

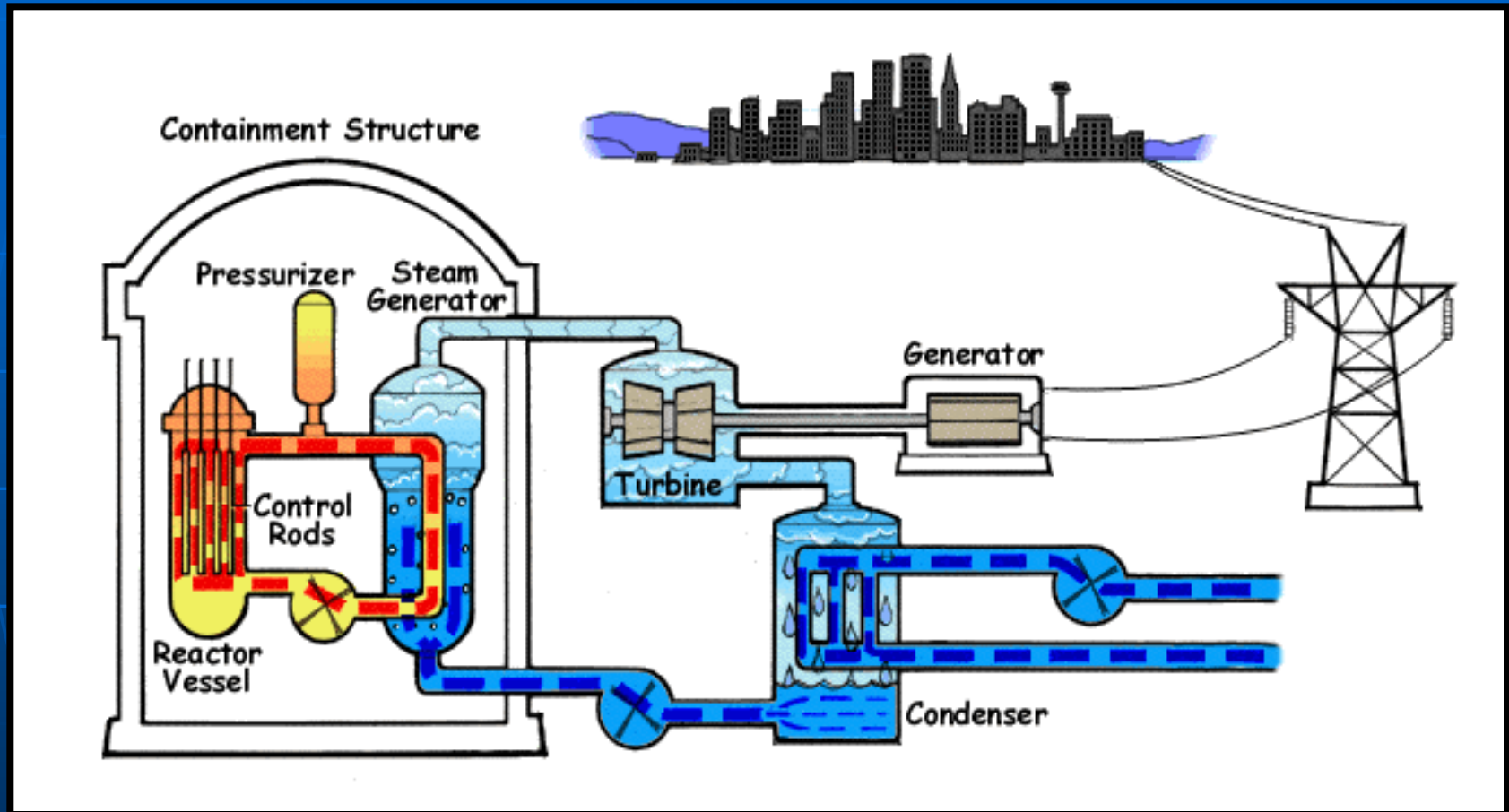
“Some Lessons Learned on Medical Preparedness and Response from Several Types of Nuclear Power Plant Accidents”

Symposium on the Science and Response to a Nuclear Reactor Accident , The National Academy of Sciences, Washington, DC, 5/13/2014

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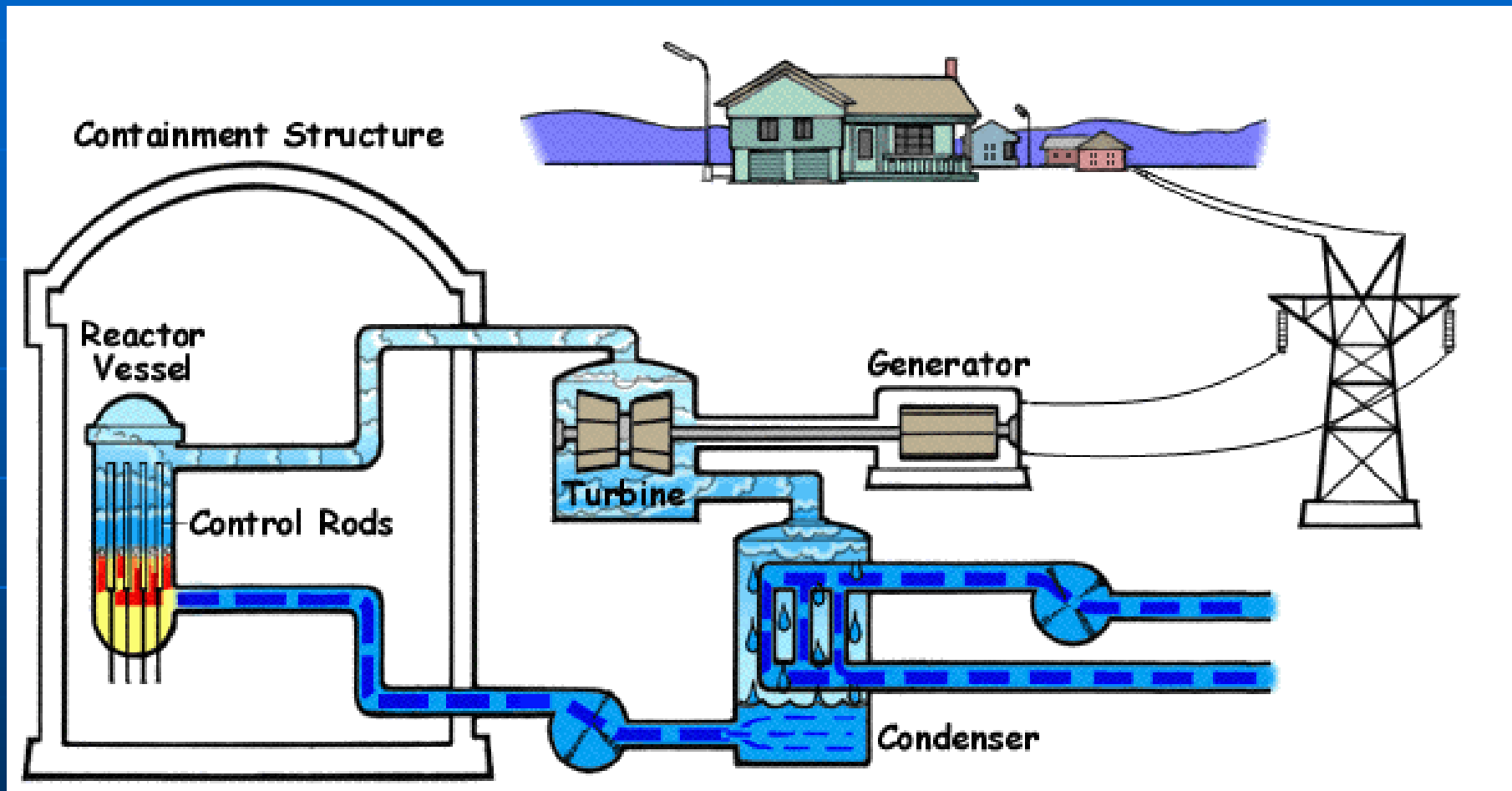
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Nuclear Reactor Schematics



Pressurized Water Nuclear Reactor

Nuclear Reactor Schematics



Boiling Water Nuclear Reactor

Reactor Accidents

- Loss of Coolant Accident (LOCA)
- Pipe breaks in the primary loop remove cooling water from the core, leading to an increase in core temperature
- Fuel rods heat up and fail, releasing volatile radionuclides (Noble Gasses, Iodine, Cesium, Strontium, Pu. Uranium, etc.)
- Core meltdown, ? containment vessel

Reactor Accidents

- Most likely and most significant early route of exposure to the public in most scenarios is due to inhalation of an atmospheric release.
- Plume materials could consist of particulates, vapors, mists, or gases.
- Plume could be short duration (puff) or continuous.
- Particulates will tend to settle to the ground as the plume drifts from the plant, but later may be re-suspended for additional inhalation.

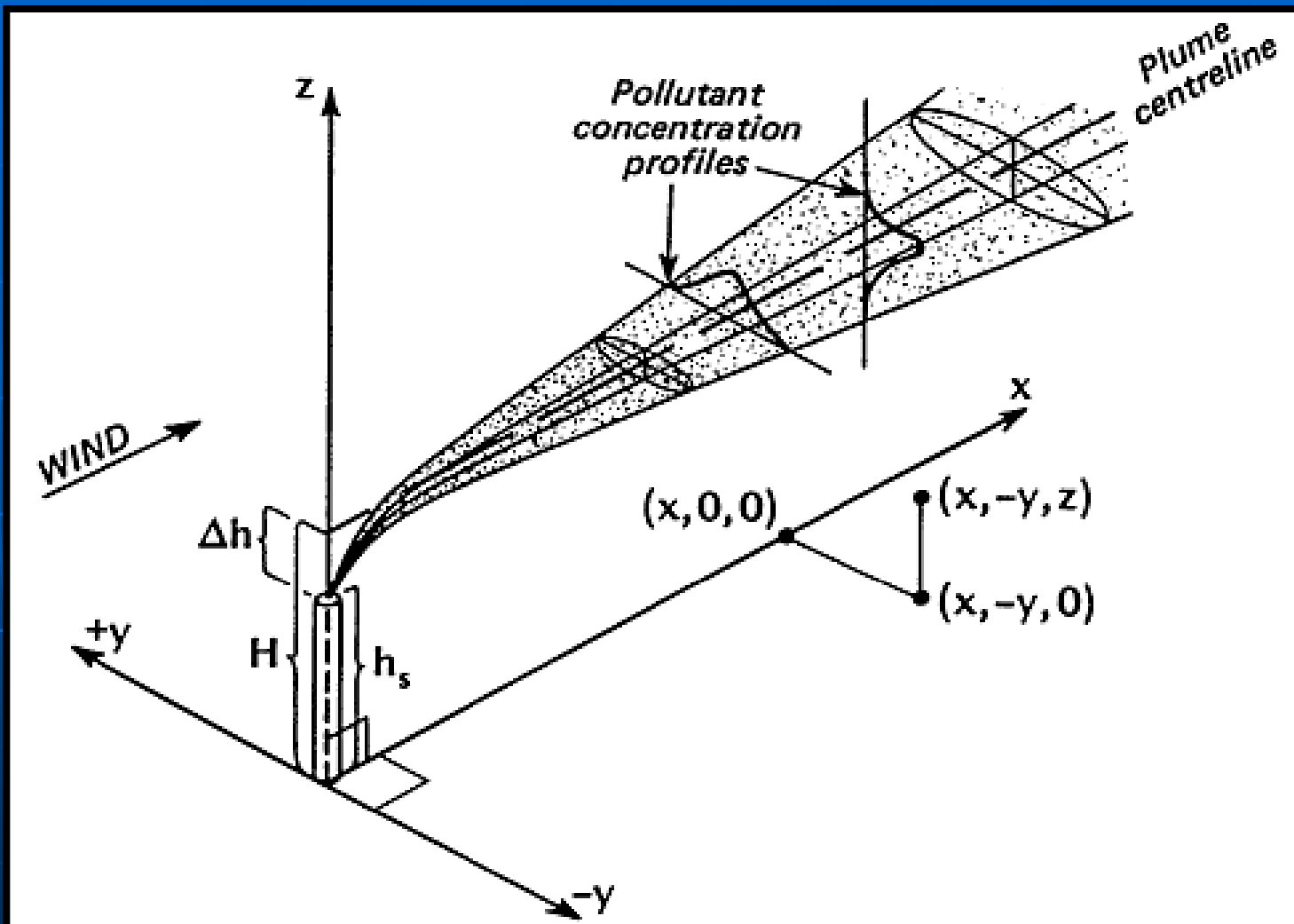
Atmospheric Releases

- Volatile radionuclides may be released or escape from the containment structure
- Principal airborne radionuclide of concern to public initially is ^{131}I
- Releases are monitored by sensors and air monitors placed in and around the NPP
- Plume dispersal is mathematically modeled by DOE assets, taking local current weather and local terrain into account (NARAC). These models are later modified by ground (RAP teams) and aircraft measurements (AMS)

Airborne Radioactivity

- **“Source term” - source of the exposure**
 - examples - stack effluent, fire , explosion,etc.
 - complex function of the material (quantity and type), flow rate,distribution,etc.
 - units - activity/unit of time (e.g., Ci/sec; Bq/sec)
- **Population/personnel exposure**
 - airborne (radioactivity) concentration
[$\mu\text{Ci/ml}$; Bq/m^3]
 - resuspended (ground/surface) contamination
[$\mu\text{Ci/ft}^2$; $\text{Bq/m}^2 \rightarrow \mu\text{Ci/ml}$; Bq/m^3]

Plume Dispersion



Exposure Pathways

- External dose from plume overhead (cloud shine) or material on ground (ground shine).
- Internal dose due to inhaling materials directly from plume or possibly from stirred dust or, for some nuclides, through skin.
- Ingestion of contaminated materials in the form of food or water.

Emergency Planning Zone

- Areas for which planning is needed to assure that prompt and effective actions can be taken to protect the public
- Plume EPZ: radius of approximately 10 miles
- Ingestion EPZ: radius of approximately 50 miles

Accident response

- Independent of the type of accident:
 - determine and control hazards to responders & victims
 - assess, treat, evacuate victims
 - implement further control procedures
 - assess personnel exposures
 - monitor clean-up
 - verify clean-up effectiveness

Guidance for Population Protection: 1st Principle

- Intervention to avoid radiation dose and subsequent serious, prompt health effects should be carried out as a first radiation protection priority
 - serious prompt health effects may be expected in susceptible populations acute doses > 1 Gy (100 rad), and in all at doses > 2 Gy (200 rad) (whole-body)
 - evacuation is usually the only effective intervention measure in high dose areas.

Guidance for Population Protection: 2nd Principle

- Protective actions to avoid delayed health effects should be initiated(When they will produce more Good than Harm in the “Affected Population” !)
 - iodine prophylaxis in case of radioiodine releases
 - sheltering in place, evacuation, or temporary relocation

Guidance for Population Protection: 3rd Principle

- These actions should be considered as flexible during the event to allow periodic changes of the levels to cause a maximum net benefit to the population
 - guidelines available from USEPA, IAEA, and IRPA
 - Levels may well be driven primarily by logistical and infrastructure considerations (e.g., availability of roads, power, transport, availability of temporary shelters, etc.)

Protective Actions Available to the Public

- Sheltering
- Evacuation
- Stable Iodine Prophylaxis
- Other actions to reduce dose

Personnel Monitoring Guidelines

➤ EXTERNAL

- Hand-held monitoring (“frisking”)
- Portal monitors
- Decon (self or assisted) at 2-3 x background

➤ INTERNAL

- Whole-body counting/chest counting
- Excreta bioassay, examples:

Radionuclide	Feces	Urine	Quantity
Plutonium	24 hours	2-3 weeks	24 hr excretion
Uranium	24 hours	24 hours	24 hr excretion
Tritium	N/A	12 hours	single voiding

Logistical Requirements for Early Protective Actions

- Sheltering:
 - Normal emergency services; additional police
- Evacuation:
 - Transportation
 - Temporary housing (schools, tentage, etc.)
 - Food and water
 - Sanitation
- Iodine prophylaxis:
 - KI tablets or solution –need pre-distribution or capability for rapid distribution(within 6hr)

Logistical Requirements for Control of Food and Water

- Need monitoring and embargo capabilities
- Centralized distribution
- Alternate (distant) sources
- In case of food shortages, alternate (higher) action levels should be considered

Three Mile Island



Goldsboro, Pennsylvania



Three Mile Island

- Unit 2 feedwater pump tripped at 4:00 a.m. on March 28, 1979
- Reactor scrammed 8 seconds later
- Pressure relief valve stuck open, so ECCS water lost
- Pressurizer (only way of controlling water level and pressure in primary loop) filling up, so high pressure injection pumps shut down

TMI, con't

- Core partially uncovered by 6:15 a.m.
- Site emergency declared at 7:00 a.m.
- General emergency declared at 7:24 a.m.
- Radiation levels indicated fuel damage around 8:00 a.m.
- Core covered with water by 10:30 a.m.

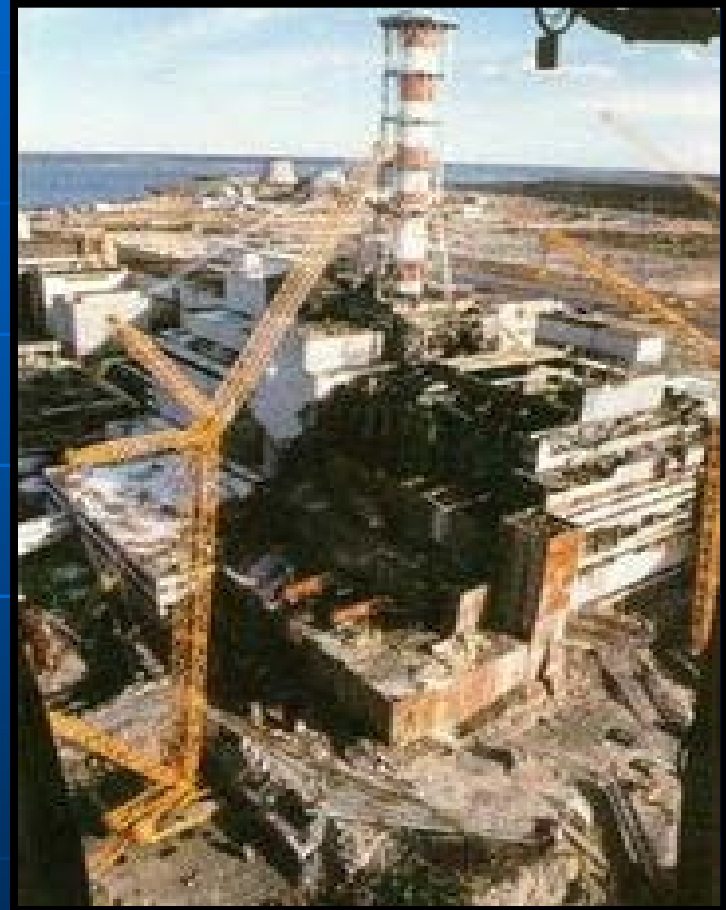
TMI, con't

- State route 441 closed at 12:45 p.m.
- Everything fairly calm the next day
- Because of confusion and concern over the “hydrogen bubble”, evacuation advised for pregnant women and preschool children with 5 miles at 12:30 on March 30
- Schools closed and further evacuation planned
- Supplies of KI shipped in

TMI Medical Lessons:

- Miscommunication between NRC/ State/Public Media as to whether hydrogen bubble or meltdown was a risk, or not, caused public/and responder fear!
- Many families(including some health care providers) left city, evacuation accidents)—TMI showed : Need for Medical and Responder Radiological Preparedness and Response Training—and Exercises!
- Containment bldg. prevented public exposure/ radiation effects -but ,TMI was the first NPP accident noted to cause such public anxiety,fear, Psychological Effects!

Chernobyl



Chernobyl



Figure 31. Radiation Hotspots Resulting From the Chornobyl' Nuclear Power Plant Accident



The Chernobyl Experience

➤ I. Evacuation:

- Accident occurred 26 April 1986 at 1:23 am
- 49,000 evacuated from Pripyat (3 km from station) on April 27
- 53,000 evacuated from 30-km exclusion zone over next 10 days

The Chernobyl Experience

➤ II. Sheltering:

- 270,000 persons remained in controlled area (10,300 sq. km with $^{137}\text{Cs} > 15 \text{ Ci/sq. km}$)
- delivery of non-contaminated meat and dairy products continues
- agricultural products monitored for contamination before release for consumption
- slow decontamination of settlements
- 5 year external dose about 5 rem

Chernobyl Medical Effects:

➤ Health effects:

- 2 acute trauma fatalities
- 237 suspected cases of acute radiation syndrome(103 confirmed)
- 28 acute fatalities(Lesson: poorly matched donor stem cell transplants were unsuccessful ,some even died of GVHD)
- Many possible radiation related fatalities during 10-year follow-up of workers
- 54 local radiation injuries, 14 severe
- Lesson:50-100 X childhood thyroid cancer(Lesson: KI Distribution/Plume issues)

Major Causes of Acute, Deterministic Effects/Death in the Chernobyl Emergency Responders

- Radiation Induced Hematopoietic Injury with Subsequent Infections; and GVHD with some stem cell transplants
- Thermal Burns/Radiation Skin Injury/pneumonitis/GI injury

A. Baranov et al, New England J Med 321:205,1989

Chernobyl Medical Lessons Learned and Response: Chernobyl Demonstrated the Need for Better Cytokine and Stem Cell Science and Availability for Mass Casualty Radiation Scenarios

- Lesson: Chernobyl responders died from poorly matched bone marrow and other stem cell transplants Graft/Host issues, etc.

Response: Now, US Congress Legislation* facilitates/supports matched stem cell and cord blood availability for transplantation in radiation mass casualty scenarios and is part of the National Marrow Donor Program.

- * The US Rep., CW Bill Young Transplantation Program

Medical Management of the Acute Radiation Syndrome: Recommendations of the Strategic National Stockpile Radiation Working Group

Jamie K. Waselenko, MD; Thomas J. MacVittie, PhD; William F. Blakely, PhD; Nicki Pesik, MD; Albert L. Wiley, MD, PhD;
William E. Dickerson, MD; Horace Tsu, MD; Dennis L. Confer, MD; C. Norman Coleman, MD; Thomas Seed, PhD;
Patrick Lowry, MD; James O. Armitage, MD; and Nicholas Dainiak, MD

Physicians, hospitals, and other health care facilities will assume the responsibility for aiding individuals injured by a terrorist act involving radioactive material. Scenarios have been developed for such acts that include a range of exposures resulting in few to many casualties. This consensus document was developed by the Strategic National Stockpile Radiation Working Group to provide a framework for physicians in internal medicine and the medical subspecialties to evaluate and manage large-scale radiation injuries.

Individual radiation dose is assessed by determining the time to onset and severity of nausea and vomiting, decline in absolute lymphocyte count over several hours or days after exposure, and appearance of chromosome aberrations (including dicentrics and ring forms) in peripheral blood lymphocytes. Documentation of clinical signs and symptoms (affecting the hematopoietic, gastrointestinal, cerebrovascular, and cutaneous systems) over time is essential for triage of victims, selection of therapy, and assignment of prognosis.

Recommendations based on radiation dose and physiologic response are made for treatment of the hematopoietic syndrome. Therapy includes treatment with hematopoietic cytokines; blood transfusion; and, in selected cases, stem-cell transplantation. Additional medical management based on the evolution of clinical signs and symptoms includes the use of antimicrobial agents (quinolones, antiviral therapy, and antifungal agents), antiemetic agents, and analgesic agents. Because of the strong psychological impact of a possible radiation exposure, psychosocial support will be required for those exposed, regardless of the dose, as well as for family and friends. Treatment of pregnant women must account for risk to the fetus. For terrorist or accidental events involving exposure to radioiodines, prophylaxis against malignant disease of the thyroid is also recommended, particularly for children and adolescents.

Ann Intern Med. 2004;140:1037-1051.

For author affiliations, see end of text.

www.annals.org

Clearly, serious hematopoietic depression from ARS must be averted to avoid lethal sepsis.

Thus, the limited clinical data base for an effective use of cytokines and stem cells for ARS must be supplemented by animal data (Per the FDA's “animal rule”).

Another Chernobyl lesson: *Biodosimetry*

- “Gold” standard for acute whole body radiation dose assessments

- ONLY 2 Labs in US (REAC/TS and AFFRI)

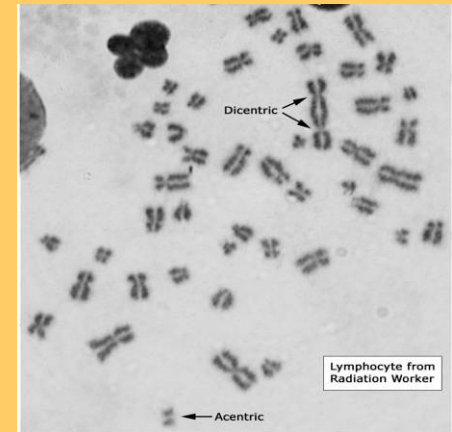
Utilizes metaphase spreads of lymphocytes to search for chromosome aberrations (dicentrics) specific to radiation exposures. Micronuclei, EPR and FISH analysis also useful

Automated Workstations and Web Experts for Scoring Will Be

Important for Mass Casualties !



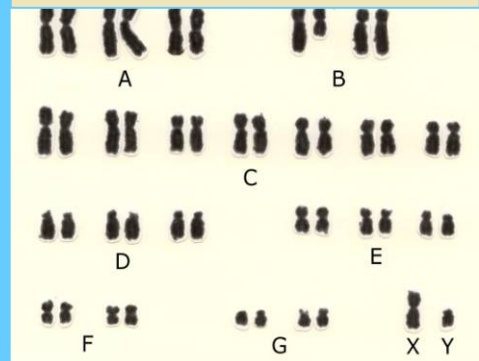
Old



Labor Intensive

Output

Karyotype





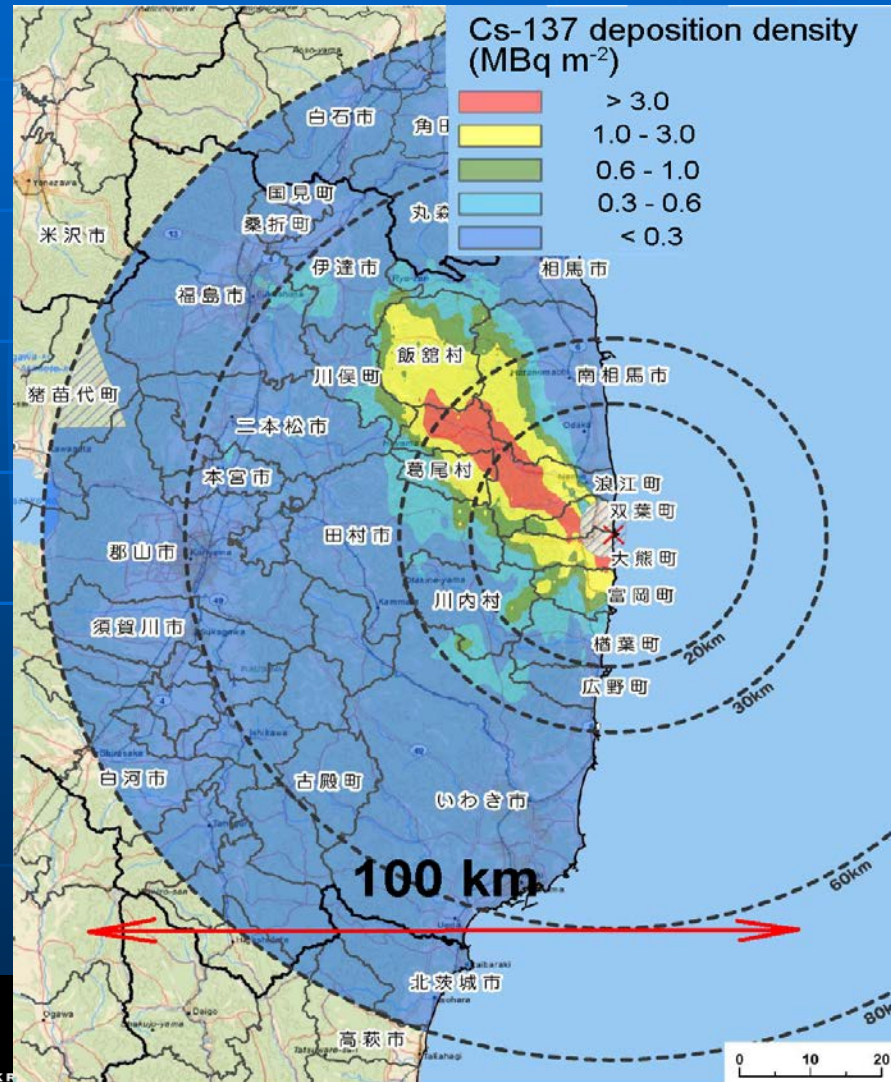
Fukushima NPP Accident: Map of U.S. military bases

Lessons. 1) Like with other NPP accidents there was a need for TRAINING of medical and other responders about Medical Radiological Preparedness and Response – both near and distant medical centers should have been prepared to accept contaminated people ,since clinics near the NPP were inoperable due to the Tsumani damage.

2) In PAG- generated evacuation of people in hospitals, nursing homes, etc. , at least 60 of these people died from lack of medical supportive care and basics such as food,water ,heat. .Yet, there were NO deaths or injury from radiation.

Lesson: ?More harm than benefit in the uniform,unquestioned enforcement of radiation evacuation PAGs of special needs populations.

^{137}Cs deposition (MBq m^{-2}), Fukushima .Required many bioassays of I,Cs and Sr; severely stressing bioassay lab and whole body counter capabilities.



Examples, Medical Countermeasures

Generally Element Specific

Nuclide	Medication	Comments
Am-241	Ca and Zn DTPA by IV, aerosol, ?IM	Chelation best within a few hrs but liver decorp even after mo/yr
Cf-252	Ca and Zn DTPA	
Cs-137	Prussian Blue	Binds Cs, hepato-enteric cycle
Co-60	penicillamine	Gastric lavage, ?DTPA
Fission Products	Depends on mixture	Spectroscopic identification of nuclides ; isotope, specific RX
H-3	Forced H ₂ O	Isotopic dilution
I-131	KI or SSKI	Essential to dose within 1-6 hrs
Pu-238,39	Ca and Zn DTPA	Optimal to dose within a few hrs
Sr-89,90	Ca gluconate	Consider alginates

Clinical Decision Guidelines (CDG)

CDG = the maximum, once-in-a-lifetime intake of a radionuclide that represents:

- ✓ “Avoidance of deterministic effects as judged by the calculated 30d RBE-weighted absorbed doses to red marrow and lungs, with allowance for the significant uncertainties often involved in an initial evaluation of the chemical and physical form of a radionuclide and the level of activity taken into the body during an incident.”

Clinical Decision Guidelines (CDG)

CDG = the maximum, once-in-a-lifetime intake of a radionuclide that represents:

- ✓ “Stochastic risk, as judged by the calculated ED over 50Y for intake by adults and to age 70Y for intake by children, that is in the range of risks associated with guidance on dose limits for emergency situations (DOE, 2008a; FEMA, 2008; ICRP, 1991a; NCRP, 1993; 2005a)”

CDG =

$$\text{MIN} \left[\frac{0.25 \text{ Sv}}{e(\text{Sv Bq}^{-1})}, \frac{0.25 \text{ Gy-Eq}}{d_{\text{Red Marrow}}(\text{Gy-Eq Bq}^{-1})}, \frac{1.0}{d_{\text{Lung}}(\text{Gy-Eq Bq}^{-1})} \right] \quad (11.1)$$

where:

e = effective dose coefficient for the radionuclide

$d_{\text{Red Marrow}}$ and d_{Lung}
= RBE-weighted absorbed-dose coefficients for red marrow and lung, respectively

MIN = minimum value of the three arguments

TABLE 11.1—(continued)

	Intake Mode ^b	Form ^{b,c}	Effective Dose Coefficient		CDG (intake activity)		Early Excretion and Retention (percentage of intake)			Early Excretion and Retention Levels Indicative of Intake of 1 CDG (dpm)			
			(Sv Bq ⁻¹)	(mrem μ Ci ⁻¹)	(Bq)	(μ Ci)	Urinary Excretion 0 – 24 h	Retention in Chest at 24 h ^a	Total-Body Retention at 24 h	Urinary Excretion 0 – 24 h	Retention in Chest at 24 h ^a	Total-Body Retention at 24 h	Nasal Swab Soon After Inhalation ^f
¹³⁷ Cs	Inhalation	Type F	4.3×10^{-9}	1.6×10^1	5.8×10^7	1.6×10^3	2.2	NA	58	7.7×10^7	NA	2.0×10^9	1.7×10^8
¹³⁷ Cs	Ingestion	Soluble	8.9×10^{-9}	3.3×10^1	2.8×10^7	7.6×10^2	4.5	NA	95	7.6×10^7	NA	1.6×10^9	NA
¹⁴⁴ Ce	Inhalation	Type M	2.3×10^{-8}	8.5×10^1	1.1×10^7	2.9×10^2	0.052	5.7	50	3.4×10^5	3.7×10^7	3.2×10^8	3.2×10^7
¹⁴⁴ Ce	Inhalation	Type S	2.9×10^{-8}	1.1×10^2	8.6×10^6	2.3×10^2	0.00088	6.4	49	4.6×10^3	3.3×10^7	2.5×10^8	2.6×10^7
¹⁵³ Sm	Inhalation	Type M	3.2×10^{-9} h	1.2×10^1 h	3.1×10^8	8.5×10^3	0.16	4.0	35	3.0×10^7	7.5×10^8	6.6×10^9	9.4×10^8
¹⁵³ Sm	IV injection	Soluble	5.8×10^{-10} i	2.2×10^0 i	4.3×10^8	1.2×10^4	5.8	NA	65	1.5×10^9	NA	1.7×10^{10}	NA
¹⁵⁴ Eu	Inhalation	Type M	3.2×10^{-8}	1.2×10^2	7.8×10^6	2.1×10^2	0.50	5.8	49	2.3×10^6	2.7×10^7	2.3×10^8	2.3×10^7
¹⁵⁴ Eu	Inhalation	Type S	2.4×10^{-8}	8.9×10^1	1.0×10^7	2.8×10^2	0.0084	6.4	49	5.2×10^4	4.0×10^7	3.1×10^8	3.1×10^7
¹⁸⁸ Re	IV injection	Soluble	1.4×10^{-9}	5.2×10^0	1.8×10^8	4.8×10^3	9.0	NA	31	9.6×10^8	NA	3.3×10^9	NA
¹⁹² Ir	Inhalation	Type M	1.7×10^{-8} h	6.3×10^1 h	5.9×10^7	1.6×10^3	0.31	5.7	49	1.1×10^7	2.0×10^8	1.7×10^9	1.8×10^8
¹⁹² Ir	Inhalation	Type S	2.0×10^{-8} h	7.4×10^1 h	5.0×10^7	1.4×10^3	0.038	6.4	49	1.1×10^6	1.9×10^8	1.5×10^9	1.5×10^8
²¹⁰ Po	Ingestion	Soluble	3.7×10^{-7}	1.4×10^3	6.8×10^5	1.8×10^1	0.059	NA	73	2.4×10^4	NA	3.0×10^7	NA
²¹⁰ Po	Inhalation	Type M	2.3×10^{-6}	8.5×10^3	1.1×10^5	2.9×10^0	0.12	5.7	50	7.8×10^3	3.7×10^5	3.2×10^6	3.3×10^5
²²⁶ Ra	Inhalation	Type M	2.2×10^{-6}	8.1×10^3	1.1×10^5	3.1×10^0	0.16	5.8	50	1.1×10^4	4.0×10^5	3.4×10^6	3.4×10^5

NCRP 161 (2010) Bair, W; Bloch, W; Dickerson, W; Eckerman, K; Goans, R; Karem, A; Leggett, R; Lipstein, J; Stabin, M; Wiley, A

Summary of Medical Lessons Learned

- Medical preparedness/response for nuclear power plant incidents range from the need to reassure large populations that they are not at risk, by use of bioassays/ application of CDG– to the medical care of serious ARS casualties.
- Need radiation emergency managers who have broad technical skills, keen situation awareness and are critical thinkers since public health issues rapidly escalate with sheltering, evacuation, and contamination of food supplies.

Thank You!
Questions?
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