Nuclear and Radiation Safety: Disaster Preparedness and Response

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Disclosures

- The content of this presentation does not relate to any product of a commercial interest. Therefore, there are no relevant financial relationships to disclose.

- The speaker is currently the medical consultant at a nuclear energy plant in New England.

Objectives

- Have an understanding of some of the unique weapons used in war and terrorism throughout history.
- Have a basic understanding of radiation, including the terms and units of measure used to describe radiation.
- Know that there are ways to protect yourself and others and survive a radiation incident.


SPEED
LIMIT
85
Chevys
Just do
the Best
you Can


NUCLEAR WARHEAD
HANDLE WITH CARE
DEAR JOHN

Historical reference: BC

- Assyrians 600 B.C. – poisoned wells with rye ergot (alkaloid)
- Solon 600 B.C. – “Incapacitating is better”
  - Poisoned River Pleisthnes with root of Hellebores plant (skunk cabbage)
- Hannibal 200 B.C. – Intentional retreat from encampment
  - Left behind wine treated with Mandagora
  - Romans drank it, suffered narcotic effects
  - Also in naval battles hurled snakes onto other vessels

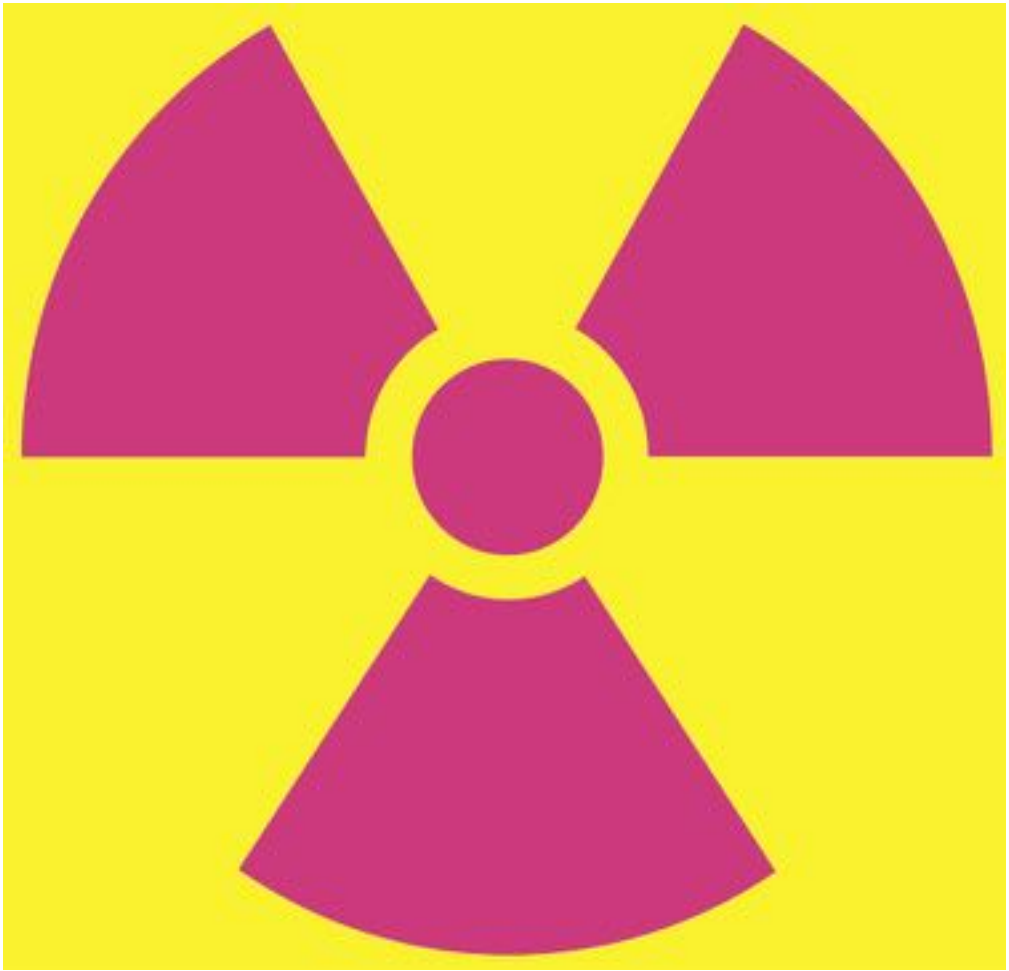
History: Middle ages

- Kaffa 1346 – Tartars used trebuchet's to hurl cadavers into Kaffa
- Carolstein 1422 – Coribut threw bodies of his dead soldiers into city
- Belgrade 1456 – Turks soaked rags with toxic gas
- Cortez 1520 – Introduced smallpox to the Aztecs
- Mexico 1532 – Francisco Pizzaro gave smallpox blankets to the Incas
- Russian-Swedish war 1710 – Plague infected bodies hurled in Estonia
- French-Indian Wars 1763
- American Revolution – Gen. Washington ordered inoculation of troops

History: 20th century

- Chemical weapons (phosgene, chlorine, mustard gas) in WWI
- Biologic agents developed/used by multiple countries in WW's I & II
  - Anthrax
  - Pseudomonas glanders
  - Vibrio Cholera
  - Plague infested flea bombs
- Poisoning of water sources
- Japan attempts to poison League of Nations with cholera (1931)
  - Unit 731

Wait a minute, these are all Chemical and Biological agents…where is the radiation?

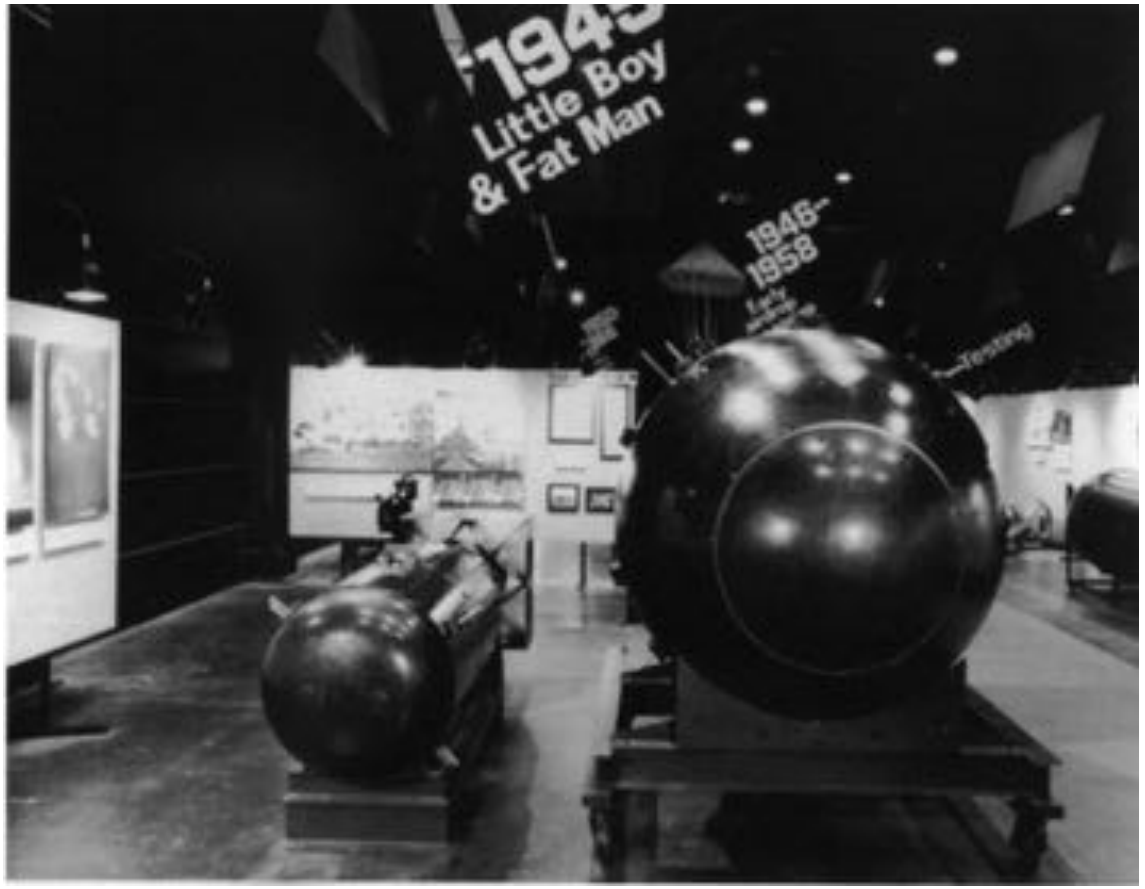


With any act of terrorism…

- …the goal is to create fear, sow chaos, and disrupt society, often by using minimal resources.
- Terrorism = the use of intentionally indiscriminate violence as a means to create terror among masses of people; or create fear to achieve a financial, political, religious or ideological aim.

Discovery of x-rays by Wilhelm Roentgen

Testing and use of atomic bombs, 1945



Old policy: Duck and cover

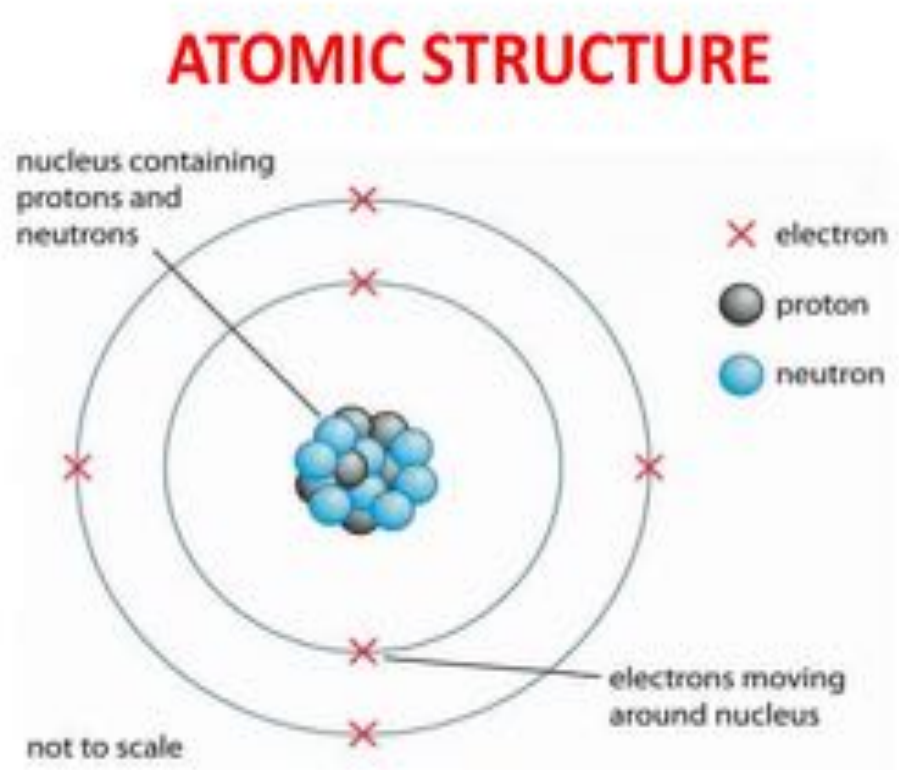
Radiation as a form of warfare or terrorism

- Radiologic weapons typically thought of as WMD's
  - Very destructive
  - Large scale
  - Limited survivability
- Small scale, targeted use
  - "Dirty" bombs
  - Individual attacks – A. Litvinenko poisoning by Po-210 Russian FSB

KGB assassination of Alexander Litvinenko

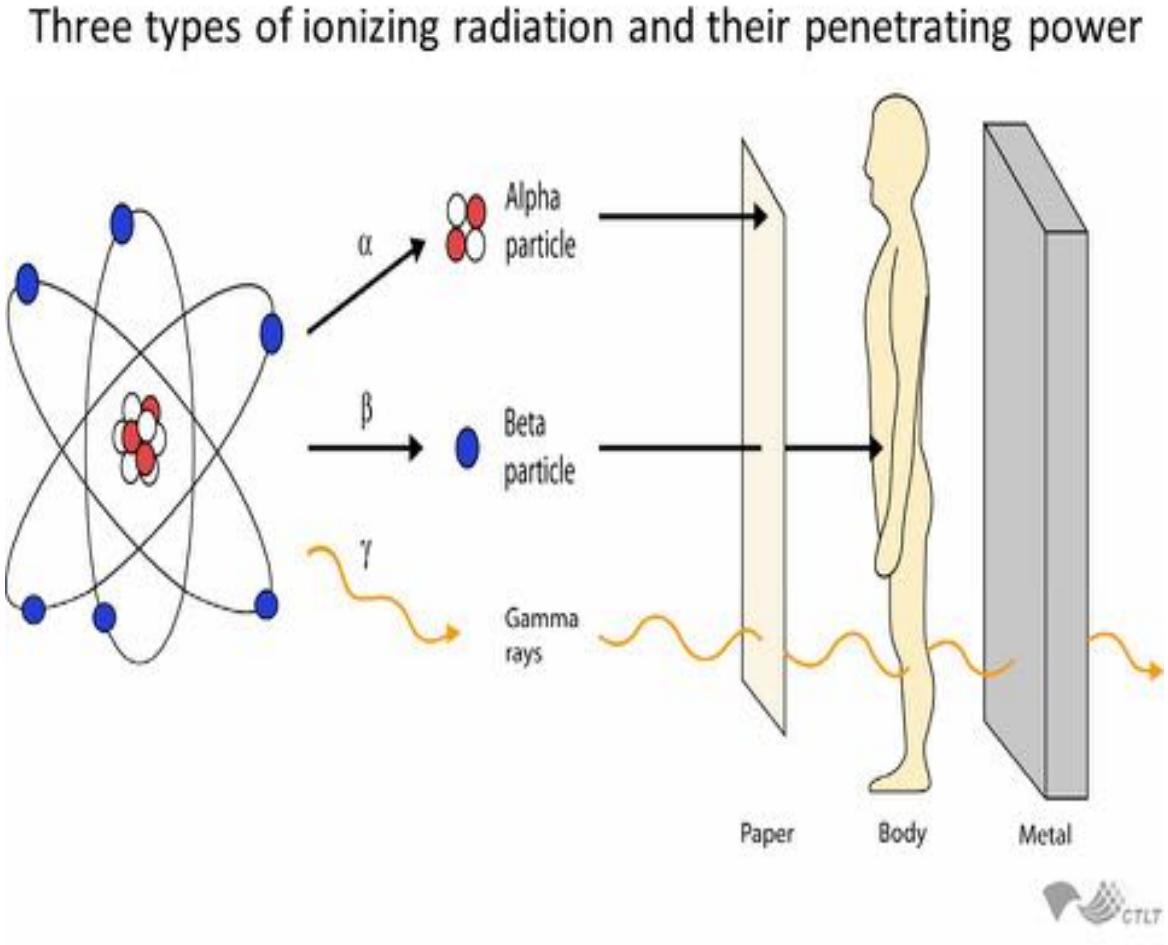
Radiation 101

- Atom = basic building blocks of all matter
  - Nucleus
    - Protons in defined numbers, positive charge
    - Neutrons, no charge, “spacers”
  - Outer shell(s)
    - Orbiting electrons, negative charge
- Release of energy from atoms
  - Particles - have mass and energy
  - Waves - no mass, just pulsating waves of electric/magnetic energy



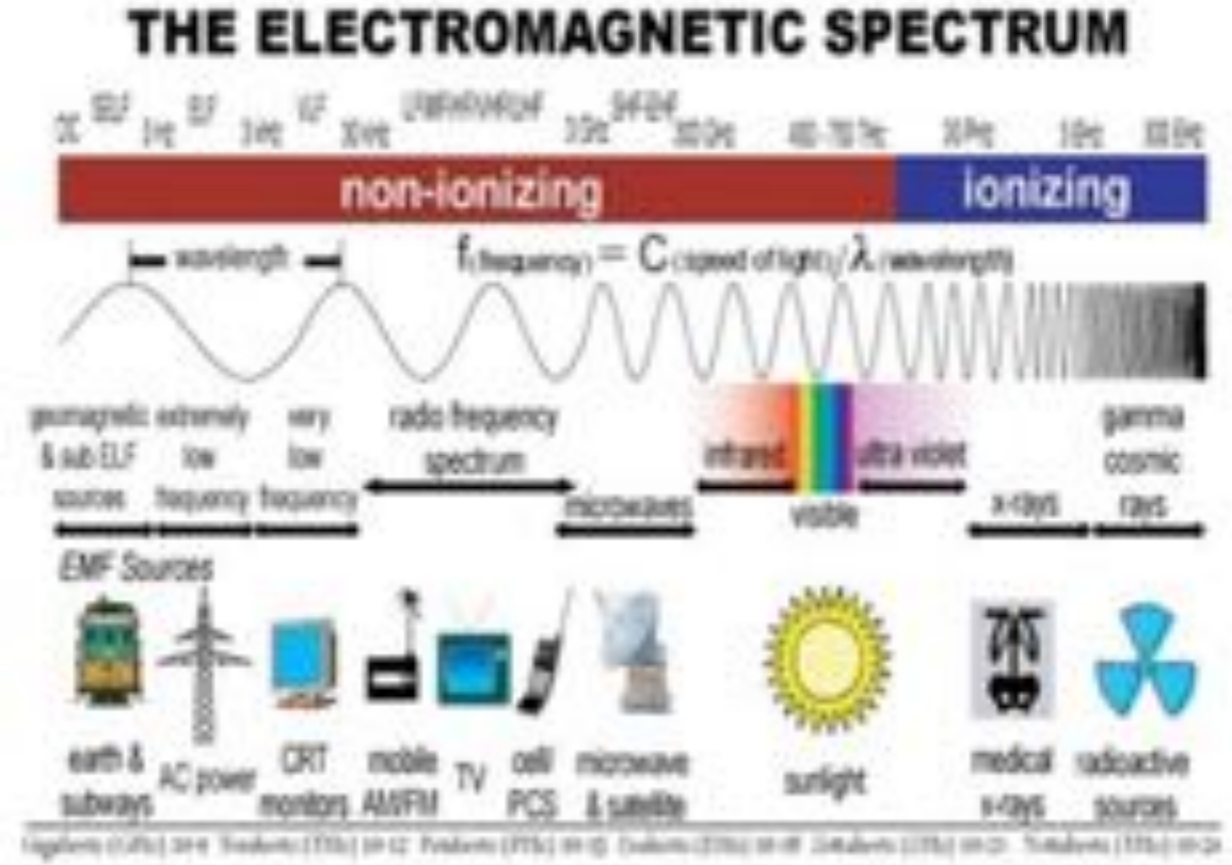
Types of radiation and particles

- Alpha - 2 protons/2 neutrons, short path with dense ionization
  - Intermediate energy: 4-8 MeV!
  - Travel limited: 1-2 cm in air, and only about 60-70 microns into tissue
- Beta – Low energy, less interaction
  - Travel: 1-2 meters in air, 1cm in tissue
- Protons – similar to alpha, but travel farther, more hazardous
- Gamma – electromagnetic energy emitted from nucleus – Dangerous!
- Xrays – similar to gamma, but long wavelength, low frequency, so lower energy

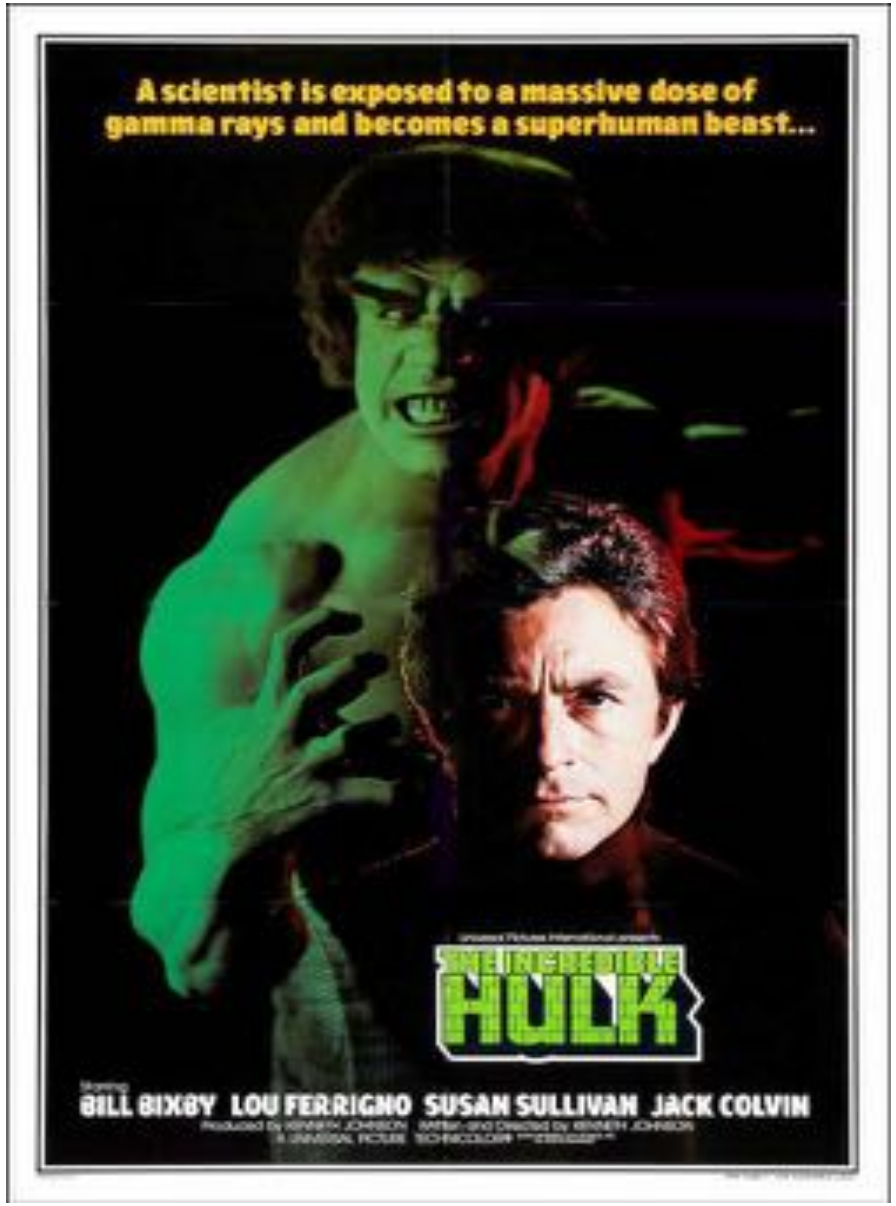


Ionizing radiation biologic effects

- Biologic damage from radiation occurs when high speed particles (usually electrons) travel through cells, depositing energy
  - 1) Knock out electrons from biomolecules (ionization)
  - 2) Breakup of chemical bonds
  - 3) Variety of other biochemical damages



Gamma rays effects?



Radiation units

- Radiation “dose” is similar to that of drugs or chemicals
- Think of it as amounts of energy absorbed by the body
- Dosing of radiation can be:
  - Acute – one time exposure
  - Chronic – cumulative dose over time
- There are two system of units to describe radiation “dose”
  - US: Rads, rems and curies
  - International: Gray, Sievert, and Becquerel
    - The Int’l system is becoming more popular,
    - Produces more practical numbers to describe effect of commonly encountered doses

Radiation units

US system

Unit (symbol) – characteristic

Relationship: US to Int'l

- Rad (rad) - Absorbed dose
  - 1 Rad = 0.01 Gray
- Rem (rem) - Dose equivalent/ Biologic Effectiveness
  - 1 rem = 0.01 Sievert
- Curie (Ci) – Activity, or rate of radioactive decay
  - 1 Ci = 3.7 x 10^{10} disintegration/sec

International System

Unit (symbol) – characteristic

Relationship: Int'l to US

- Gray (Gy) - Absorbed dose
  - 1 Gray = 100 Rad
- Sievert (Sv) – Dose equivalent/ Biologic Effectiveness
  - 1 Sievert = 100 Rem
- Becquerel (Bq) – Activity, or rate of radioactive decay
  - 1 Bq = 1 disintegration/sec = 3.7 x 10^{-10} Ci

Radiation doses in perspective

- Radioactivity has existed for millions of years – in earth's crust, building materials, food, air…everywhere.
- Most people exposed to 360 millirems/year from natural sources
- Dose of radiation received vs. likelihood of adverse effects
  - Source of radiation - Duration of exposure
  - Distance from source - Shielding
- Smoking 1.5 pack/day x 1 year – 16 rems to bronchus
- Exposure to 100 rads (1 Gy) – symptoms develop within hours/days
- Exposure to 450 rads (4.5 Gy) – 50% lethality within 60 days

Type of radiation exposure

- **External irradiation** – exposure to penetrating radiation from an external source; can be absorbed by, or pass through body
  - X-ray is an example
  - Following exposure, a person is NOT radioactive
- **Contamination** – radioactive materials (gases, liquids or solids) that are on or in a persons body
  - These individuals are at significant risk due to proximity to radiation
- **Incorporation** – uptake of radioactive materials by body cells, tissues and/or organs (e.g., bone, liver, thyroid, kidney), after internal exposure

Radioactive or not?

Detection – Three major categories

- Portable Instruments
  - Used by hospital/prehospital personnel
  - Geiger-Muller counter – detects beta and gamma only
  - Pancake probe – Detects alpha, beta, and gamma
    - Use shielding to differentiate (paper for α, aluminum for β)
- Lab instruments – Neutron meters
- Personal Dosimeters
  - Thermoluminescent Dosimeter (TLD)
  - Quartz Fiber Dosimeter

Background radiation

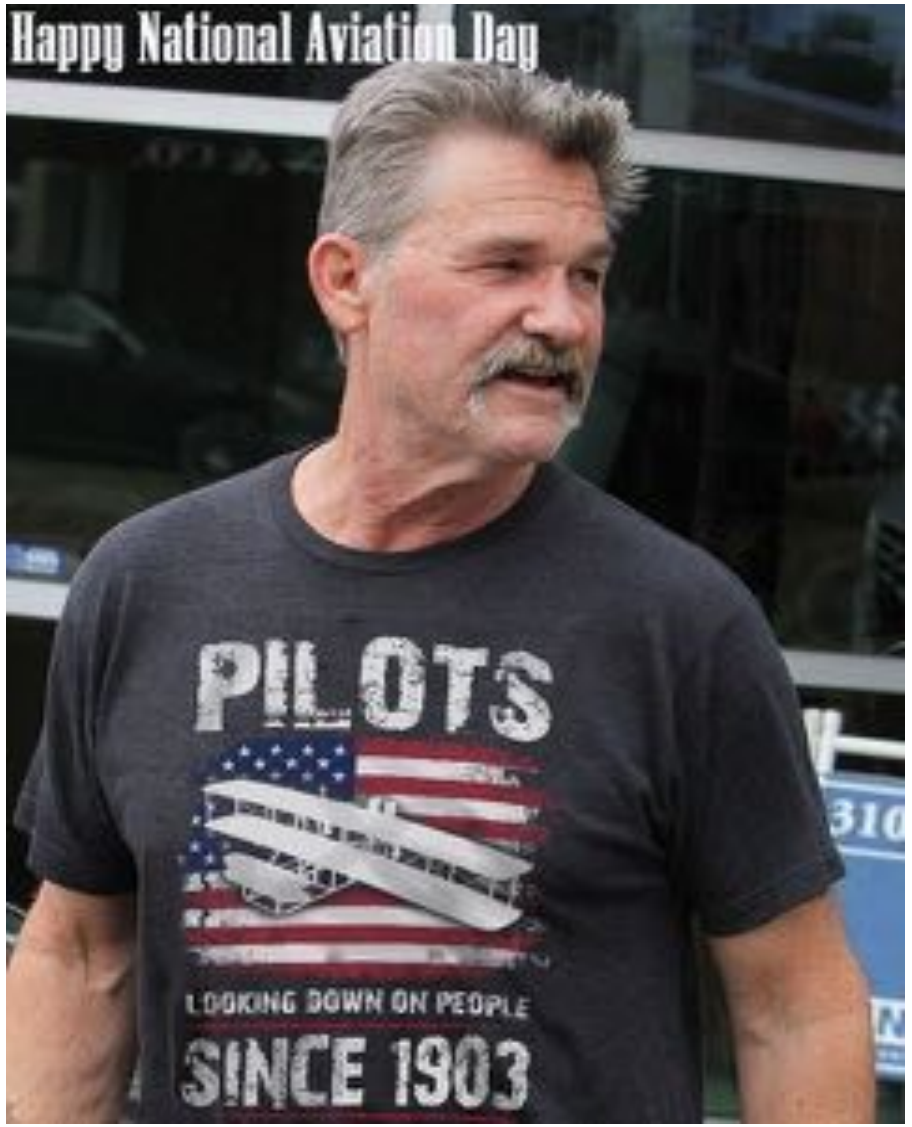
- We live in a radiation environment – 360 mrem/year in US (average)
  - Natural/background (~87%), medical (~11.5%), nuclear testing fallout (~0.5%), air travel (~0.5%), occupational exposure (~0.5%)
- Radiation exposure from medical source- approximately 11.5% annual
  - Chest x-ray → 0.1 mSv vs. CT scan → 7 mSv (70x as much radiation!)
  - Weigh benefit vs. risk when deciding on imaging
- Radiation exposure from air travel*
  - Higher radiation standing in line than going through x-ray backscatter scanner
  - X-ray scanner dose equivalent to:
    - Standing on terra firma for 1.8 minutes
    - Sitting on a plane flight for 12 seconds
    - Would have to have 22,500 scans/year to reach maximum yearly safe dose (600 mrem)

*Source: American Association of Physicists in Medicine, AAPM report No. 217, Radiation Dose from Airport Scanners.

Exercise: Radiation exposure from air travel

- "Gold medalist" of airline travelers – 18,000,000 miles in 14 years!
  - Radiation dose on typical airline flight – 0.003 mSv/hr
  - Estimated cancer risk rate of 0.005% per mSv
  - Time flying (~32.7k hours) x 0.003 mSv/hr x 0.005% = **0.5% increase risk**
  - Relatively small increase in risk for person with most travel
- What about airline pilots/flight attendants?
  - Above flyer→ 2,000 hrs/year
  - Pilots average <1,000 flight hours/year
- What about standard travelers?
  - To determine your risk: Your total miles / 3,700,000,000 = approximate odds
  - Let's say it's 370,000 miles. Divide by 3.7 billion = 0.01% increase risk
  - 370,000 miles is roughly 150 round trips from BOS to LAX

Relatively low radiation risk from flight

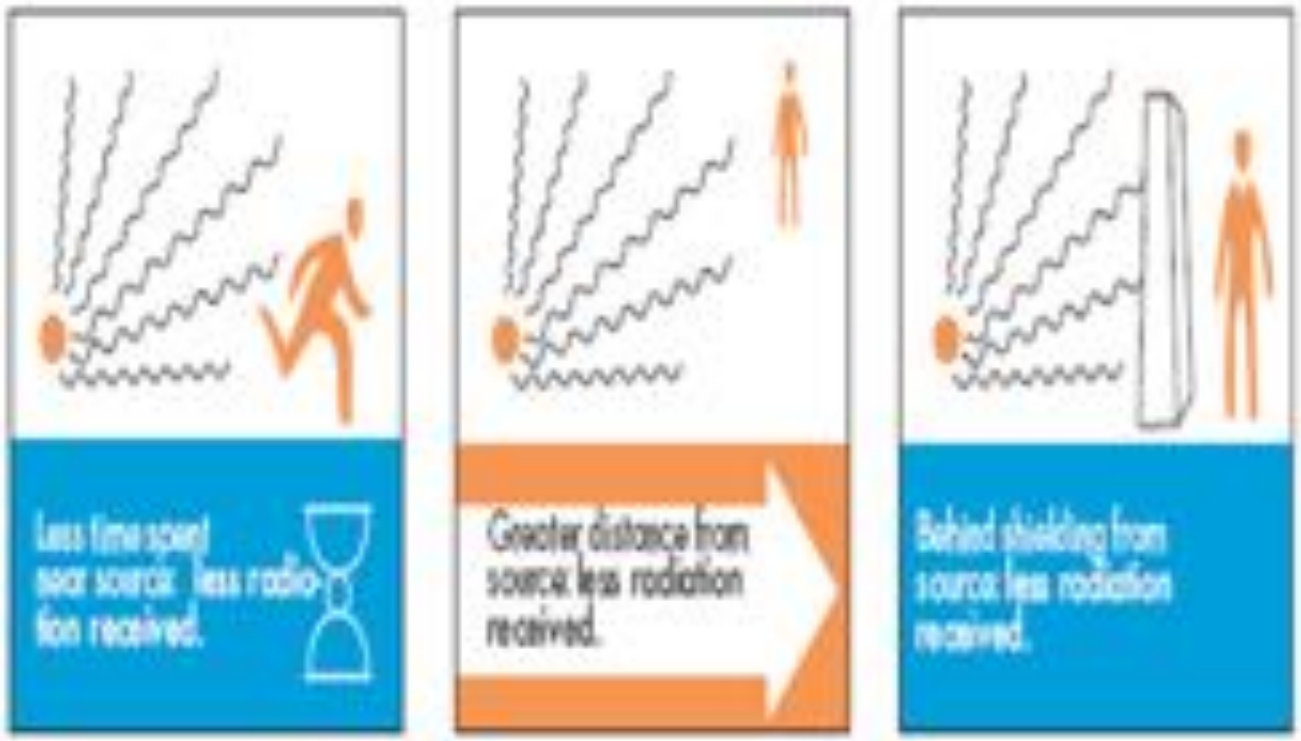


Personal Protection and Decontamination

- Personal protection for radiation incidents should be integrated into an all-hazards approach to disaster planning.
  - Predetermination of hospital/ED layout
  - Staffing for triage, decon, management of victims
  - Proper equipment/training of PPE use
  - Availability of expert advice
  - Awareness of/Agreements with specialized treatment centers

Personal protection

- Remember principles of protection
  - *Time* - Reduce time, rotate staff
  - Distance - Inverse square law
    - Double the distance, ¼ the dose
    - Dose of 8 rads at 1’ away → 2 rads at 2’ away → 0.5 rads at 4’ distance
  - *Quantity* – Remove clothing (double bag, label w/ name DOB, time removed)
  - *Shielding*
- Determine type of radiation – particles vs. energy waves
  - Particle wave blocked by shielding
  - Electromagnetic radiation can only be attenuated
- Understand equipment/PPE



Personal protection

- Alpha (α) – Intermediate energy, low penetration – stopped by paper, intact skin.
  - Internal/inhalation - dangerous
- Beta (β) – Low energy, intermediate penetration – stopped by sheet of aluminum.
  - Can cause skin burns (external)
  - Internal damage (inhaled, wounds)
- Gamma (γ) – High energy, high penetration
- Neutrons – Criticality accidents involving neutrons can make a patient become radioactive
  - Na-23 + neutron → Na-24 (15h ½ life)
  - To detect: place detector on abdomen, have person bend around it - detects secondary γ radiation.

Treatment of Radiation Exposure

- Likelihood of terrorist group using some type of nuclear device is high
- Treatment of radiation injuries not taught in medical schools
- Requires multi-specialty collaboration (Emergency and ICU physicians, general and plastic surgeons, hematologists, toxicologists, pathologists, dermatologists, nutritionists, others likely)
- Help from nuclear, medical and health physics specialists
- Mass influx of casualties, and worried well
- Also, “silent” attack possible (use of sealed source w/out explosion)

Radiation syndromes

- Acute Radiation Syndrome (ARS) – occurs after exposure to whole body dose of radiation delivered rapidly at high dose rate.
- Four phases: 1) Prodromal, 2) Latent, 3) Illness, and 4) Outcome (either Recovery or Death)
- A couple of concepts to understand:
  - Cell death – stopping of cell division
  - LD_{50} – acute dose of whole body exposure required to kill 50% exposed
- ARS can be expressed as injury to several major organ systems: Hematopoietic, GI, Pulmonary, cardiovascular, and central nervous system – expression of damage depends on dose received.

Stages of radiation sickness – 1) Prodromal

- Prodromal phase: Vague, nonspecific symptoms, onset minutes to hours
  - Nausea, vomiting, diarrhea, headache, increased core temp.
  - *Most important prognostic indicator: time of onset to vomiting – within 2-4h bad*
- Doses <100 rads (1 Gray): Few or mild symptoms, no treatment
- Doses of 100-200 rads (1-2 Gy): Vomiting usually develops, advisable to admit patients for observation and symptomatic treatment
- Dose 200-400 rads (2-4 Gy): Vomiting within 8 hours
- Dose 400-800 rads (4-8 Gy): Vomiting within 2 hours
- Dose >800 rads (8Gy)
- Caution: Potentially misleading presentations – sometimes misdiagnosed, or not seen (ref. Goiania, BZ, 10% monitored unexposed!)

Stages of ARS – 2) Latent

- During latent phase, exposed person can appear asymptomatic
- Generally at 2-4 weeks post-exposure, but less if higher dose received
- Can be skipped entirely, if very high dose received
- Rapidly dividing cells become depleted → infections develop
- Treat with prophylactic antibiotics, antifungals, antivirals

Stages of ARS – 3) Illness, 4) Outcome

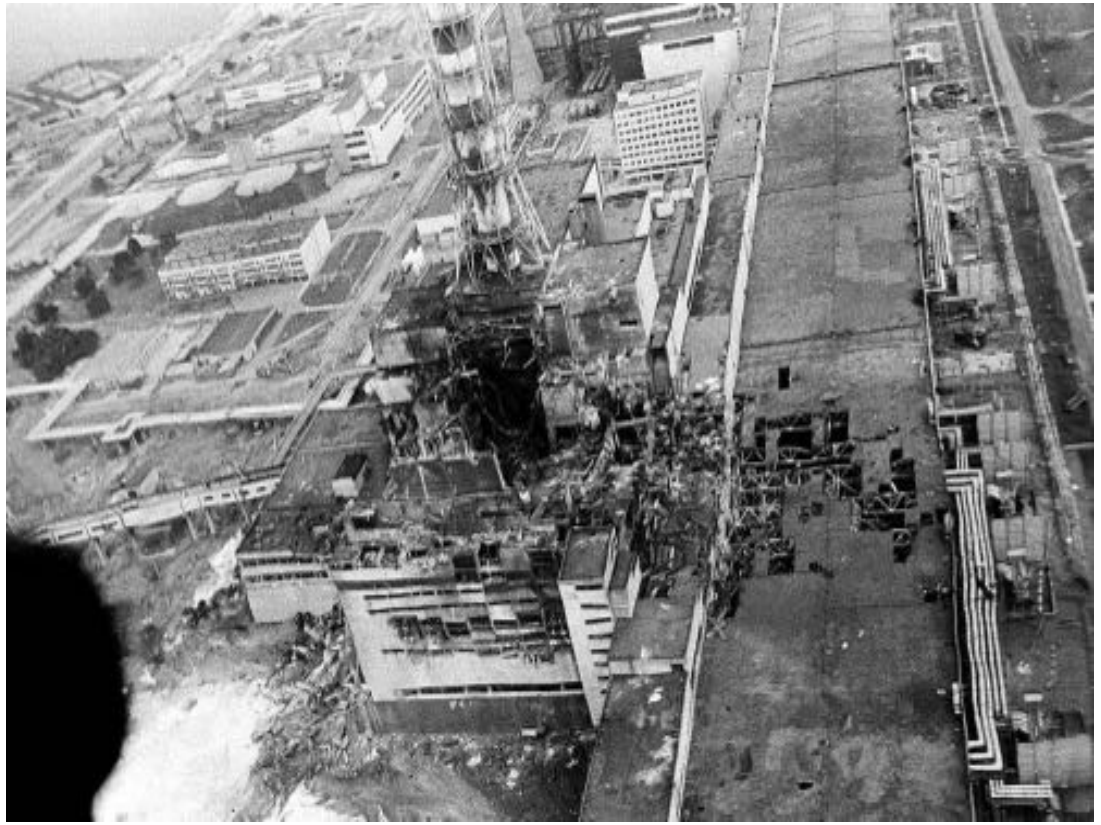
- Illness phase expressed by damage to specific organ systems
- Depends on level of whole body exposure dose
  - Great strides made in treating hematopoietic; but still can be fatal ~60 days
  - No recovery possible for GI (1-2 weeks) or CVS/CNS (48 hours!) syndromes
- Recovery, if possible, takes several weeks to months – lifelong follow up.
- Three radiation syndromes:
  - 1) Hematopoietic/Bone
  - 2) Gastrointestinal (GI)
  - 3) Cardiovascular/Central Nervous System (CVS/CNS)

Acute Radiation Syndrome

Approximate Dose	Onset of Prodrome	Duration of Latent Phase	Manifest Illness
>2 Gy (200 rad)	Within 2 d	1–3 wk	Hematopoietic syndrome with pancytopenia, infection, and hemorrhage; survival possible
>6 Gy (600 rad)	Within hours	<1 wk	GI syndrome with dehydration, electrolyte abnormalities, GI bleeding, and fulminant enterocolitis; death likely
>20–30 Gy (2000–3000 rad)	Within minutes	None	Cardiovascular/central nervous system syndrome with refractory hypotension and circulatory collapse; fatal within 24–72 h

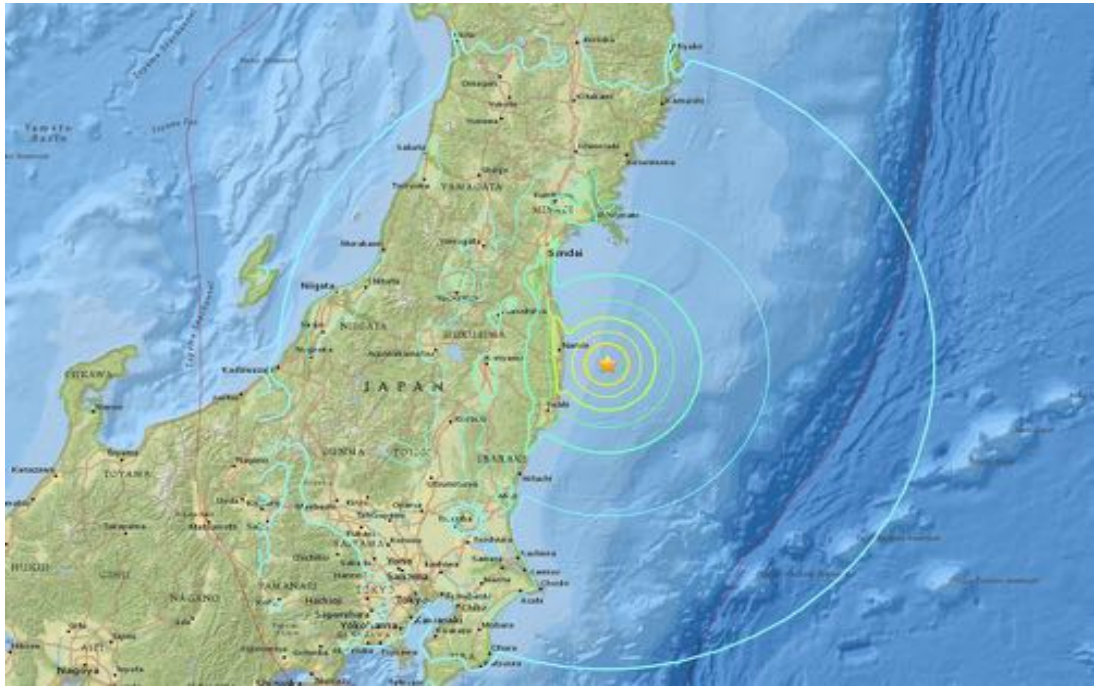
Worst nuclear accidents

- 1986 Explosion in Reactor 4, Chernobyl, Former Soviet Union
- 1957 Storage tank failure at Mayak, Former Soviet Union
- 2011 Chemical accident at Marcoule Nuclear site, France
- 1961 Explosion of the SL-1 due to meltdown, Idaho*



Worst nuclear accidents

- 1957 Fire at Windscale Nuclear Facility, Great Britain
- 1979 Nuclear meltdown at Three Mile Island, Pennsylvania
- 1993 Explosion in Tomsk-7 facility, Siberia
- 2011 Tsunami shuts down Fukushima Daichi, Japan



Criticality Incident – Tokai Mura, 9/30/1999

The Tokaimura criticality accident

September 30, 1999, uranium conversion test plant of JCO Co. Ltd. in Tokai-mura, 115 km northeast from the center of Tokyo. Three workers (A, B and C) were involved in the process of enriching U-235. The criticality chain reaction started when B was pouring uranyl nitrate solution into a tank through a peephole, while A who was standing beside the tank supported the funnel that was inserted into that hole. C, the supervisor, was in the next room.

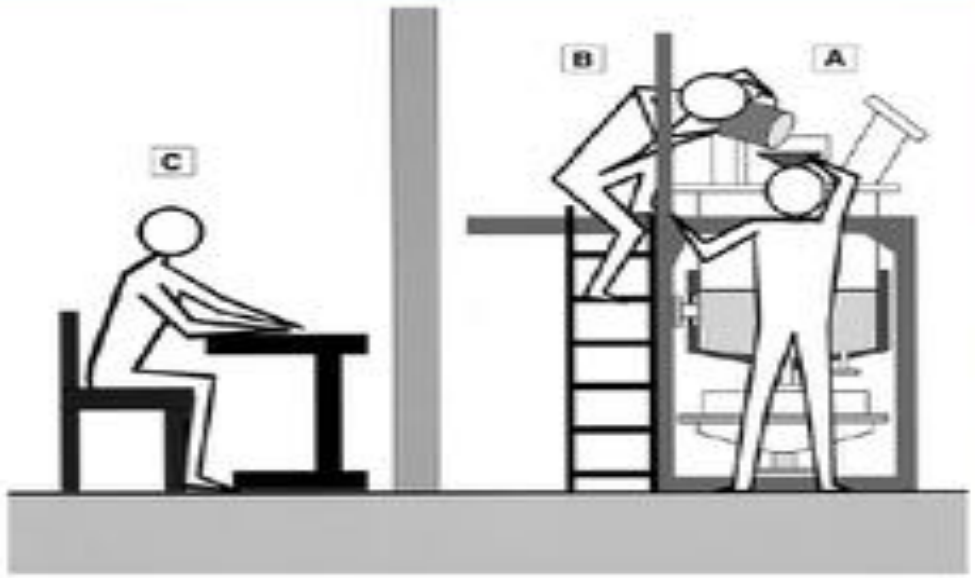


Figure 1. The positions and postures of the victims of the accident at the moment when criticality was triggered, reconstructed by interviewing Workers B and C.

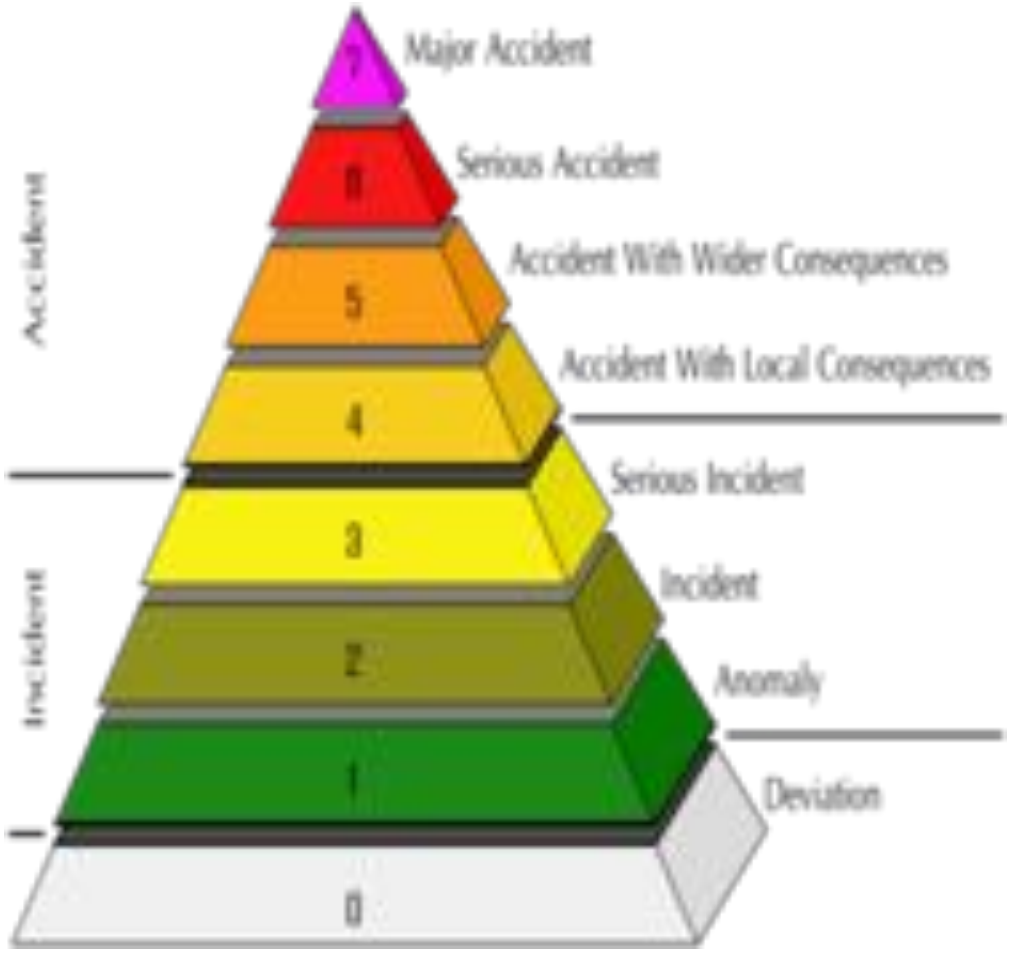
Tokai Mura Criticality incident

- 3 Workers preparing batch of fuel for experimental reactor
- After 7th bucket or uranyl nitrate added, criticality reached
- Blue flash observed (Cherenkov)
- Workers A & B – pain, nausea, SOB immediately
  - Worker A – 17 Sv, de. 12/21/1999
  - Worker B – 10 Sv, de. 4/27/2000
- Reaction continued for 20 hours
- 667 workers/residents exposed

Worst military nuclear accidents

- 1968 Leaked radiation onboard K-27 submarine, former S.U.
- 1966 Midair collision of B-52 with KC-135 (USAF), Spain
- 1970 Safety cap failure during Yucca Flat test, Nevada
- 1985 K-431 submarine reactor explosion, Vladivostok, F.S.U.
- 1968 Crash of B-52 with nuclear payload, Thule, Greenland

International Nuclear Event Scale



- 7 – Chernobyl 1986; Fukushima Daiichi 2011
- 6 – Kyshtm (Mayak) 1957
- 5 – Windscale 1957; TMI 1979; Goiania 1987
- 4 – Tokaimura 1999; SL-1 1961 (others)
- 3/2/1/0 – Multiple
- Adequacy of scale?
  - No rating beyond 7?
  - Not scientifically based (public relations tool)
  - Conflates magnitude (physical energy) with intensity (effects)
- Proposed new rating – Nuclear Accident Magnitude scale

Current events

- “Sonic blast” on US Embassy in Cuba, November, 2016
  - 21 diplomats fell ill with headaches, nausea, dizziness, hearing loss, fatigue
  - Occurred shortly after diplomats/families heard high pitched sounds
  - JAMA team hypothesized cause was “unknown energy source”
  - Current theory is microwave radiation in directed beam
- Considered re-introduction of “low-yield” nuclear weapons
- Countries with nuclear programs
  - Nuclear weapons states: US, Russia, UK, France, China (Israel?)
  - Declared possession: India, Pakistan, No. Korea
  - Formerly possessing: S. Africa, Belarus, Ukraine, Kazakhstan

Nonconventional Radiation exposure/devices

- Radiation Dispersal Device (RDD)
  - Simple radiological device – spreading radioactive material without explosive
  - Dirty bomb – combining explosive agent with radioactive material
- Unconventional
  - Airplane or drone filled with materials
- Non-explosive device
  - 1987 Goiania, Brazil – thieves stole a radiotherapy source from abandoned clinic

Goiania, Brazil, 1987

- Abandonded radiotherapy machine taken, dismantled
- Radioactive Cesium Cl cake removed, sold multiple times
- Children played with it, attracted to blue light emanating
- 4 people died from ARS, 249 others suffered ill effects


8:07
Saturday, January 13
EMERGENCY ALERTS
now
Emergency Alert
BALLISTIC MISSILE THREAT INBOUND TO HAWAII. SEEK IMMEDIATE SHELTER. THIS IS NOT A DRILL.
Slide for more

Current events: Hawaii missile alert 1/13/18

- Unscheduled drill at shift change for HI Emergency Management Agency
- “Exercise. Exercise. Exercise.”
- Script deviation “…this is not a drill…”
- Recent North Korea tensions, missile tests

Psychological effect of fear

- The aim is to create fear, panic, disruption
- Use of limited/minimal resources
- Minimal physical impact, but potentially complicating
- Heavy psychologic impact, high cost
- What can we do as individuals
- What can workplaces do

What can a person do:

- Be informed – learn about radiation, exposure hazards, prevention
- Educate others – prevent misinformation from circulating
- Maintain skills – be available in case of an event
- Prepare; make a survival kit, first aid, plan ahead, etc.
- In the event of an attack – 1) Remain Calm.
- Follow emergency instructions
- Take shelter
- Take care of yourself, and then assist others

Workplace preparedness

- Prepare ahead, have a strategic plan. Individual vs. Comprehensive
- Educate employees.
- Emergency notification system
- Chain of command
- Install or update safety features/equipment/resources
- Evacuation/egress routes
- Protocols for responders, post-evacuation
- Culture of safety
- Resources: OSHA How to Plan for Workplace Emergencies and Evacuation

Resources

- Department of Homeland Security www.Ready.gov
- Radiation Emergency Assistance Center / Training Site (REAC/TS) www.orau.gov/reacts
- CDC http://emergency.cdc.gov/radiaton
- Armed Forces Radiobiology Research Institute www.afrri.usuhs.mil

Questions after next speaker