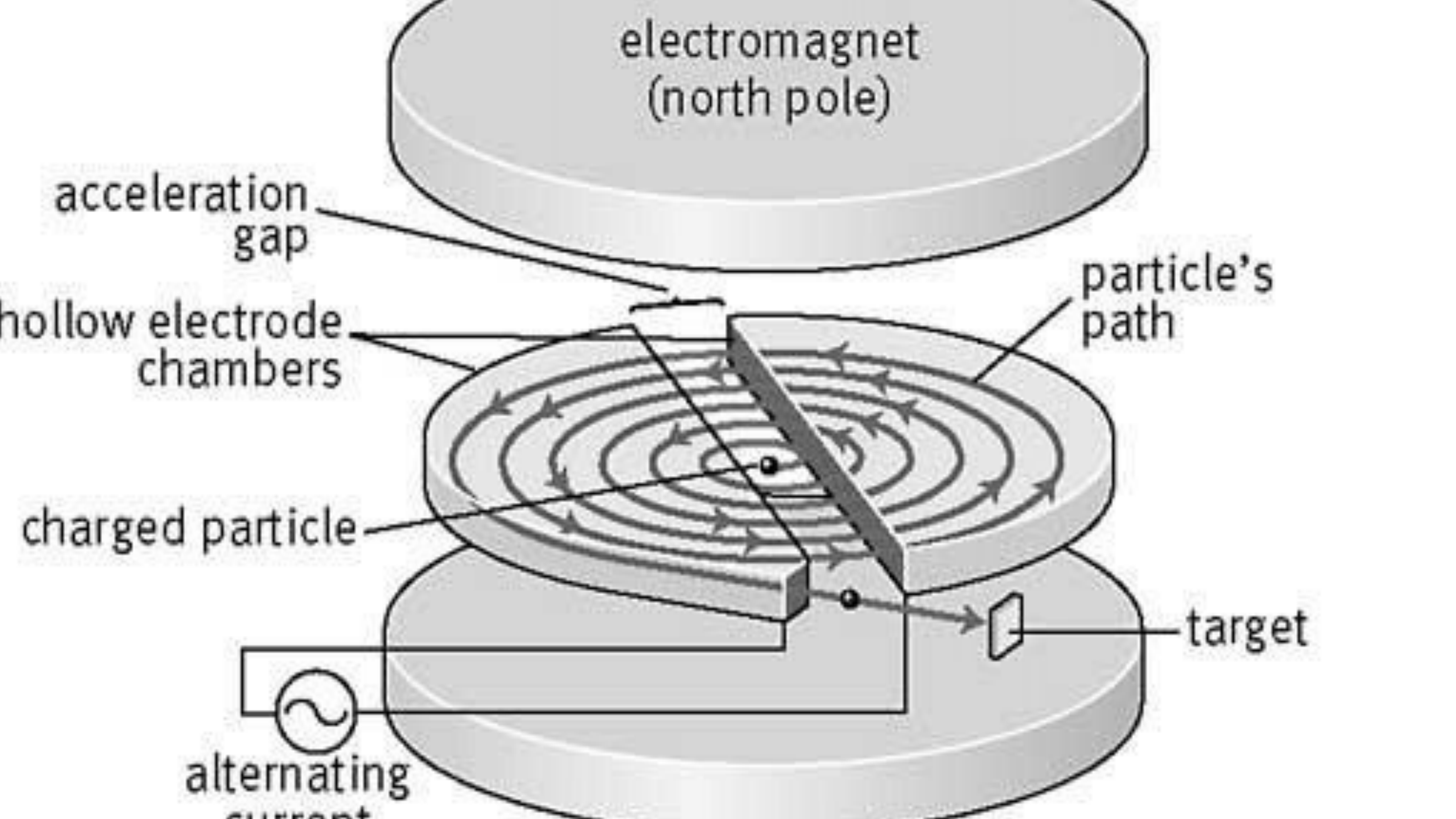
- Hershberg is Professor of History and International Affairs at GWU's Elliot School of International Affairs, and the author of *James B. Conant: Harvard to Hiroshima*.
- Conant was responsible for selecting the direction of the MED program: three paths to pure U^{235} (gaseous diffusion, electromagnetic separation and centrifuge) and one using the recently discovered Pu^{239}. He chose to proceed with all four on the grounds that selecting one would cause the proponents of the other three to take their grievances to the public.
- Mechanical problems dropped the centrifuge method from pursuit, while early indications were that Pu^{239} would be more powerful than U^{235}.

Vannemar Bush (1890 – 1974)

- Bush was an MIT engineer and inventor, who invented the first practical ANALOG COMPUTER (i.e., non-digital) in 1930. He headed the Office of Scientific Research and Development. He and Conant were aware that the Germans were avidly producing “heavy water” (D_2O), suggesting that they were pursuing plutonium production using heavy water reactors.
- In November 1942, Compton “casually remarked” that the Chicago Pile was being built under the university’s Stagg Field bleachers in Chicago, causing Conant to turn white. On December 2, 1942, the Chicago pile went critical during a routine test while it was only 2/3 constructed.

ERNEST ORLANDO LAWRENCE (1901-1958)

- Born in South Dakota, Lawrence graduated from the University of South Dakota and went to graduate school at the University of Minnesota under W.F.G. Swann. As Swann was wooed to move first to the University of Chicago and then Yale, Lawrence followed, getting his PhD from Yale in 1925. He joined the faculty at Yale and began creating small versions of accelerators. To realize his dream of a large accelerator in 1928 he accepted an appointment as Associate Professor at the University of California's Berkeley Campus.
- In 1939, he received the Nobel Prize in Physics for his pioneering work with cyclotrons. He would also earn a reputation in the 1930s as a top scientist-administrator overseeing scores of Rad Lab staff and young physicist cyclotroneers and securing funding for Laboratory research. By the outbreak of the Second World War, Lawrence had made Berkeley a major center for nuclear physics, joining Chicago and Columbia.


electromagnet
(north pole)
acceleration
gap
hollow electrode
chambers
particle's
path
charged particle
target
alternating

OAK RIDGE, TENNESSEE

- A large plot of mostly virgin timber covering a series of roughly parallel ridges was near the recently finished Tennessee Valley Authority power plants. A map with a grid of numbered and lettered coordinates was established, but for purposes of secrecy the numbers and letters were in an arbitrary order.
- The best three proposed methods of making fuel for the bomb were each given a widely separated location on this map.
- GASEOUS DIFFUSION of UF_6 at K-25 on the map in the West of the grid.
- ELECTROMAGNETIC SEPARATION of uranium ions at Y-12 near the center.
- PLUTONIUM PRODUCTION IN URANIUM PILES at X-10 in the far Southeast.
- The town of OAK RIDGE was in the grid to the North of X-10. The houses build for the civilian staff were on the ridge North of the town.
- The town of Clinton, Tennessee, is located northeast of Oak Ridge, and three miles outside the grid. The Clinton River runs through the town.

The **Clinton Engineer Works** (**CEW**) was the production installation of the Manhattan Project that during World War II produced the enriched uranium used in the 1945 bombing of Hiroshima, as well as the first examples of reactor-produced plutonium. It consisted of production facilities arranged at three major sites, various utilities including a power plant, and the town of Oak Ridge. It was in East Tennessee, about 18 miles west of Knoxville, and was named after the town of Clinton, eight miles to the north. The Manhattan District Engineer, Kenneth Nichols, moved the Manhattan District headquarters from Manhattan to Oak Ridge in August 1943. During the war, Clinton's advanced research was managed for the government by the University of Chicago.

OFFICE OF SCIENTIFIC RESEARCH AND DEVELOPMENT (OSRD)

- FDR authorized the OSRD to give the oversight of the MED to the military in March of 1942 (replacing the National Defence Research Council he had created in 1940) provided its head, James Conant (1893-1978) could assure complete secrecy. (Conant was a chemist for the army in WW1 who was responsible for our development of poison gas and in 1942 was the President of Harvard University.) But with no decision as to how to obtain the necessary fissile material, or what that fissile material might be, this couldn't happen. Hence in September 1942 the "Military Policy Committee was established to oversee the MED with VANNEVAR BUSH (1890-1974) at its head. Bush was an MIT engineer with patents for early analog computers (founded Raytheon) and head of the Carnegie Foundation at the time.
- This change shifted the concentration of research from proximity fuses and radar to fission explosives.

ARTHUR COMPTON (1892-1962)

- Compton was joint winner, with C.T.R. Wilson of England, of the Nobel Prize for Physics in 1927 for his discovery and explanation of the change in the wavelength of X-rays when they collide with electrons in metals. This so-called Compton effect is caused by the transfer of energy from a photon to an electron. This result is contrary to the laws of classical physics, which could not explain why the scattering of a wave should increase its wavelength. Its discovery in 1922 confirmed the dual nature of electromagnetic radiation as both a wave and a particle.
- From 1942 to 1945 he was director of the Metallurgical Laboratory at the University of Chicago

ENRICO FERMI (1901-1954)

- After receiving a doctorate in 1922, Fermi used fellowships from the Italian Ministry of Public Instruction and the Rockefeller Foundation to study in Germany under Max Born, at the University of Göttingen, 1923-1924. Oppenheimer was there 1926-1927.
- In 1929 Fermi, as Italy's first professor of theoretical physics and a rising star in European science, was named by Italian Prime Minister Benito Mussolini to his new Accademia d'Italia, a position that included a substantial salary (much larger than that for any ordinary university position), a uniform, and a title "Excellency".
- Fermi was little interested in politics, yet he grew increasingly uncomfortable with the fascist politics of his homeland. When Italy adopted the anti-Semitic policies of its ally, Nazi Germany, a crisis occurred, for Fermi's wife, Laura, was Jewish. The award of the 1938 Nobel Prize for Physics serendipitously provided the excuse for the family to travel abroad, and the prize money helped to establish them in the United States.

THE CHICAGO PILE-1

- Arthur Compton (1892-1962) at the University of Chicago directed the Metallurgical Laboratory while Enrico Fermi (1901-1954) built the Chicago Pile. Fermi had won the Nobel Physics Prize in 1927, although Conant thought him excessively optimistic, and was shocked that he had built the Chicago Pile under the football stadium bleachers.
- Previous piles at various university sites had been sub-critical (some of the fission occurs by cosmic rays and other neutron sources). On December 2, 1942, the Chicago Pile went critical (as they termed it, “exponential”, or requiring “neutron poisons” to keep the fission rate in check at exactly critical). Fermi’s “k” is the average number of neutrons produced by the capture of a neutron. To make an explosion by fission k must be much larger than 1. Conant was worried that k might be large enough for piles to act as power reactors but not large enough to to consume a large amount of fissile material in a small fraction of a second… to explode.

CP-2 and CP-3 AT ARGONNE

- The location of CP-1 just North of the University of Chicago's campus was of concern to MED. It was originally designed to be roughly spherical but achieved criticality before the original plans had been executed. It's maximum safe power was judged to be of the order of only a few watts. The construction of the first plutonium production reactor at Hanford was begun in June 1943, while the exterior building was being erected CP-1 was dismantled in the early months of 1943 and its components, with additions, used to build CP-2 in a forest area well outside Chicago. Cp-2 was assembled within a containment and was operated at hundred-watt power level gain the information to permit the design of B-reactor during its construction at Hanford.
- CP-3 was also built at what later became Argonne National Laboratory. It was built within a tank of heavy water and used to study nuclear reactors in general. All three CP reactors used natural uranium for fuel.

THE EFFECT OF MOISTURE ON K TESTS

- The conservation of linear momentum (mass times velocity) says that if a light projectile like a neutron (m=1) bounces off a heavy stationary object (m=238) then the projectile will lose 1/238 of its velocity.
- But if that m=1 projectile bounces off another m=1 object, like the hydrogen atoms in water, then both will leave the collision with significant velocities and the projectile will be slowed ON AVERAGE to ½ its original velocity and ¼ its original kinetic energy.
- Quantum mechanics says that the lower the kinetic energy of a neutron the much greater its chance of reacting with U^{238} rather than causing U^{235} to fission, so hydrogen in the pile can cause the measured k to be too low. (see page 66. note that "k2" should be "k^2" and "k3" should be "k^3")
- Note: although it wasn't known then, most of the neutrons are produced during the fission itself, and only a small fraction are emitted by fission product nuclei with short half lives. Without the delay of these emitted neutrons the control of reactors would be impossible.

ENRICO FERMI (1901 - 1954)

- “The First Pile” was a report written in 1946 by MED members from the University of Chicago because the then existing accounts contained no record of the development of CP-1, the first pile in Chicago itself before being moved to Argonne. “Fermi’s Own Story was the part of this report that was written by Fermi himself.
- “Atoms in the family” was written by Laura Fermi and published in 1995, as an account of the Fermi family on two continents.

LESLIE R. GROVES (1896 -1970)

- Groves wrote and published his memoirs in 1962 as "Now It Can Be Told." It was republished after his death in 1983 with an introduction by Edward Teller.
- Chicago Pile 1 on December 2, 1942, was a square pile of 45,000 ultra pure graphite bricks weighing 360 tons, 5.4 tons of natural uranium metal and 45 tons of uranium oxide in iron cans. It was penetrated by channels for wooden rods coated with cadmium foil (the neutron poison needed to control the neutrons). A container of a solution of cadmium salts was available above the pile as an emergency backup. The Germans were found to have tried graphite moderation but had used graphite with traces of boron. This had been a problem in Fermi's earlier pile in New York. The routine had been to add bricks and uranium while the rods were inserted, and then withdraw the rods slowly. In the new year, 1943, the pile was disassembled and rebuilt at a rural site which became the first National Laboratory.

AN ASIDE ON THE CHICAGO PILE

- When a uranium atom fissions, some neutrons are created and leave the other fission products at a very high velocity. U^{235} can be thought of as containing 92 protons and 235-92=143 neutrons. The nuclei of the fission products have far too many neutrons to be stable and decay by emitting neutrons with short half-lives. If it were not for the existence of these radioactive decays the chain reaction could “run away” before any control rod could be moved and power reactors and plutonium production reactors would be impossible. Fermi didn’t know if the delayed neutrons were going to be released slowly enough until he built and tested the pile.

1943

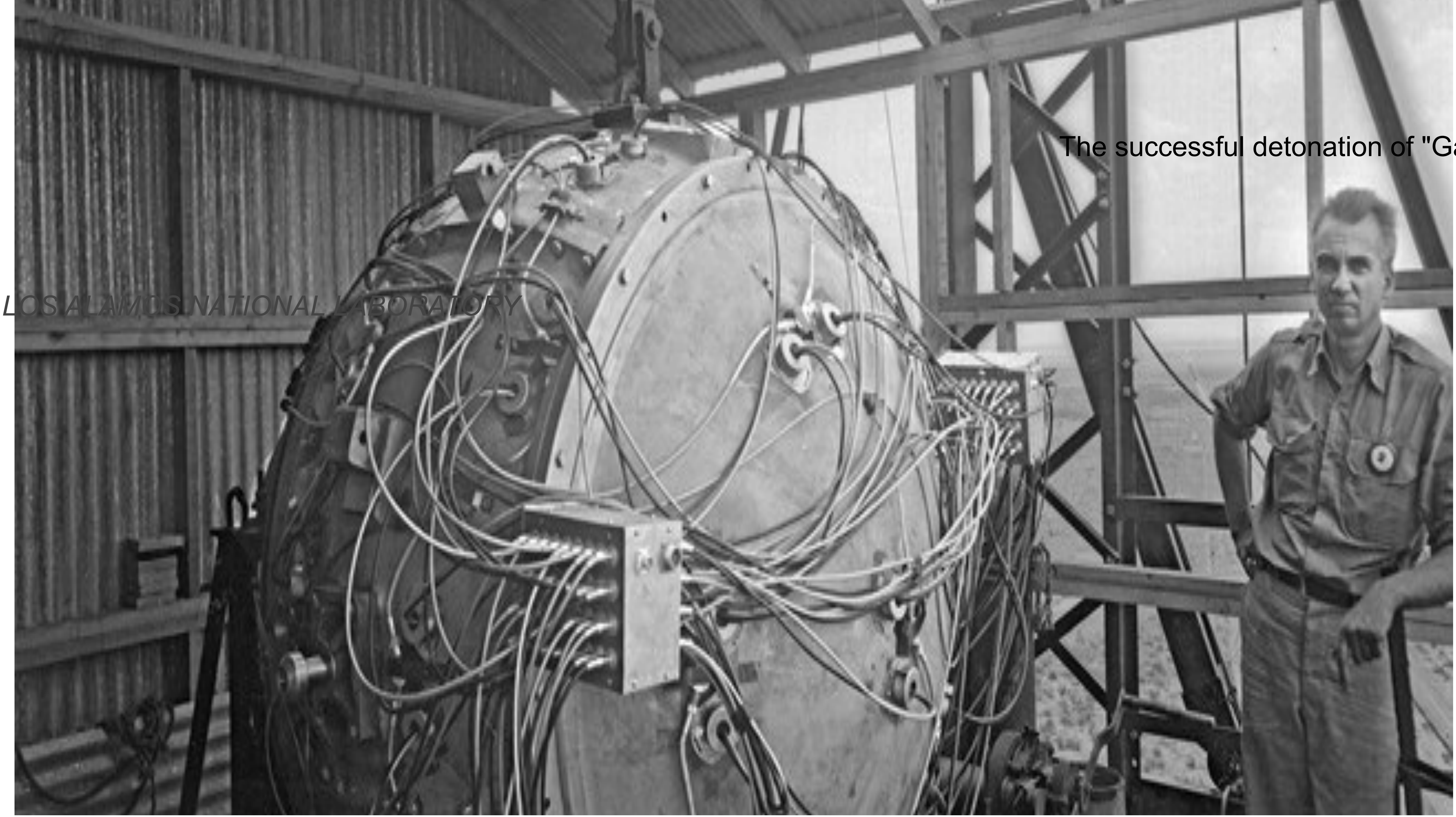
- The work on separating uranium isotopes became reduced to a contest between the gaseous diffusion of UF_6 and the magnetic separation of ionic beams. The first had a maximum enrichment of the square root of the ratio of masses of the molecules of the hexafluorides of the two isotopes, 352/349 for each diffusion step, while the second required making ions of the uranium and accelerating them in a vacuum chamber to be separated by a strong magnetic field. This required a huge amount of electrical energy, although the isotopes were separated almost completely in one step.
- Plutonium offered a third option, although it had to be made one atom at a time in a reactor less was needed for a bomb and the early “piles” could be scaled up.

OTHER PROBLEMS AROSE

- SPONTANEOUS FISSION (SF) was discovered when plutonium's properties were fully investigated. Unlike neutron-induced fission, SF competes with alpha decay and becomes more likely as the mass of the nucleus increases. SF in Pu^{239} is 100 times more likely than with U^{235} and a million times more likely in Pu^{240}, while manufacturing Pu^{239} by neutron capture of U^{238} it is impossible to avoid also producing some Pu^{240}. The "gun assembly" planned for the design of the uranium bomb to bring two sub-critical masses together rapidly will not work for a plutonium bomb.
- The comparatively trivial work of designing a gun assembly was to be joined by a huge effort to join two sub-critical pieces of fissile material to form a super-critical mass in nanoseconds rather than in microseconds.

TO APPRECIATE WHAT GROVES DID

- The Trinity bomb of July 1945 and Nagasaki bomb of August were fueled by plutonium produced by the the Hanford B-reactor. Construction of this reactor was begun on June 7, 1943, and finished in September 1944. During start-up the effects of the fission product Xe^{135} became obvious and the process had to be revised by Fermi. Like Fermi's Chicago pile the B-reactor fissioned naturally occurring uranium using graphite as a neutron moderator, but while the heat of the Chicago pile only warmed its graphite and the space under Stagg Field's bleachers, B-reactor had to be cooled by 75,000 gallons of Columbia River water per minute.


The successful detonation of "Gad
LOS ALAMOS NATIONAL LABORATORY

ROBERT SERBER (1909-1997)

- Serber was recruited for the Manhattan Project by Oppie in 1941, and was in Project Alberta at Tinian on the dropping of the bomb. When the Los Alamos National Laboratory was first organized, Oppenheimer decided not to compartmentalize the technical information among different departments. This increased the effectiveness of the technical workers in problem solving and emphasized the urgency of the project in their minds, now they knew what they were working on. So it fell to Serber to give a series of lectures explaining the basic principles and goals of the project. These lectures were printed and supplied to all incoming scientific staff, and became known as *The Los Alamos Primer*, LA-1. It was declassified in 1965.
- Serber's wife Charlotte Serber was appointed by Oppenheimer to head the technical library at Los Alamos, where she was the only wartime female section leader.

Serber discussed fission cross sections, the energy spectrum of secondary neutrons, the average number of secondary neutrons per fission (measured by then to be about 2.2), the neutron capture process in U238 that led to plutonium and why ordinary uranium is safe (it would have to be enriched to at least 7 percent U235, the young theoretician pointed out, 'to make an explosive reaction possible'). The calculations Serber reported indicated a critical mass of metallic U235 tamped with a thick shell of ordinary uranium of 33 pounds. For plutonium similarly tamped the critical mass might be 11 pounds.

Tamper always increased efficiency: it reflected neutrons back into the core and its inertia...slowed the core's expansion and helped keep the core surface from blowing away. So there might be a third basic component to their atomic bomb besides nuclear core and confining tamper: an initiator - a Po + Be source (code-named “urchin”), with the polonium attached perhaps to one piece of the core and the beryllium to the other, to smash together and spray neutrons when the parts mated to start the chain reaction. The immediate work of experiment, Serber concluded, would be measuring the neutron properties of various materials and mastering the ordnance problem - the problem, that is, of assembling a critical mass and firing the bomb.

ROBERT JUNGK (1913-1994)

- **Robert Jungk was born in Berlin. He emigrated to Paris in 1933, where he made documentary films and studied at the Sorbonne, lived in Prague from 1936-38 where he published an anti-fascist paper, and then fled to Switzerland when the Nazis entered Prague, staying there until 1945. Then, as a freelance journalist, he worked for several papers including The Observer of London, for which he covered the Nuremberg Trials.**
- **Kelly gives us Jungk to see the opposite of Groves and Oppenheimer: his books include *Brighter than a Thousand Suns, Children of the Ashes, The Nuclear State* and *The New Tyrany, How Nuclear Power Enslaves Us.***

"SWIMMING THROUGH SYRUP"

- Jungk states that WW2 "colored" the general public's view of the Manhattan Project. It wasn't a straight run from a basic plan to a foreseen triumphant conclusion. He states that the project scientists showed "determination and obstinacy ..in the Anglo-Saxon countries." But then: the scientists involved were constantly doing basic research and not planned steps in a pre-thought-out path to victory, and "barely a dozen of the total number of some 150,000 persons eventually employed on the Manhattan Project were allowed an over-all view of the plan as a whole."

RICHARD FEYNMAN (1918 - 1988)

- Feynman is famous for an accounting method he developed to keep track of terms of a long calculation (Feynman's diagrams). Along with Julian Schwinger and Shin'ichiro Tomonaga, Feynman shared the 1965 Nobel Prize in Physics for their "fundamental work in quantum electrodynamics, with deep-ploughing consequences for the physics of elementary particles." The three of them had independently come up with different ingenious ways to reconcile the electromagnetic field theory of the 19th century with the quantum mechanics of the 20th. While Tomonaga and Schwinger approached the problem using highly mathematical methods, Feynman tackled it in his own highly creative and original way; by creating his iconic "Feynman Diagrams", innovative pictures that provided a clear visual explanation of every possible interaction between electrons and photons.
- His contributions to the MED were many minor suggestions at Los Alamos. He cam to Los Alamos only because they found a sanitarium for his dying bride.

STEPHANE GROUEFF (1922-2006)

- Groueff was studying law at the University of Geneva when the communists seized power in Bulgaria in 1944. His father was Chief of Cabinet of King Boris III and was executed by the communists in 1945. Groueff lived in exile for 46 years: first in Switzerland and later in France and the US. He did not return to Bulgaria until 1990 after the collapse of the communist regime. He is the author of eight non-fiction books in French and English, one being, *Manhattan Project: The Untold Story of the Making of the Atomic Bomb*. As a historian of the construction of the first atomic bomb, he was invited as a speaker at the 60th commemoration of the Manhattan Project in Washington D.C. and in Oak Ridge, Tennessee.

NIELS BOHR (1885 – 1962)

- Bohr, along with Pauli and Heisenberg, formed one faction on the Solvay council, being in favor of belief in the message the new Quantum Mechanics seemed to be telling mankind. The other extreme was led by Einstein and his faction, mostly Rosen and Podolski, who claimed QM was an “incomplete theory” because it denied cause and effect. In 2022 the Nobel Prize was shared by three experimentalists for their work on the “Bell Experiment” the results of which showed Einstein to be wrong and Bohr correct.

BOHR'S ESCAPE

- During the 1930s, Bohr helped refugees from Nazism. Bohr offered the refugees temporary jobs at his institute, provided them with financial support, arranged for them to be awarded fellowships from the Rockefeller Foundation, and ultimately found them places at institutions around the world. After Denmark was occupied by the Germans in April 1940, he met with Heisenberg, who had become the head of the German nuclear weapon project. In September 1943 word reached Bohr that he was about to be arrested by the Germans, so he and his wife fled to Sweden. From there, he was flown to Britain in a DH Mosquito, where he joined the British Tube Alloys nuclear weapons project, and was part of the British mission to the Manhattan Project. After the war, Bohr called for international cooperation on nuclear energy. He was involved with the establishment of CERN.
- When the news of Bohr's escape reached Britain, Lord Cherwell sent a telegram to Bohr asking him to come to Britain. Bohr arrived in Scotland on 6 October 1943 in a de Havilland Mosquito operated by the British Overseas Airways Corporation (BOAC). The Mosquitos were unarmed high-speed bomber aircraft that had been converted to carry small, valuable cargoes or important passengers. By flying at high speed and high altitude, they could cross German-occupied Norway, and yet avoid German fighters. Bohr, equipped with parachute, flying suit and oxygen mask, spent the three-hour flight lying on a mattress in the aircraft's bomb bay. During the flight, Bohr did not wear his flying helmet as it was too small, and consequently did not hear the pilot's intercom instruction to turn on his oxygen supply when the aircraft climbed to high altitude to overfly Norway. He passed out from oxygen starvation and only revived when the aircraft descended to lower altitude over the North Sea. The Mosquito was largely made of wood and had a top speed of over 400 MPH.