RADIATION EFFECTS ON MATTER

- IMMEDIATELY AFTER THE DISCOVERY OF X-RAYS, IT WAS OBSERVED THAT RADIATION CHANGES MATTER
- 1901 P. Curie FOUND THAT RADIUM PLACED ON HIS SKIN WOULD CAUSE WOUNDS THAT DID NOT EASILY HEAL.
- GLASS AMPULES CONTAINING mg QUANTITIES OF RADIUM DARKENED WITHIN A FEW MONTHS & SEVERELY CRACKED.
- AMONG THE MANY RADIATION EFFECTS OBSERVED
  - FLUORESCENCE INDUCED IN DIFFERENT SALTS & CHANGES TO THEIR CRYSTALLOGRAPHIC FORM
  - METALS WERE FOUND TO LOSE THEIR ELASTICITY & BECOME BRITTLE
  - RADIATION WAS FOUND TO HAVE PROFOUND EFFECTS ON THE CHEMICAL COMPOSITION OF SOLUTIONS & GASES.
    - ↳ WATER, AMMONIA, & ORGANIC SUBSTANCES DECOMPOSED INTO MORE ELEMENTARY CONSTITUENTS
    - ↳ THEY ALSO COMBINED INTO MORE COMPLEX POLYMERIC PRODUCTS.

RADIATION DECOMPOSITION ≡ RADIOLYSIS ≡ OF WATER CAUSED BY PRODUCTION OF HYDROGEN + OXYGEN & FORMATION OF HYDROGEN PEROXIDE

CONVERSELY WATER COULD BE SYNTHESIZED BY IRRADIATION of $H_2 + O_2$ MIXTURE. 2/

1911 S, LIND MEASURED THAT 1 g, I C: R_a CAUSED 0.7 g of OZONE IN AIR PER HOUR.

↳ FIRST "RADIATION YIELD" MEASUREMENT

THE INAUGURAL QUANTIFICATION OF RADIATION-INDUCED CHANGES

CHEMICAL EFFECTS OF RADIATION DEPENDS ON

THE COMPOSITION of MATTER & AMOUNT OF ENERGY DEPOSITED FROM RADIATION.

1) CHARGED PARTICLE → DIRECT
2) NEUTRAL PARTICLES → INDIRECT
3) E.M. RADIATION

ENERGY IMPARTED TO GIVEN VOLUME IS

$$\epsilon_{imp} = \epsilon_{in} + \sum Q - \epsilon_{out}$$

- ϵ_{in}: KE in, E_γ etc
- $\sum Q$: SUM OF ALL Q-VALUES FOR NUCLEAR TRANSFORMATIONS (NUCLEAR TRANSFORMATIONS)
- ϵ_{out}: ENERGY LEAVING VOLUME

CHARGED PARTICLES

WE'VE LEARNED THAT ENERGY IS MAINLY ABSORBED THROUGH IONIZATION + ATOMIC EXCITATION. (e^+ ANNIHILATION, e^- BREM...) ← NEGLECTED

AVERAGE W ENERGY, ENERGY FOR ION-PAIR IN GASEOUS MATERIAL IS BETWEEN 25 + 40 eV. ~ FAIRLY INDEPENDANT OF RADIATION TYPE

IONIZATION POTENTIALS (j) ARE LESS THAN W VALUES.

~ ≤ 5 eV per atom

SO W - j MUST BE USED FOR EXCITATION.

→ SEVERAL EXCITED ATOMS ARE PRODUCED FOR EACH ION PAIR.

Q: SPECIFIC ENERGY LOSS OF A PARTICLE IN MATTER IS

$$S = dE_{loss}/dx \quad \left(J/m\right)$$

1ST APPROX S IS DETERMINED BY ATOMIC COMPOSITION + INDEPENDENT OF CHEMICAL BONDS.

- SPECIFIC IONIZATION

$$J = dN_j/dx \quad (\text{ION. PAIRS}/m)$$

$$S = W J \left(J/m\right)$$

{ NOTE MASS STOPPING POWER $\left(S/\rho = MeV/g \cdot cm^2\right)$ }

$$L.E.T. = dE_{ABS}/dx$$

HIGH ENERGY e^- (ALSO APPROX γ-RAYS)

β^- PARTICLES (ALSO APPROX. SOFT X-RAYS)

PROTONS

DEUTERONS

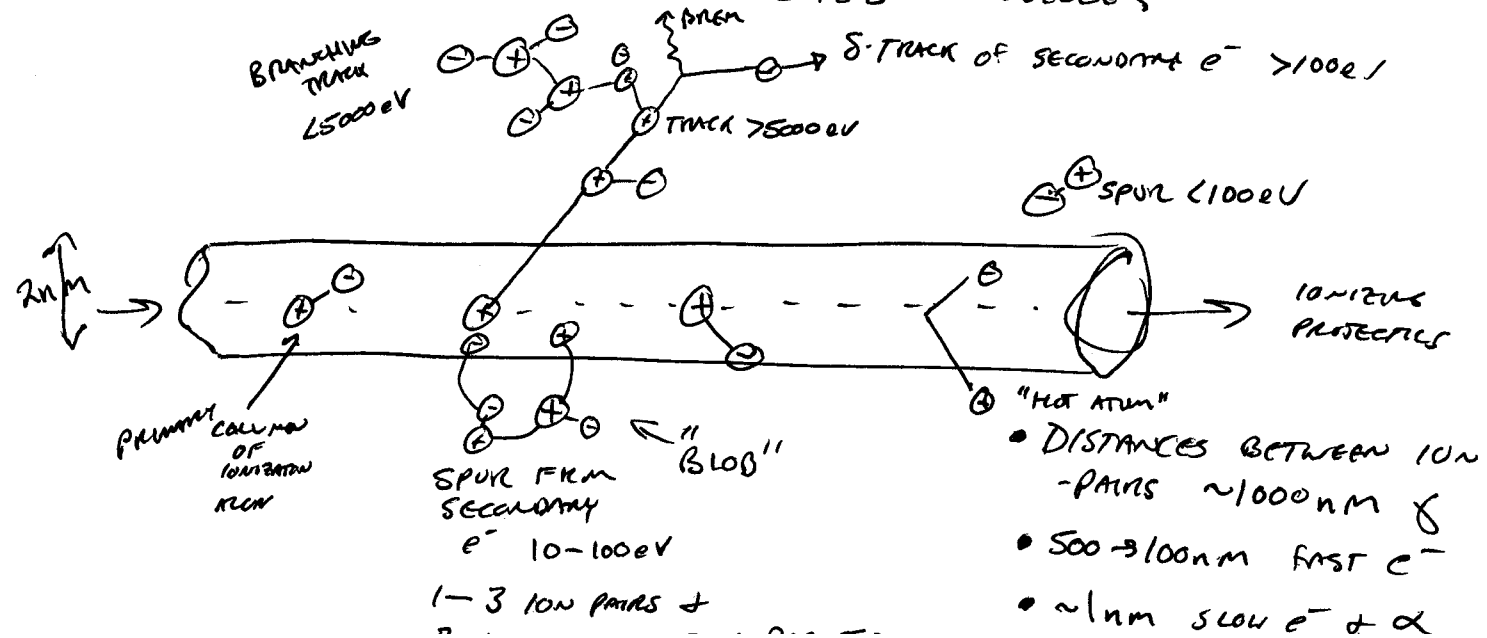
α-PARTICLES

HEAVY ION (ION N, O, ETC)

FISSION FRAGMENTS.

RADIATION TRACKS

ENERGY LOST WHEN A HIGH-ENERGY CHARGED PARTICLE IS SLOWED IN MATTER GIVES RISE TO A TRAIL OR "TRACK" OF IONIZED & EXCITED MOLECULES



$R \equiv 2.58 \times 10^{-4}$ C/kg

CORRESPONDS TO 1.61×10^{15} ION PAIRS/kg IN AIR OR 8.8×10^{-3} J/kg WITH AVG ION-PAIR E 34 eV

$D = dE_{ABS}/dm$ ← UNIT MASS

$E_{ABS} = E_{in} - E_{out}$

RADIATION CHEMICAL YIELD G-VALUES

$G(X) \equiv \frac{\#\text{ OF MOLECULES OF X TRANSFORMED}}{100\text{ eV}}$

MOST REACTIONS HAVE G-VALUES LESS THAN 10.

METALS

METALS ARE A SOLID LATTICE OF ATOMS WHOSE VALENCE ELECTRONS ARE NOT CONSIDERED TO BELONG TO ANY PARTICULAR ATOM, BUT RATHER TO A PARTICULAR FILLED CONDUCTION BAND.

RADIATION CAN CAUSE EXCITATION OF BOUND e^- IN THE ATOM TO THE CONDUCTION BAND

γ-RAYS & e^- HAVE LITTLE EFFECT ON METALLIC PROPERTIES, BUT HEAVY PARTICLES CAUSE SERIOUS DAMAGE THROUGH COLLISION WITH ATOMS IN THE METAL LATTICE NETWORK.

→ RESULTS IN DISPLACEMENTS

OF ATOMS FROM THEIR LATTICE POSITIONS.

OF DISPLACEMENTS (N_{DISP}) DEPENDS ON THE AMOUNT OF ENERGY TRANSFERRED IN THE COLLISION EVENT (E_{TR}) TO THE RECOILING ATOM (→ TARGET) + ENERGY REQUIRED FOR DISPLACEMENT

$$E_{DISP} \sim 10 \rightarrow 30 \text{ eV}$$ FOR MOST METALLIC MATERIALS

$$N_{DISP} \leq E_{TR} / 2 E_{DISP}$$

CALCULATE ENERGY X-FER BY ASSUMING PURELY ELASTIC COLLISIONS BETWEEN HARD SPHERES. LIKE BEFORE-

1.5 MeV $\gamma N \rightarrow E_{TR}(MAX)$

425 keV IN CARBON
104 keV IN Fe
25 keV IN U

SO WITH $E_{DISP} \approx 25 eV$

8500 C
2080 Fe
500 U

DISPLACEMENTS CAN OCCUR PER ABSORBED FISSION 6N
(NEGLECTING NUCLEAR REACTIONS)

THESE ATOMIC DISPLACEMENTS CAUSE MANY CHANGES IN THE PROPERTIES OF METALS.

- ELECTRICAL RESISTANCE
- VOLUME
- HARDNESS, TENSILE STRENGTH INCREASE
- DENSITY DECREASE
- DUCTILITY DECREASE

- MICRO CRYSTALINE PROPERTIES ARE PARTICULARLY INFLUENCED BY IRRADIATION.

REACTOR VESSEL
- STAINLESS STEEL (18% Cr 8% Ni) BECOMES BRITTLE FROM IRRADIATION DUE TO THE FORMATION OF MICROSCOPIC He Bubbles

(n, α) REACTIONS ^{54}Fe + (n, α) WITH LIGHT ELEMENTS

YOU COULD IMAGINE THIS IS EVEN WORSE IN U METAL OF REACTORS — FISSION PRODUCTS SOME FISSION PRODUCTS ARE GASES

↳ HENCE MODERN REACTORS USE NON-METALIC URANIUM COMPOUNDS

ANNEALING

DISPLACED ATOMS MAY RETURN TO THEIR ORIGINAL LATTICE POSITIONS THROUGH DIFFUSION, ASSUMING THEY ARE NOT TRAPPED REQUIRING SOME ENERGY FOR ACTIVATION.

→ ENERGY CAN BE PROVIDED BY HEAT OR SUBSEQUENT IRRADIATION. OF e^- OR γ-RAYS. (ASSUMING THESE DO NOT CAUSE NEW DISPLACEMENTS)

THIS "HEALING" IS REFERED TO AS ANNEALING.

ANNEALING $\propto$ TEMPERATURE

~ 10 kGy

33:17 min

55.51 + 10 min

INORGANIC COMPOUNDS

TIME FOR HIGH ENERGY PARTICLE TO PASS BY AN ATOM $\leq 10^{-16}$ S. THIS IS WHEN IT BECOMES EXCITED OR IONIZED, BUT, LESS DIRECT COLLISION, IT DOES NOT ~~BECOME~~ CHANGE POSITION.

- EXCITED ATOMS RE-LAX THROUGH EMISSION OF FLUORESENCE RADIATION, $\sim 10^{-8}$ S.
- IONIZATION CAN RESULT IN TRAPPING OF e^- & PRODUCTION OF HOLES AT IMPURITY SITES.
  - → THIS EXCESS OR DEFICIENCY ~~CHARGE~~ OF CHARGE LEADS TO ELECTRONIC STATES WITH ABSORPTION BANDS IN VISIBLE OR UV SPECTRUM.

I.e. LiCl → WHITE → YELLOW
LiF → BLACK
KCl → BLUE

HEATING THESE WILL RETURN THEM TO NORMAL STATE.

I.e. T.D

FOLLOWING A COLLISION BETWEEN A HEAVY PARTICLE (n, p, etc) AND A TARGET ATOM IN A CRYSTALINE MATERIAL, THE RECOILING ION PRODUCES LATTICE VACANCIES & UPON STOPPING, MAY OCCUPY A NON-EQUILBRIUM INTERSTITIAL POSITION.

→ THE LATTICE DEFECTS INCREASE THE ENERGY CONTENT OF THE CRYSTAL,

→ EX: SEMICONDUCTORS, WHERE CONCENTRATION OF CHARGE CARRIERS IS VERY SMALL, HAVE THEIR CONDUCTIVITY REDUCED BY INTRODUCING LATTICE DEFFECTS FROM IRRADIATION.

→ THE PRODUCTION OF INTERSTITIAL ATOMS MAKES THE GRAPHITE MODERATOR IN NUCLEAR REACTORS STRONGER, HARDER, & MORE BRITTLE.

→ SINCE THESE DISLOCATED ATOMS ARE MORE ENERGETIC THAN THE ATOM IN THE LATTICE, LEAD TO AN ENERGY STORAGE

THIS IS THE WIGNER EFFECT, WHICH CAN BE QUITE SIGNIFICANT

- FOR REACTOR GRAPHITE @ 30°C

VALUES AS HIGH AS 2000 kJ/kg FOR FLUENCES OF 2×10^{21} n/cm^2

↳ ROOM TEMPERATURE THEY CAN RETURN TO THEIR POSITIONS VERY SLOWLY ... ANNEALING.

↳ THIS RATE IS TEMPERATURE DEPENDENT. Q DO U SEE THE PROBLEM IF THE ELIMINATION OF INTERSTITIAL ATOMS OCCURS TOO RAPIDLY, RELEASE OF ENERGY CAN HEAT MATERIAL TO IGNITION ?

— WIND SCALE VIDEO —

33 min ± 3

55 min ± 10 min