# Reactor Health Physics

# Objectives

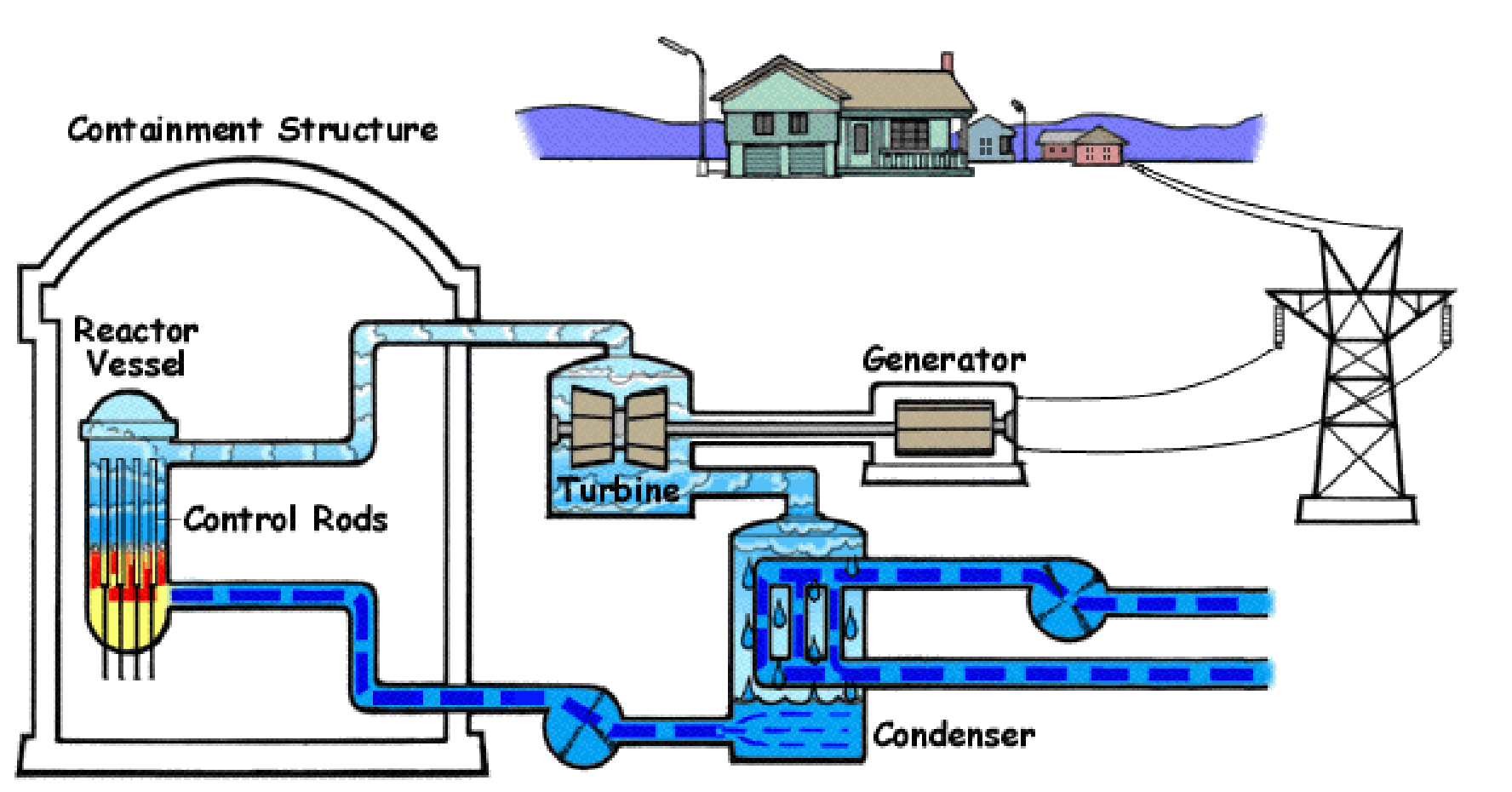
- Briefly discuss the differences in BWRs and PWRs from a health physics standpoint
- Discuss the uranium fission process and the fission and activation products produced at LWRS
- Discuss radiological controls at LWRs
- Describe personnel monitoring requirements at LWRs
- Discuss occupational radiation exposure at nuclear power plants

# Objectives

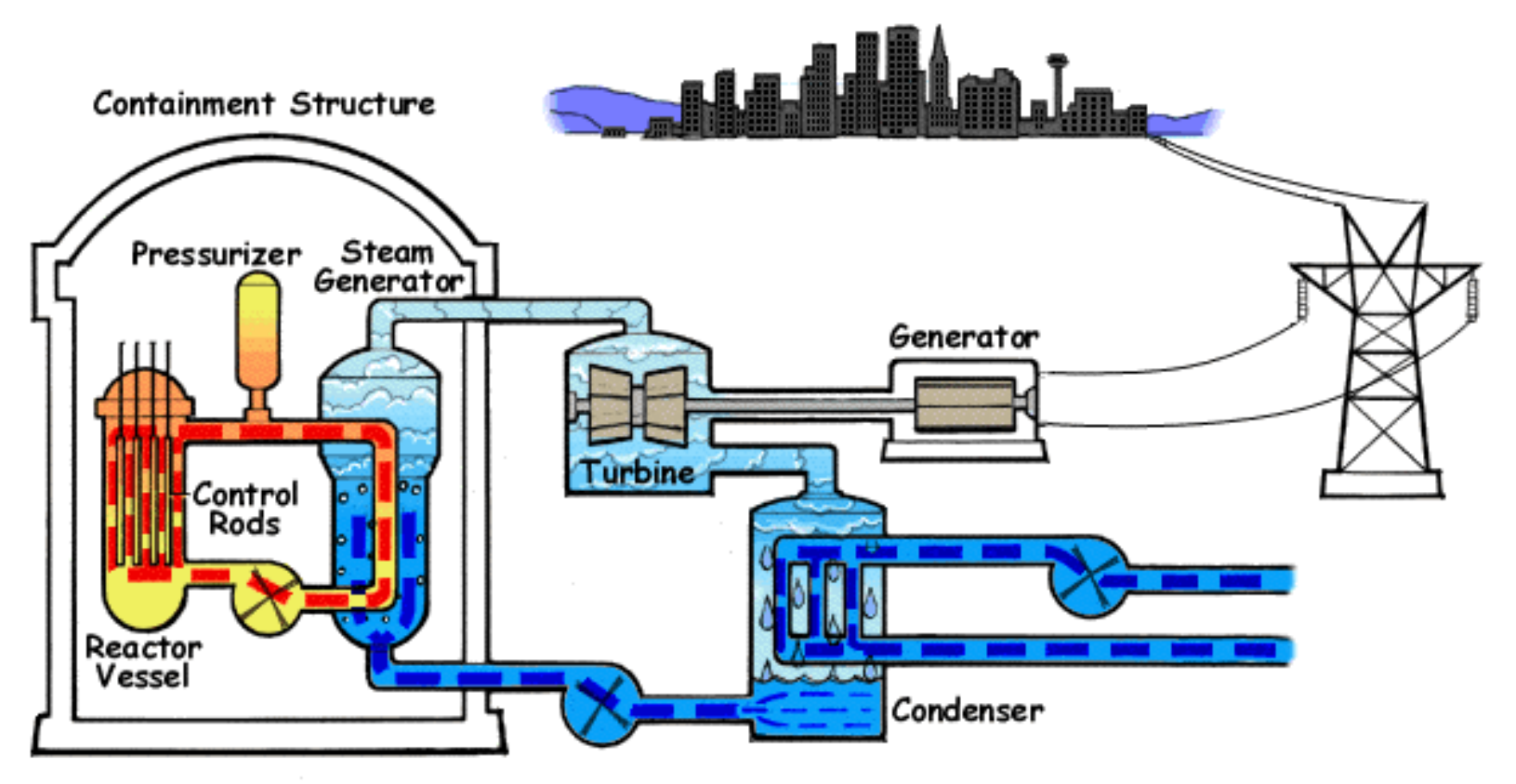
- Describe the philosophy of ALARA
- Identify high exposure situations and areas at BWRs and PWRs
- Discuss the major radiological environmental pathways from routine reactor operations
- Review Emergency Preparedness requirements for radiological emergencies
- Discuss the use of radioprotective drugs (KI)

# Light Water Reactors

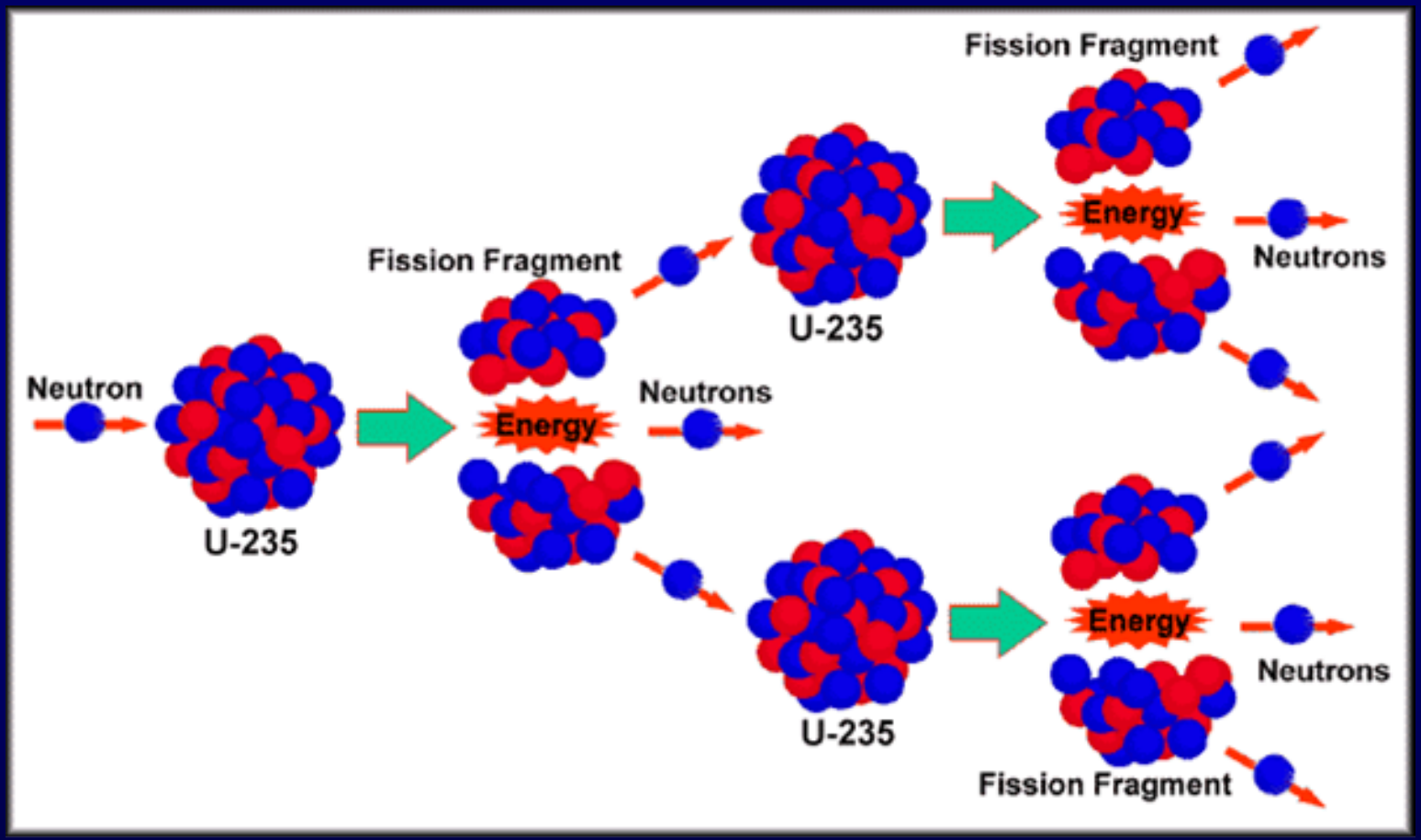
# Boiling Water Reactor (BWR)



# Pressurized Water Reactor (PWR)



# Uranium Fission Process



# Fission Products

- Neutrons and gamma rays released during and immediately following fission process
- Radioactive products normally contained within the reactor vessel
- Fission product barriers are pellet, fuel rod, reactor coolant system and
- Escape from fuel damage, core damage, etc.

# Fission Products

- Radioiodines; e.g., I-131 (Thyroid)
- Noble gases, primarily Kr and Xe, are an external (submersion) hazard to the whole body, skin or lens of eye
- Long-lived particulate radionuclides such as Cs-137, Sr-90, and C-14

# Activation Products

- Materials absorb neutrons and become radioactive (activation)
- Located in RCS and easily transported to support systems
- Source of majority of contamination and occupational exposures (e.g., Co-60)

# Activation Products

- Co-60
  - produced by neutron activation of stable Co-59, which corrodes off of valve parts and control rod blades, enters the coolant and becomes radioactive by neutron capture
- N-16
  - O-16 absorbs neutron; 7 MeV gamma ray with 7 second half-life
- Other activation products (Fe-59, Mn-54, and Zn-65, & H-3)

# Nitrogen-16

- N-16 is carried over in steam in a BWR to the Turbine Building
- N-16 is one of the most intense gamma emitters known (7 MeV!)
- Source of exposure to site personnel and contributes to offsite doses, i.e., “skyshine”
- N-16 half-life is only 7 seconds

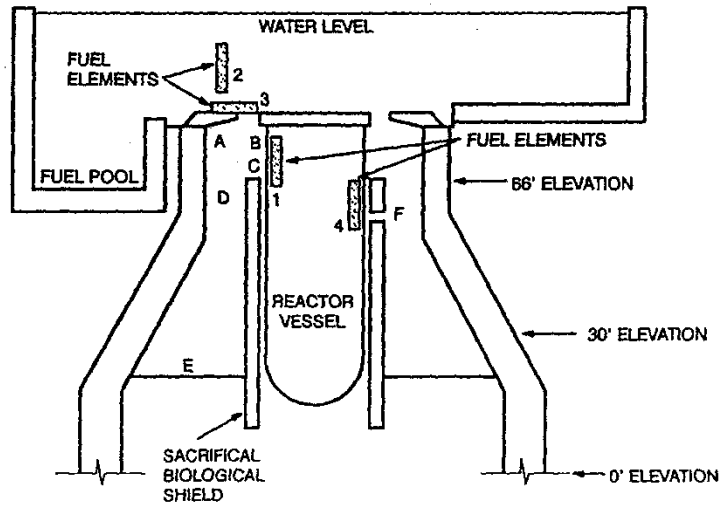
# Occupational Exposures

- External dose >>>>>> internal dose
- Exposure increases during outages
- Refueling activities are carefully controlled to prevent overexposures
- Spent fuel remains underwater in pool
- Limited access to high and very high radiation areas

# High Dose Rate Areas in Nuclear Plants

| Potential Radiation Fields | General Exposure Ranges |
|---|---|
| Spent fuel transfer tube | 10,000 – 50,000 rads/hr |
| Letdown IX/ filter | 1,000 – 10,000 rads/hr |
| Spent Fuel (in pool) | 100,000 – 1,000, 000 rads /hr |
| Radwaste Resin Tank | 5,000 rads/hr |
| TIPs and cables, SRMs & IRMs | 1 – 100,000 rads/ hr |
| Reactor Cavity with thimbles withdrawn | 200 – 2,000 rads/hr |
| Thimbles | 50,000 rads/hr |
| Reactor cavity (in core) | > 1,000 rads/hr |
| Steam Generator Channel Head | 10 -40 rads/hr |

# Dose Rates in BWR Drywell During Fuel Movement




Dose Rates During Refueling
(R/hr without/with moveable shield)

| Location | Fuel Position | | | |
|---|---|---|---|---|
| | 1 | 2 | 3 | 4 |
| A | –/– | 30/0.3 | $8x10^4$/15 | –/– |
| B[1] | 10/– | –/– | –/– | –/– |
| C[2] | 50/– | –/– | –/– | –/– |
| D | –/– | $3/3x10^{-2}$ | $2x10^3$/1.5 | –/– |
| E | –/– | $0.13/1x10^{-4}$ | $5x10^2$/0.15 | –/– |
| F | –/– | –/– | –/– | 3/– |

Foot Note: 1. Measured 2 ft. from reactor vessel
2. Measured on contact with reactor vessel

Figure B-2 Dose Rates in BWR Drywell During Spent Fuel Transfer

# PWR Cavity with TIPs Withdrawn

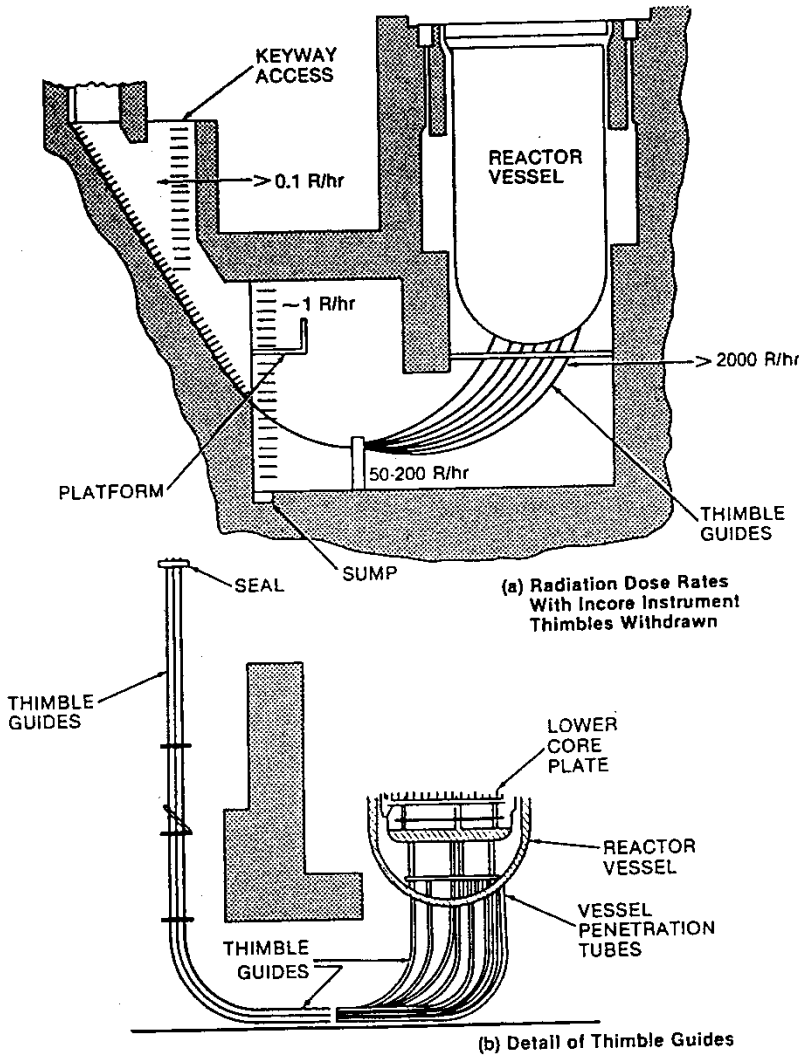
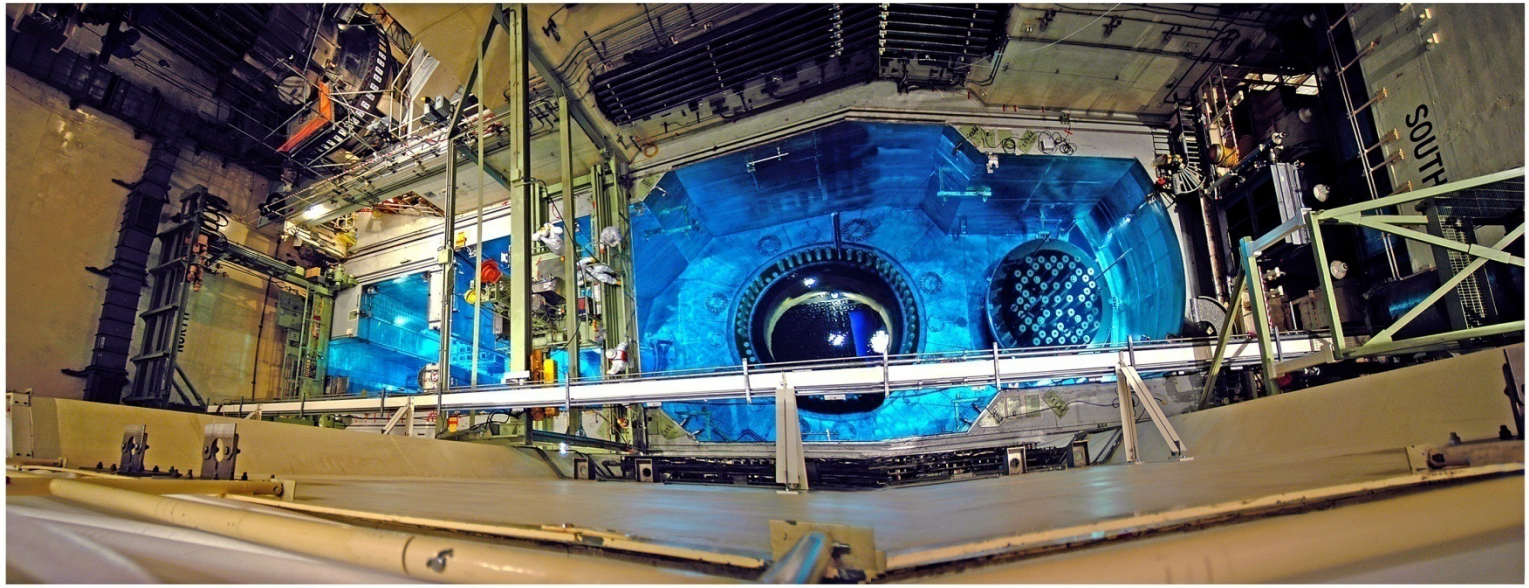



Figure B–1 Pressurized Water Reactor Cavity

# Comanche Peak – Reactor Core

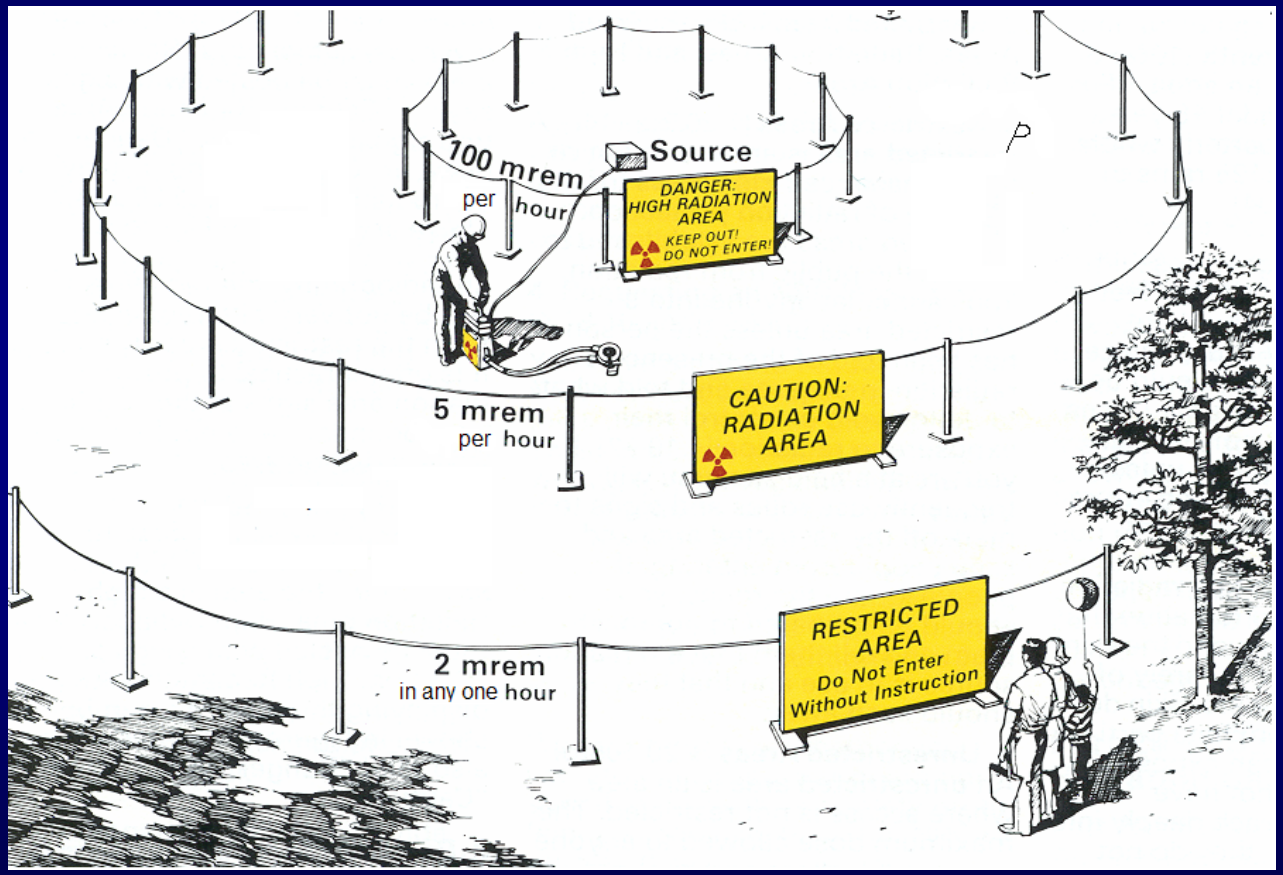


# Comanche Peak – Dual Unit PWR

# Radiological Controls

- Access Control (Radiation Work Permits, signs, postings, barricades and locks)
- Surveys (direct radiation, contamination & airborne)
- Remote Monitoring and Health Physics Coverage

# Controlled Areas



# Radiological Areas defined in 10 CFR Part 20

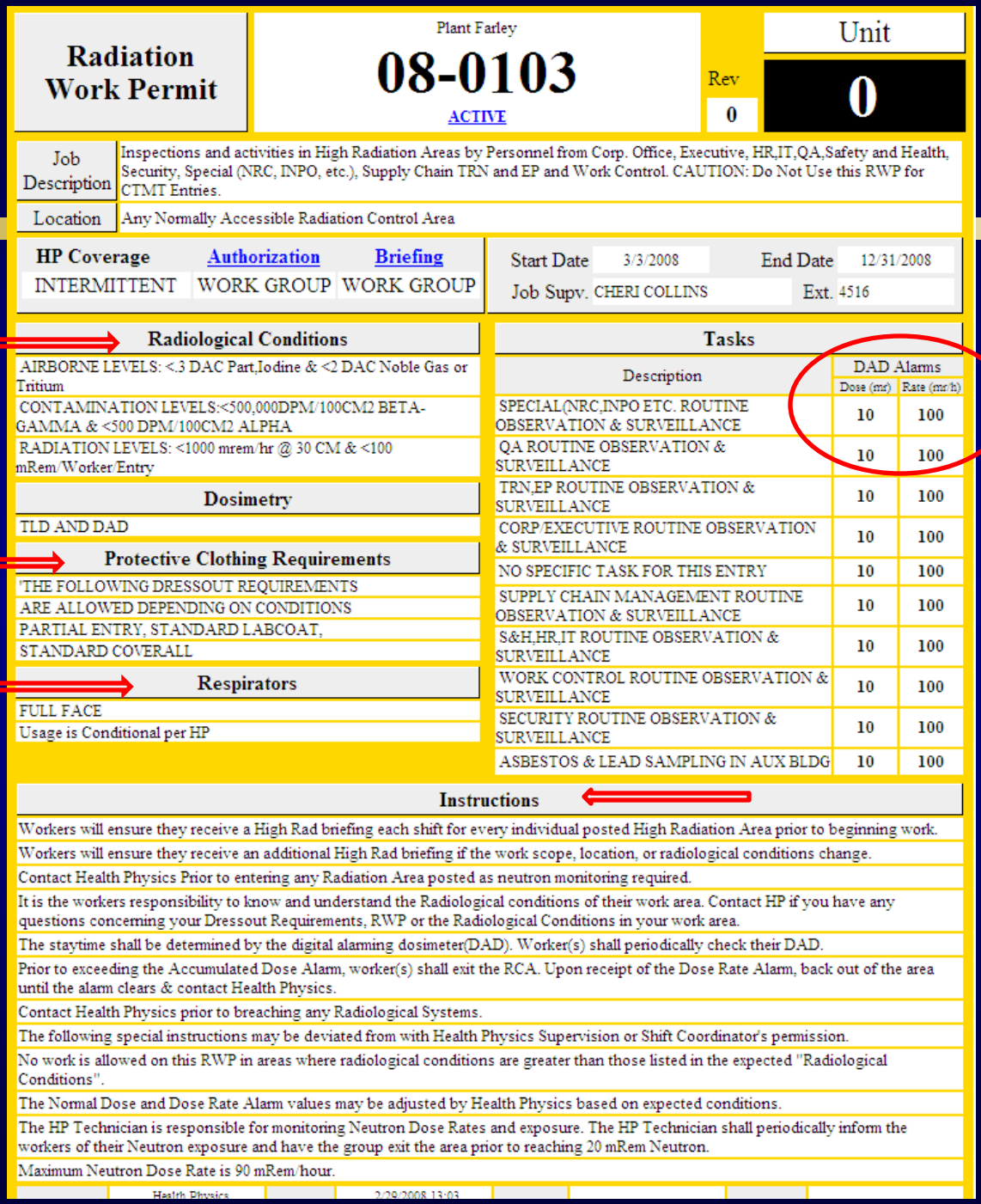
- Radiation Area > 5 mrem/hour @ 30 cm (from the source or any surface that it penetrates): "CAUTION, RADIATION AREA."
- High Radiation Area > 100 mrem/hour @ 30 cm: "CAUTION, HIGH RADIATION AREA" or "DANGER, HIGH RADIATION AREA."
- Very High Radiation Area > 500 rads/hour @ 1 m: "GRAVE DANGER, VERY HIGH RADIATION AREA."
- Airborne Radioactivity Area –airborne concentrations are > 1 DAC, or an individual present without respiratory protection equipment could exceed an intake of 0.6% ALI or 12 DAC-hours (30% of a DAC) in a work week: "CAUTION, AIRBORNE RADIOACTIVITY AREA" or "DANGER, AIRBORNE RADIOACTIVITY AREA."

# Radiological Signs and Postings




# Radiological Signs

# RWP Example



**Radiation Work Permit**

Plant Farley

**08-0103**

ACTIVE

Rev 0

Unit 0

| | |
|---|---|
| Job Description | Inspections and activities in High Radiation Areas by Personnel from Corp. Office, Executive, HR,IT,QA,Safety and Health, Security, Special (NRC, INPO, etc.), Supply Chain TRN and EP and Work Control. CAUTION: Do Not Use this RWP for CTMT Entries. |
| Location | Any Normally Accessible Radiation Control Area |

| HP Coverage | Authorization | Briefing |
|---|---|---|
| INTERMITTENT | WORK GROUP | WORK GROUP |

Start Date 3/3/2008 End Date 12/31/2008

Job Supv. CHERI COLLINS Ext. 4516

**Radiological Conditions**

- AIRBORNE LEVELS: <.3 DAC Part,Iodine & <2 DAC Noble Gas or Tritium
- CONTAMINATION LEVELS:<500,000DPM/100CM2 BETA-GAMMA & <500 DPM/100CM2 ALPHA
- RADIATION LEVELS: <1000 mrem/hr @ 30 CM & <100 mRem/Worker/Entry

**Dosimetry**

- TLD AND DAD

**Protective Clothing Requirements**

- 'THE FOLLOWING DRESSOUT REQUIREMENTS
- ARE ALLOWED DEPENDING ON CONDITIONS
- PARTIAL ENTRY, STANDARD LABCOAT,
- STANDARD COVERALL

**Respirators**

- FULL FACE
- Usage is Conditional per HP

**Tasks**

| Description | DAD Alarms Dose (mr) | DAD Alarms Rate (mr/h) |
|---|---|---|
| SPECIAL(NRC,INPO ETC. ROUTINE OBSERVATION & SURVEILLANCE | 10 | 100 |
| QA ROUTINE OBSERVATION & SURVEILLANCE | 10 | 100 |
| TRN,EP ROUTINE OBSERVATION & SURVEILLANCE | 10 | 100 |
| CORP/EXECUTIVE ROUTINE OBSERVATION & SURVEILLANCE | 10 | 100 |
| NO SPECIFIC TASK FOR THIS ENTRY | 10 | 100 |
| SUPPLY CHAIN MANAGEMENT ROUTINE OBSERVATION & SURVEILLANCE | 10 | 100 |
| S&H,HR,IT ROUTINE OBSERVATION & SURVEILLANCE | 10 | 100 |
| WORK CONTROL ROUTINE OBSERVATION & SURVEILLANCE | 10 | 100 |
| SECURITY ROUTINE OBSERVATION & SURVEILLANCE | 10 | 100 |
| ASBESTOS & LEAD SAMPLING IN AUX BLDG | 10 | 100 |

**Instructions**

- Workers will ensure they receive a High Rad briefing each shift for every individual posted High Radiation Area prior to beginning work.
- Workers will ensure they receive an additional High Rad briefing if the work scope, location, or radiological conditions change.
- Contact Health Physics Prior to entering any Radiation Area posted as neutron monitoring required.
- It is the workers responsibility to know and understand the Radiological conditions of their work area. Contact HP if you have any questions concerning your Dressout Requirements, RWP or the Radiological Conditions in your work area.
- The staytime shall be determined by the digital alarming dosimeter(DAD). Worker(s) shall periodically check their DAD.
- Prior to exceeding the Accumulated Dose Alarm, worker(s) shall exit the RCA. Upon receipt of the Dose Rate Alarm, back out of the area until the alarm clears & contact Health Physics.
- Contact Health Physics prior to breaching any Radiological Systems.
- The following special instructions may be deviated from with Health Physics Supervision or Shift Coordinator's permission.
- No work is allowed on this RWP in areas where radiological conditions are greater than those listed in the expected "Radiological Conditions".
- The Normal Dose and Dose Rate Alarm values may be adjusted by Health Physics based on expected conditions.
- The HP Technician is responsible for monitoring Neutron Dose Rates and exposure. The HP Technician shall periodically inform the workers of their Neutron exposure and have the group exit the area prior to reaching 20 mRem Neutron.
- Maximum Neutron Dose Rate is 90 mRem/hour.

Health Physics 2/29/2008 13:03

# Surveys and Area Monitoring


# Alarming Dosimeters

# Dosimeters

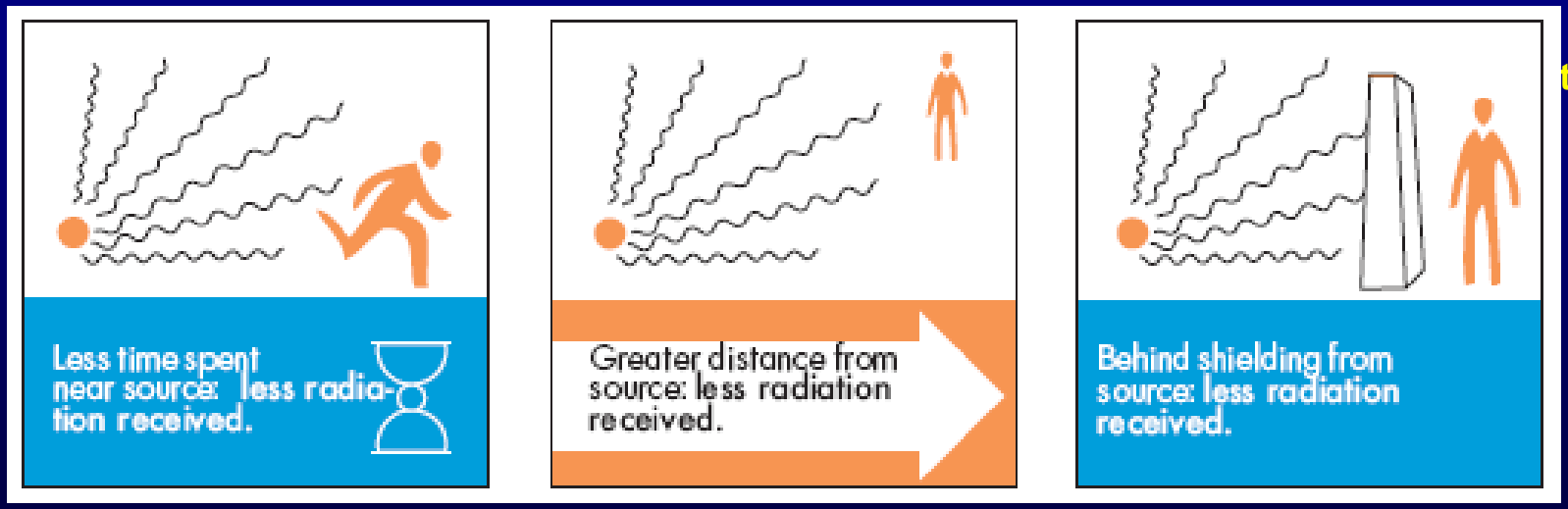

# ALARA

- As low as is reasonably achievable

- **Making EVERY REASONABLE EFFORT to maintain exposures to radiation AS FAR BELOW THE DOSE LIMITS in this part AS IS PRACTICAL CONSISTENT WITH the purpose for which the licensed activity is undertaken, taking into account the state of TECHNOLOGY, the ECONOMICS of improvements in relation to state of technology, the economics of improvements in relation to BENEFITS to the public health and safety, and other SOCIETAL AND SOCIOECONOMIC CONSIDERATIONS, and in relation to UTILIZATION of nuclear energy and licensed materials IN THE PUBLIC INTEREST.**

# ALARA: Reducing Exposure

**"Although exposure to ionizing radiation carries a risk, it is impossible to completely avoid exposure. Radiation has always been present in the environment and in our bodies. We can, however, avoid undue exposure through the following protection principles:"**

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# ALARA


DO NOT
LINGER!
Dose Rate at
This Point is
mRem/hr


SOURCE OF
RADIATION
MINIMIZE
TIME IN AREA


HOT
SPOT
600 MR/HR
04-002

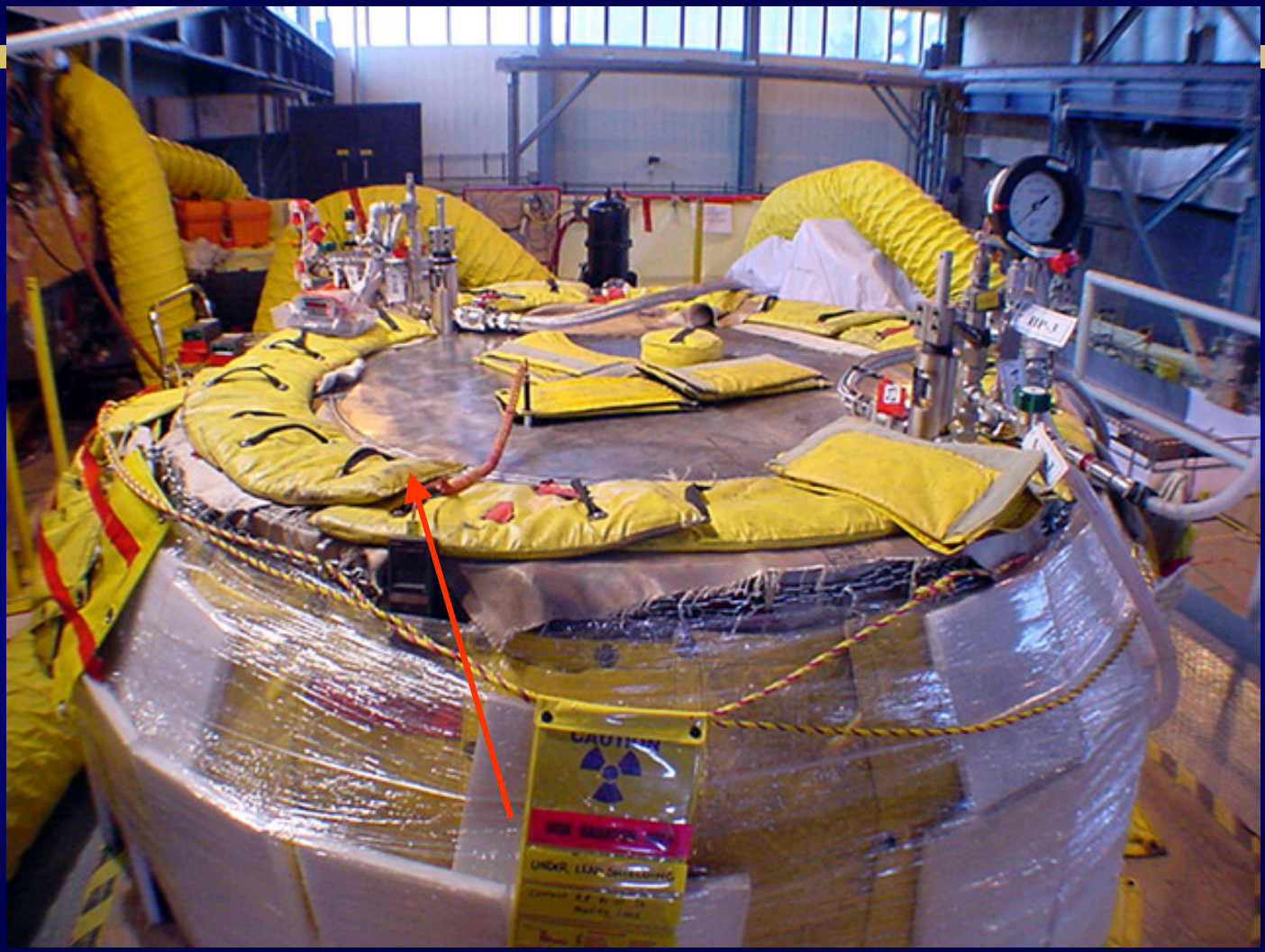

Dose Rate
57.9 mR/h


LOW DOSE
WAITING
AREA

# Low Dose Areas

# Shielding

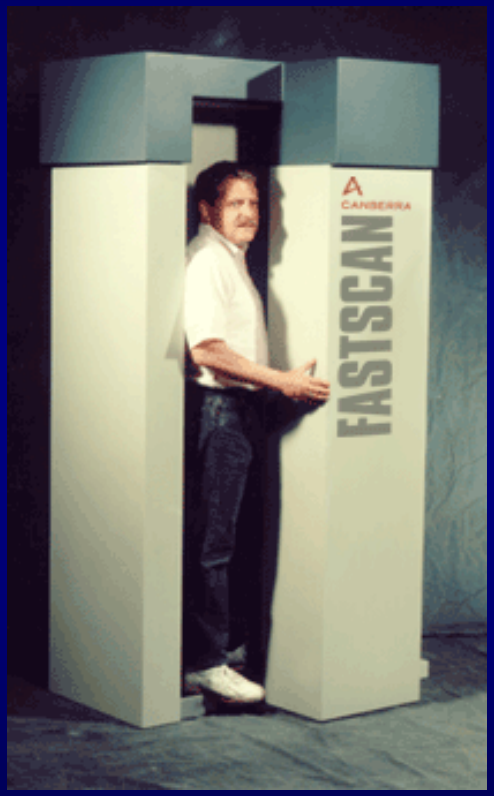
Lead "blankets" used for shielding



# Internal Exposure Controls

- Engineering Controls
- Respiratory Protection
- Airborne Radioactivity Monitoring
- Bioassay (in vivo and in vitro analysis)

# Internal Exposure Controls & Monitoring



# TEDE ALARA

- A documented analysis of the job conditions and the potential for both external and internal dose
- Use of respirators can lead to worker inefficiency and longer exposure times
- 10 CFR 20 based on risk, therefore the total dose (TEDE) that must be minimized

# Contamination Control

- Cleaning and Decontamination
- Ventilation from low to high contaminated areas
- Designated contaminated areas with protective clothing requirements
- Routine Surveys for contamination monitoring

# Hot Particles

- Small radioactive particles, less than 1 mm in any dimension, with a high specific activity
- Present beta-gamma exposure problem to skin and can also irradiate deeper tissue
- Due to small size, they can be easily overlooked and remain undetected

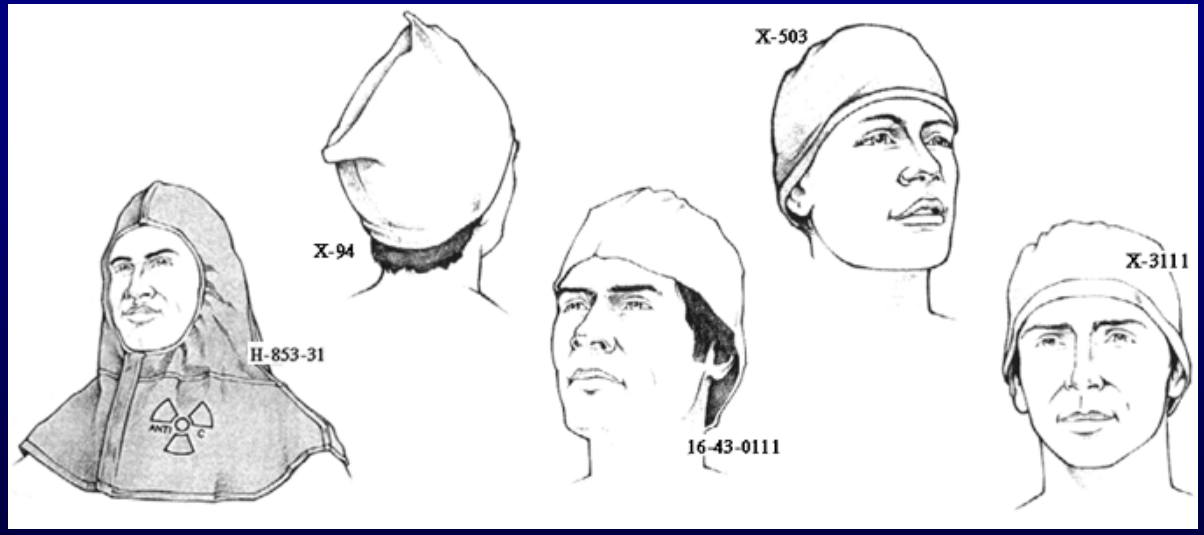
# Types of Hot Particles

- "Fuel fleas" - composed of fission products and other components of fuel
- Activation product hot particles - Co-60, Co-58
- Biological concern for hot particles is non-stochastic (deterministic ) effects such as skin reddening and ulceration of small area of skin
- Stochastic risk of skin cancer is very small, about $7 \times 10^{-9}$ per rad (per NCRP)

# Protective Clothing

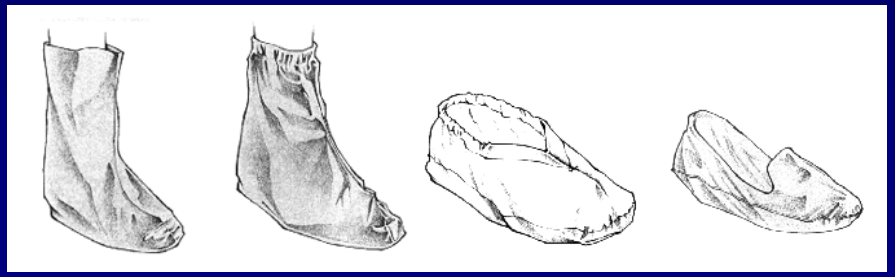

## Coveralls

## Headware

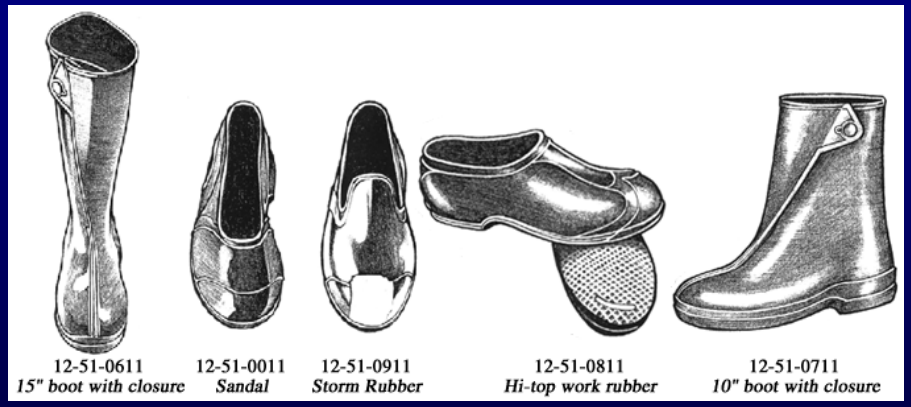


# Protective Clothing

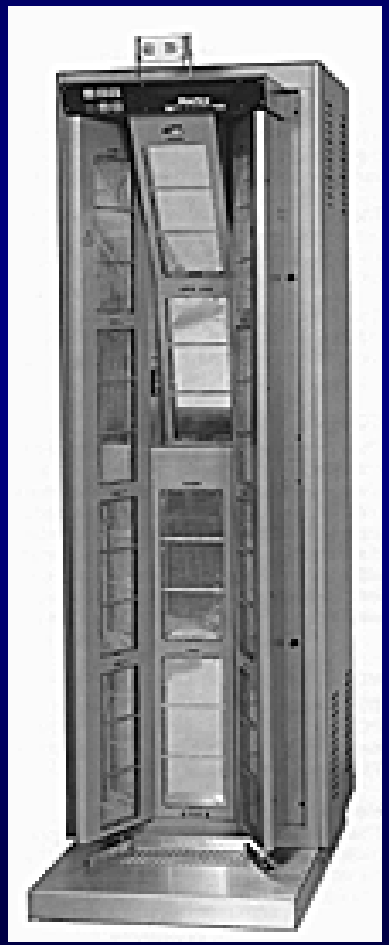
## Booties

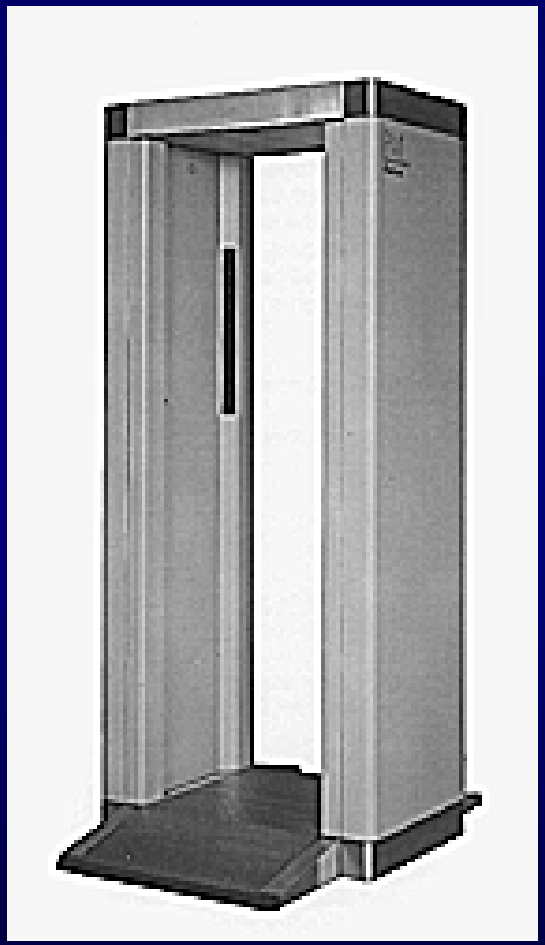


## Shoe Covers

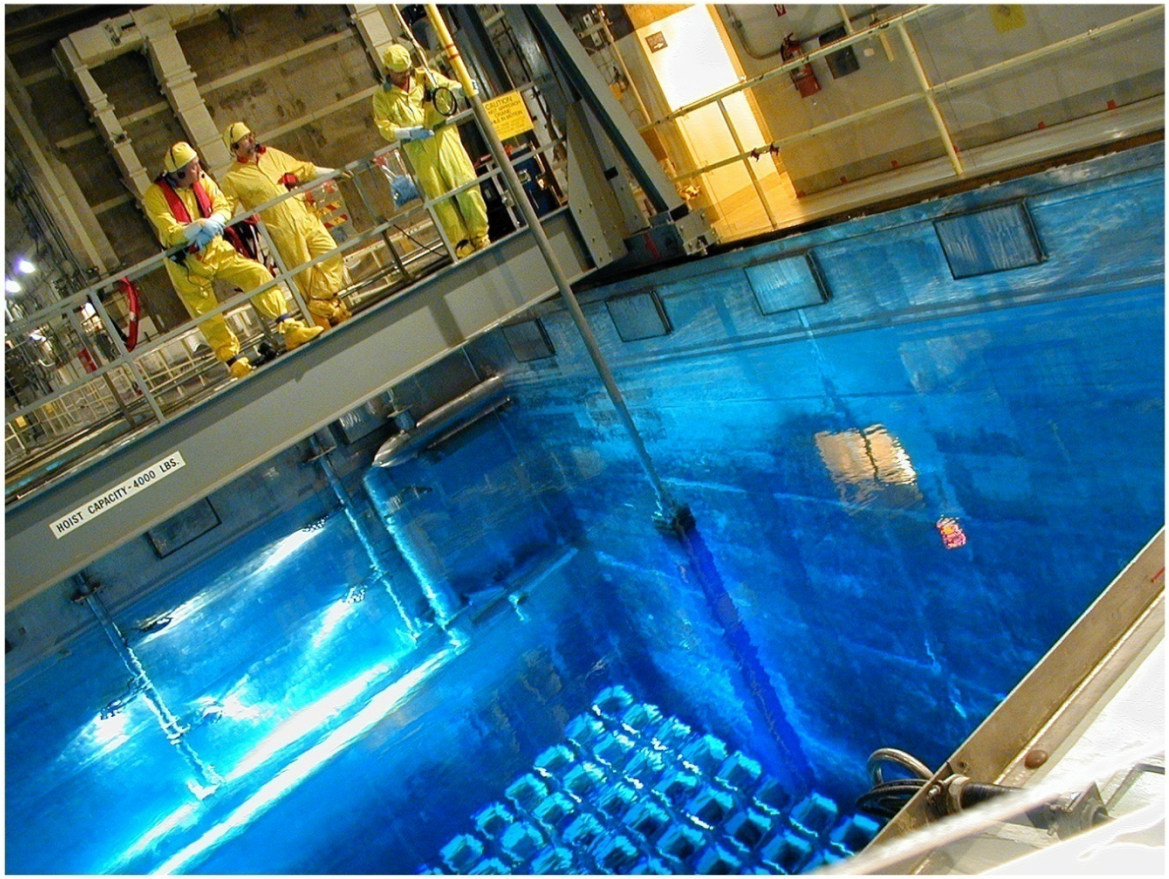


# Contamination Monitoring Equipment





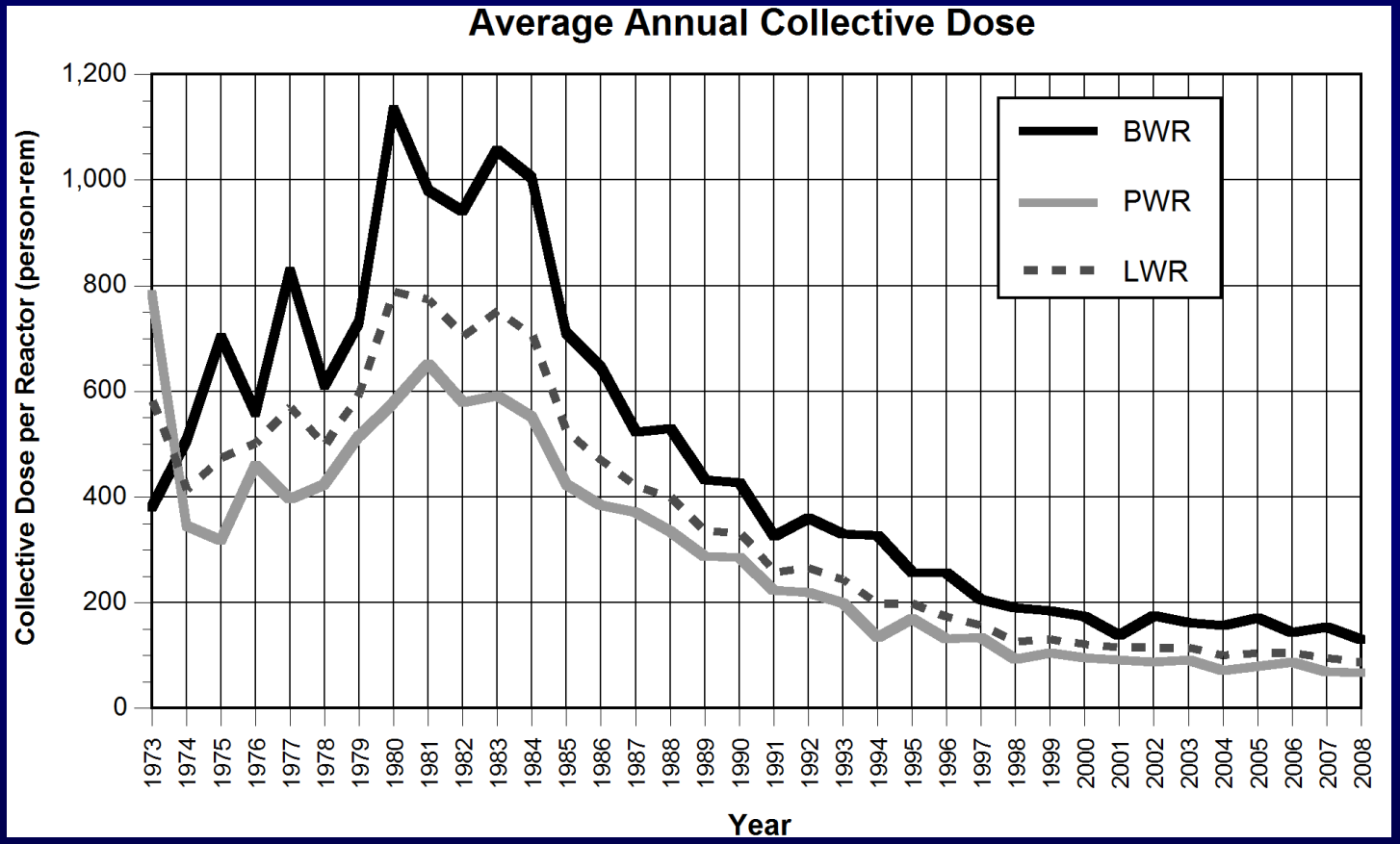
# Spent Fuel Pool



# Routine Occupational Doses Commercial Light Water Reactors

| Year | Number of Licensees | Average Measurable TEDE per Worker (REM) |
|---|---|---|
| 2008 | 104 | 0.10 |
| 2007 | 104 | 0.11 |
| 2006 | 104 | 0.13 |
| 2005 | 104 | 0.12 |
| 2004 | 104 | 0.14 |
| 2003 | 104 | 0.14 |
| 2002 | 104 | 0.14 |
| 2001 | 104 | 0.16 |

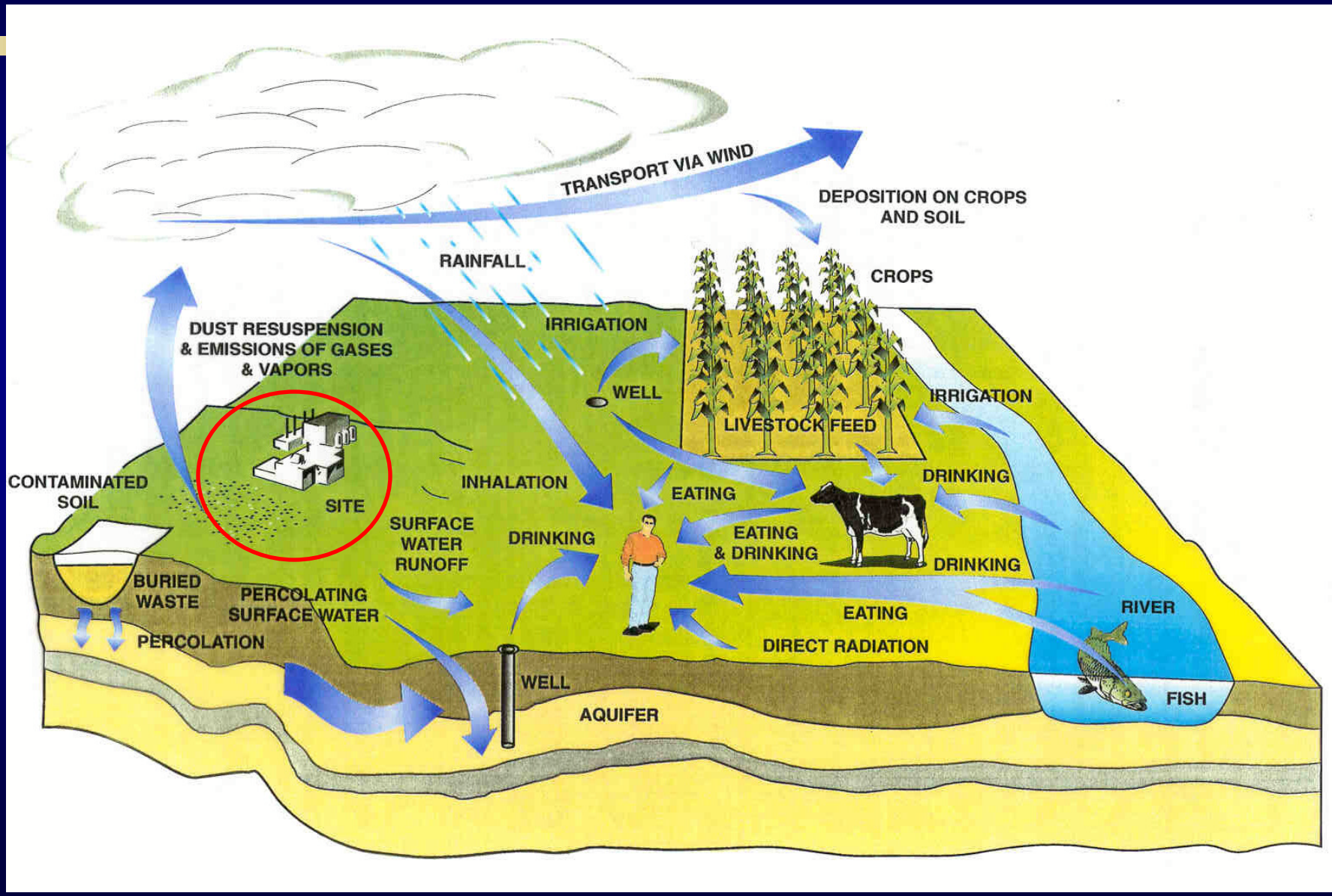
# Collective Dose (Person-rem)



# Environmental Pathways

- Three major exposure categories:
  - Direct radiation
  - Airborne contaminants
  - Waterborne contaminants

# Environmental Pathways



# Dose to Members of the Public

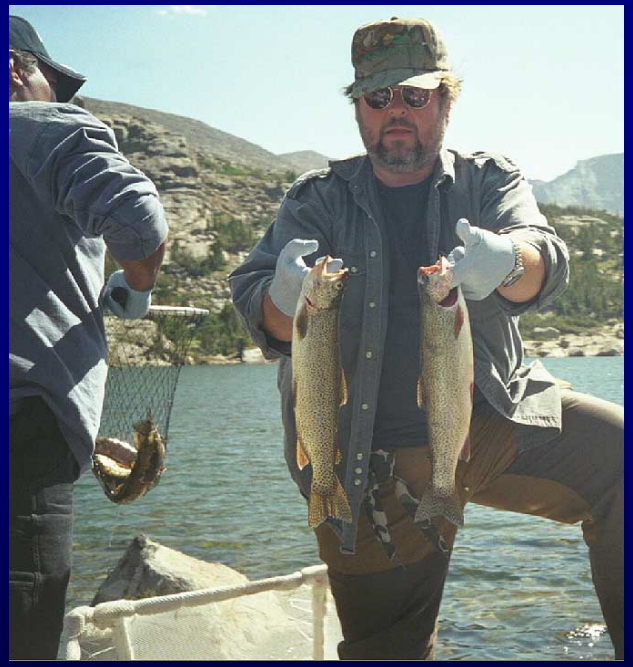
- 10 CFR 20 - 100 mrem/yr TEDE to member of public
- 40 CFR 190 - 25 mrem/yr to whole body and 75 mrem/yr to thyroid and 25 mrem/yr to other organs of a member of public from entire fuel cycle
- Appendix I to 10 CFR 50 - 5 mrem/yr from gaseous effluents and 3 mrem/yr from liquid effluents

# Soil/Sediment Sampling

# Ground Water Monitoring

# Vegetation Sampling

# Fish Sampling



# Tritium

- Naturally-occurring radioactive form of Hydrogen found in groundwater
- Byproduct from nuclear plants
- Tritium bonds with oxygen to form tritiated water (HTO)

# Tritium (H-3) Releases

- Inadvertent releases of H-3 from different nuclear power plants from leaks and spills
- Releases have been through unapproved (unplanned and unmonitored) systems/pathways not designed for such releases (e.g., leaks in pipe valves, spent fuel pools, etc.)
- H-3 is one of the least hazardous of the radioisotopes

# Radiological Emergencies at Nuclear Power Plants

# Emergency Preparedness

- Ensures power plants can implement adequate measures to protect public health & safety
- Condition of License
- NRC inspects & evaluates facility readiness

# Emergency Classifications

Set of plant conditions which indicate a level of risk to public

- Notification of Unusual Event
- Alert
- Site Area Emergency
- General Emergency

# Emergency Preparedness

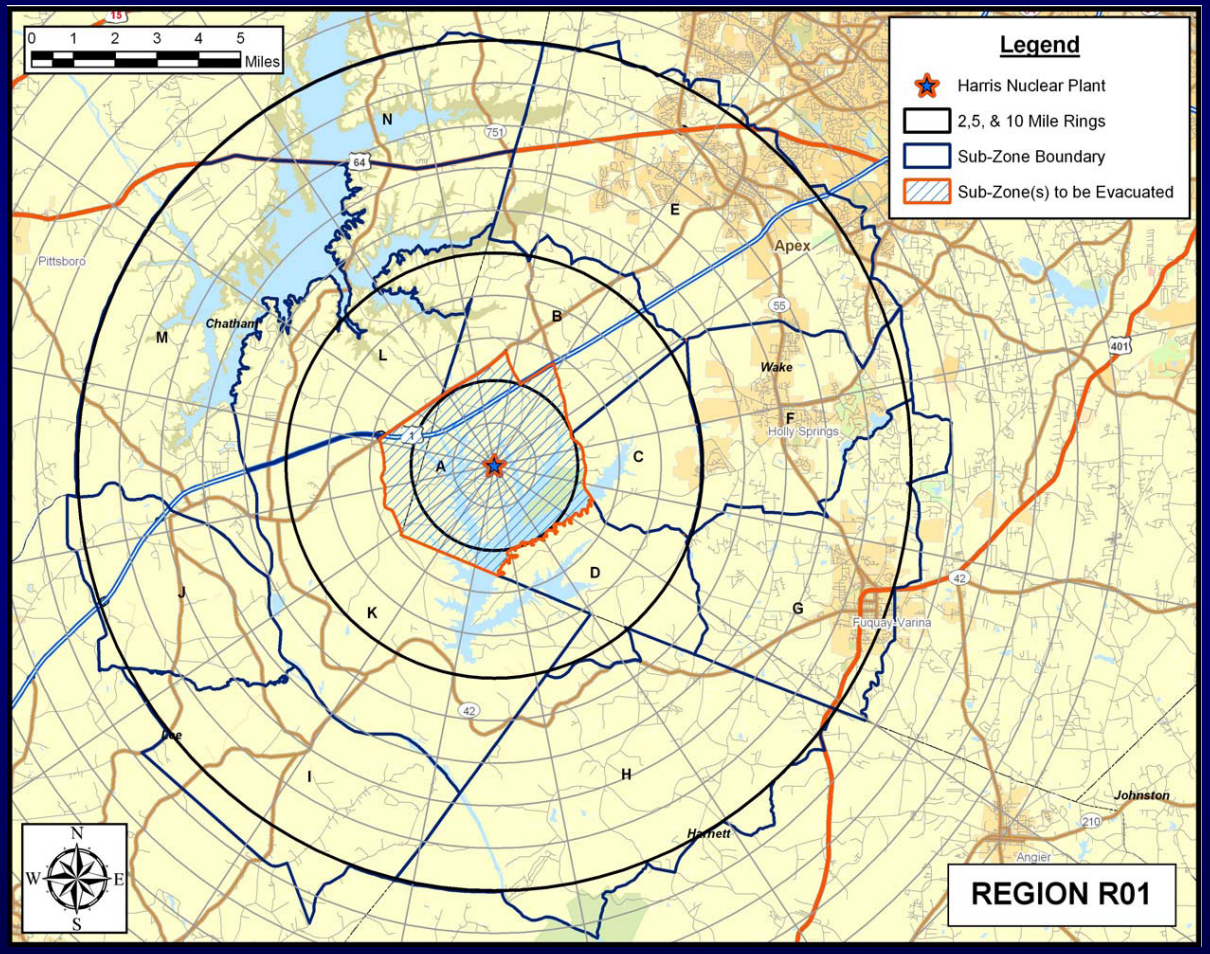
- Emergency Planning Zones (10 mile EPZ, 50 mile EPZ)
- Protective Action Guides (PAGs)
- Alert and Notification System (sirens, tone-alert radios, route alerting)
- Emergency Information distributed to Public

# Emergency Planning Zones

- Plume Exposure Pathway (10 miles from reactor site) – designed to avoid of reduce dose from exposure or radioactive material

- Ingestion Exposure Pathway (50 miles from reactor site) – designed to avoid or reduce exposure from ingestion of radioactive materials; ban on contaminated food and water

# Example of 10 Mile EPZ of Nuclear Power Plant



# Radioprotective Drugs

- Potassium Iodide (KI) – reduces thyroid dose from radioiodine
- States with a population within the 10-mile emergency planning zone can issue KI as protective measure for the general public (2001)
- Supplements sheltering and evacuation in the unlikely event of a severe nuclear power plant accident

# END OF REACTOR HEALTH PHYSICS