Pacific Northwest NATIONAL LABORATORY

Using Risk Assessment to Guide Environmental Remediation Decisions: A Primer

July 26, 2022

Amoret Bunn, PNNL
Vicky Freedman, Sealaska Technical Services
Laura Buelow, EPA Region 10

REMPLEX
CENTER FOR THE REMEDIATION OF COMPLEX SITES
@PNNL

U.S. DEPARTMENT OF ENERGY BATTELLE

PNNL is operated by Battelle for the U.S. Department of Energy

PNNL-SA-175606

Pacific Northwest NATIONAL LABORATORY

Outline

- What is a risk?
- What is risk assessment?
- Why conduct a risk assessments?
- Risk assessment conceptual site models
- Dose vs. Risk

REMPLEX CENTER FOR THE REMEDIATION OF COMPLEX SITES @PNNL

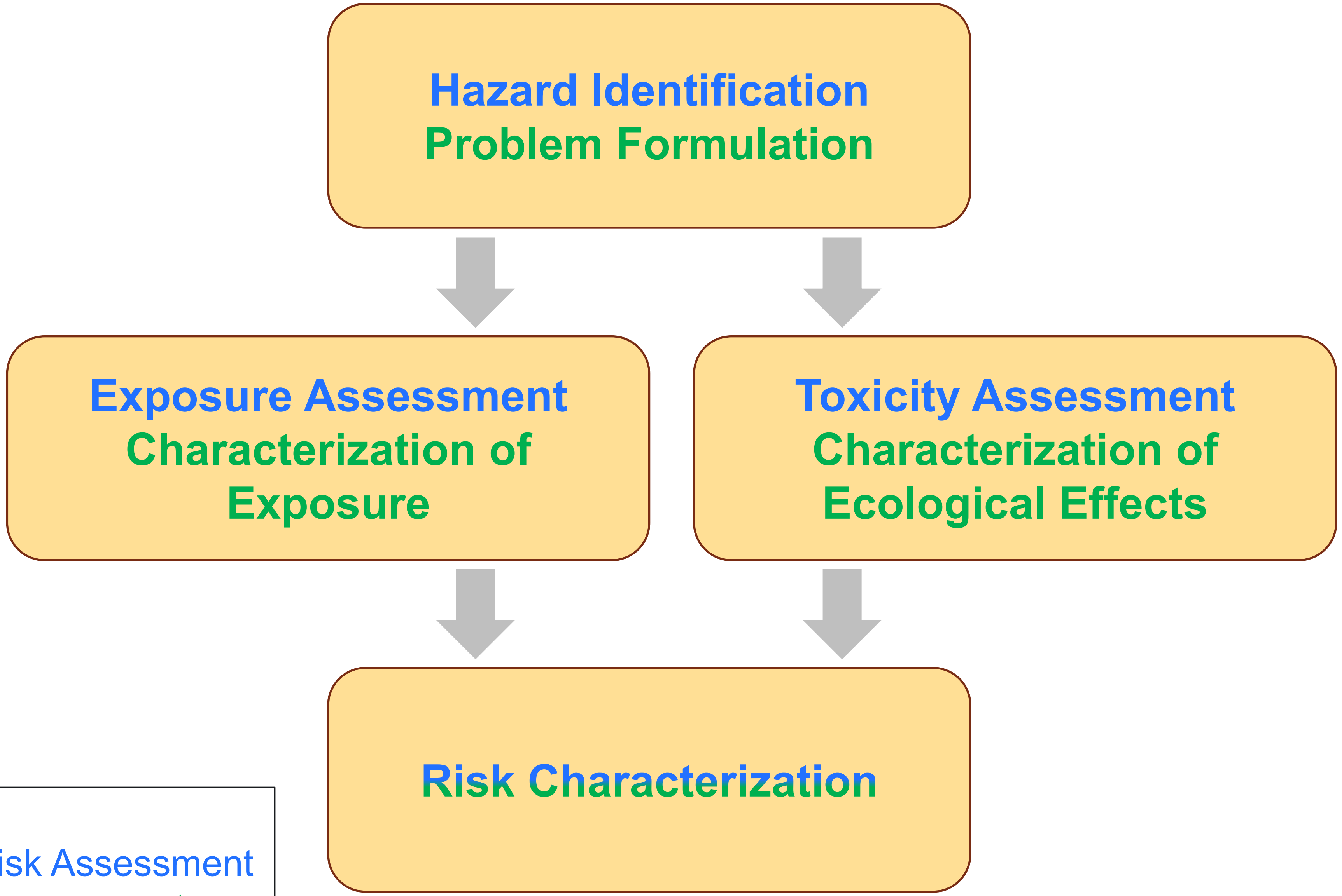
Pacific Northwest NATIONAL LABORATORY

Risk Defined for Human Health and the Environment

- Many definitions of "*risk*"
- For our purposes today:
  - ✓ *Risk* is the chance of harmful effects to human health or to ecological systems resulting from exposure to an environmental "*stressor*".
  - ✓ A stressor is any physical, chemical, or biological entity that can induce an adverse effect in humans or ecosystems.
  - ✓ Stressor = contaminant of concern = radionuclide
- Depends upon:
  - ✓ How much of a contaminant is present in an environmental medium (e.g., soil, water, air) over what geographic area,
  - ✓ How much contact (exposure) a person or ecological receptor has with the contaminated environmental medium, and
  - ✓ How the contaminant affects the health of humans (e.g., toxicity) or ecological receptors (e.g., fish killed by lack of oxygen).

What is Risk Assessment?

Systematic process to determine if contaminants detected at a site are of concern to human health and the environment

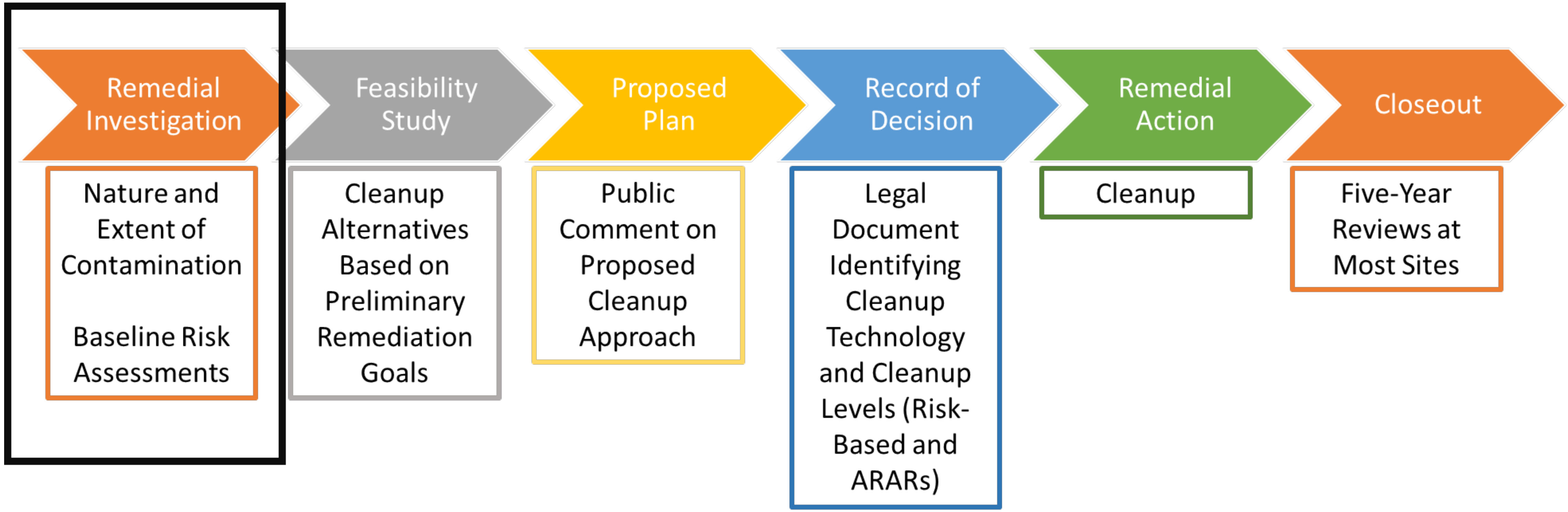


Risk = Consequence X Likelihood

Legend:
- Human Health Risk Assessment
- Ecological Risk Assessment

Why conduct a risk assessment?

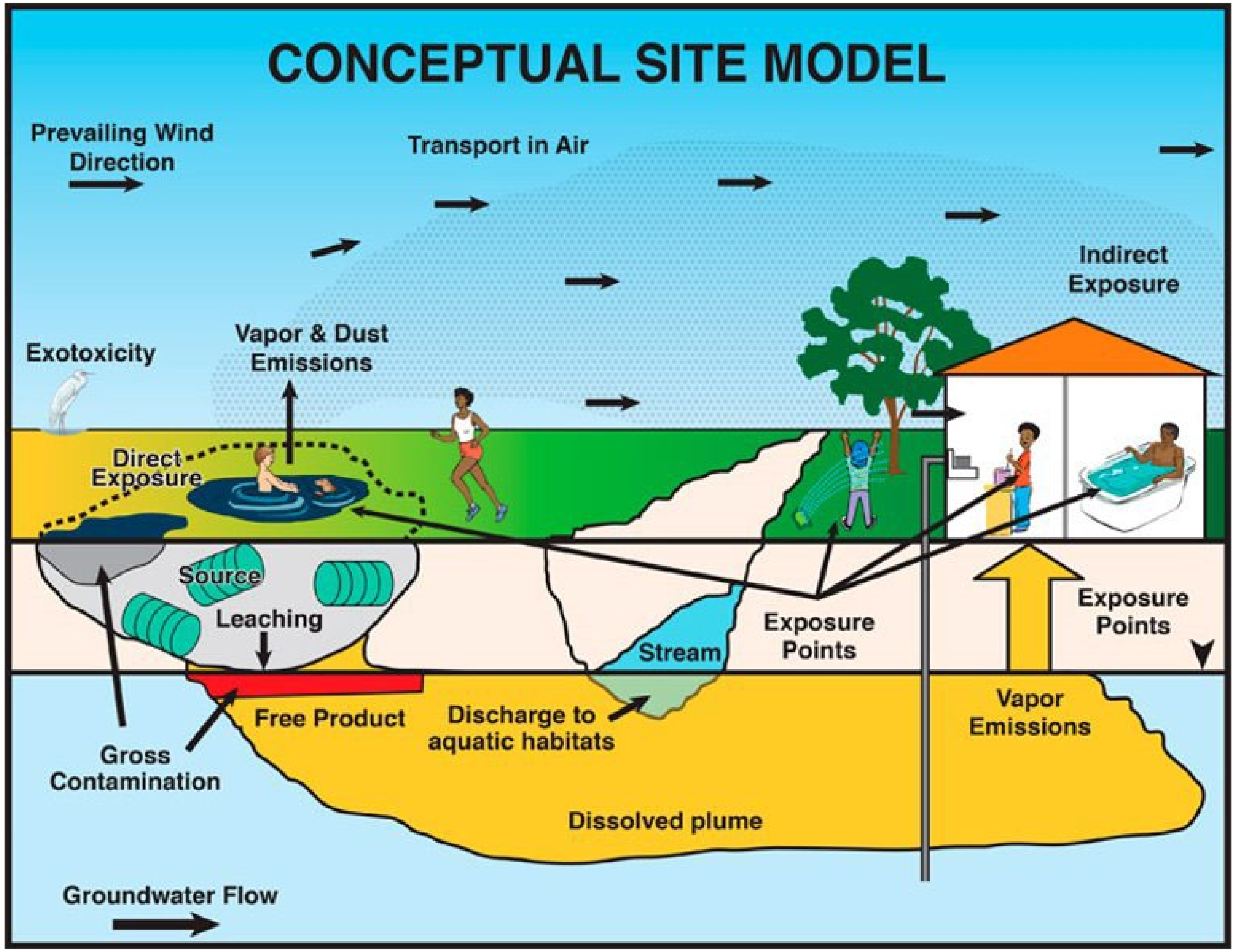
- A step within the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA or Superfund)
  - Helps determine a need for action
  - Basis for determining levels of contaminants that can remain onsite while still adequately protecting public health
  - Basis for comparing potential health impacts of different future site uses and/or various remedial alternatives



REMPLEX
CENTER FOR THE REMEDIATION OF COMPLEX SITES
@PNNL

Risk Assessment are Dependent on Conceptual Site Model

- Developed for both Human Health and Ecological Risk Assessments
- Exposure media: soil, water, air
- Exposures through variety of pathways: inhalation, ingestion, and direct exposure
- Considers both current and future land use

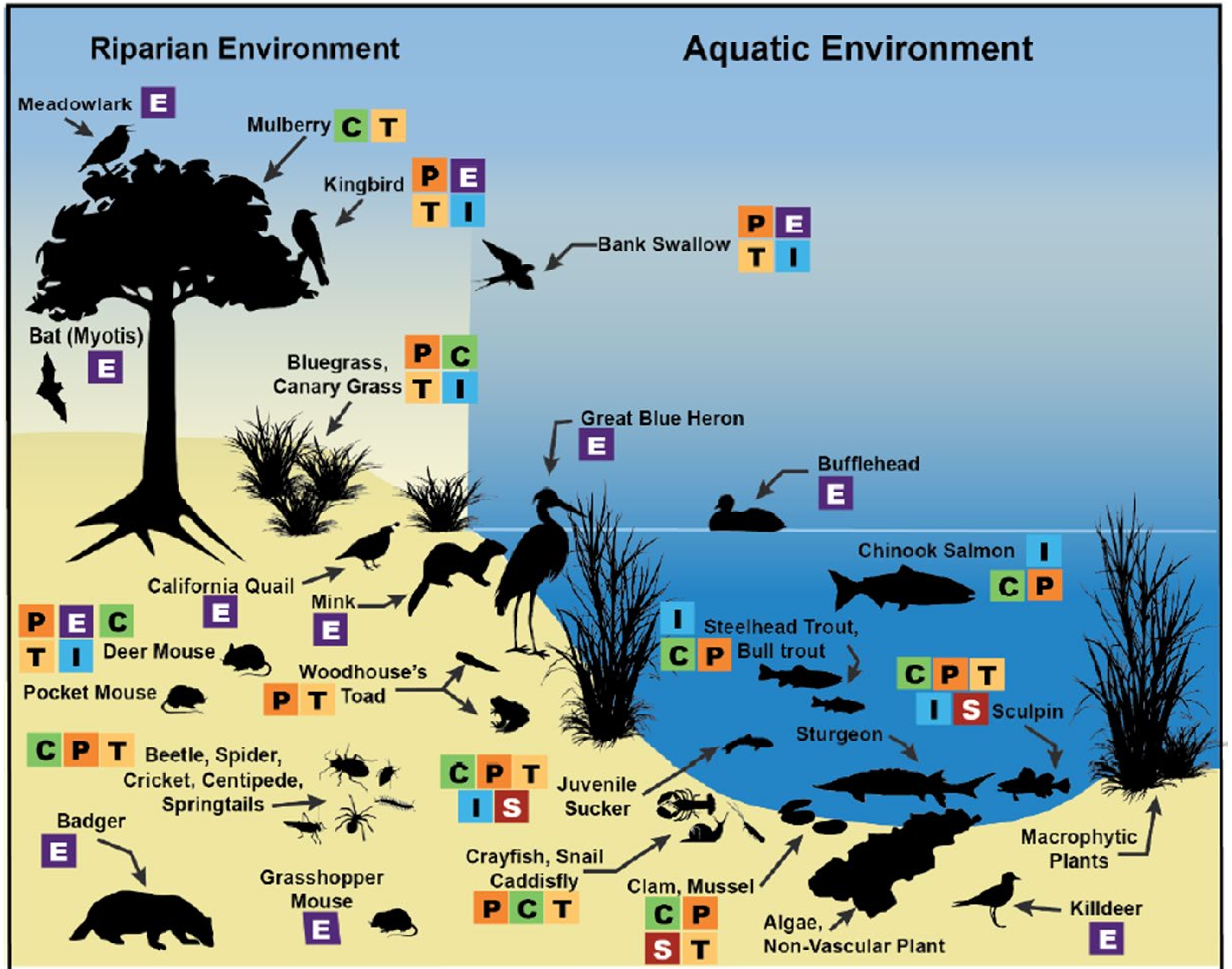


Ecological Risk Assessment Conceptual Site Model

Example: Conceptual Model for Ecological Risk Assessment, Hanford, *Risk Corridor Baseline Risk Assessment*

Assessment of Conditions:

- **C** Community level
- **I** Individual level
- **P** Population level
- **S** Sub organism level (histology)
- **E** Wildlife exposure analysis
- **T** Measurements of tissue concentrations

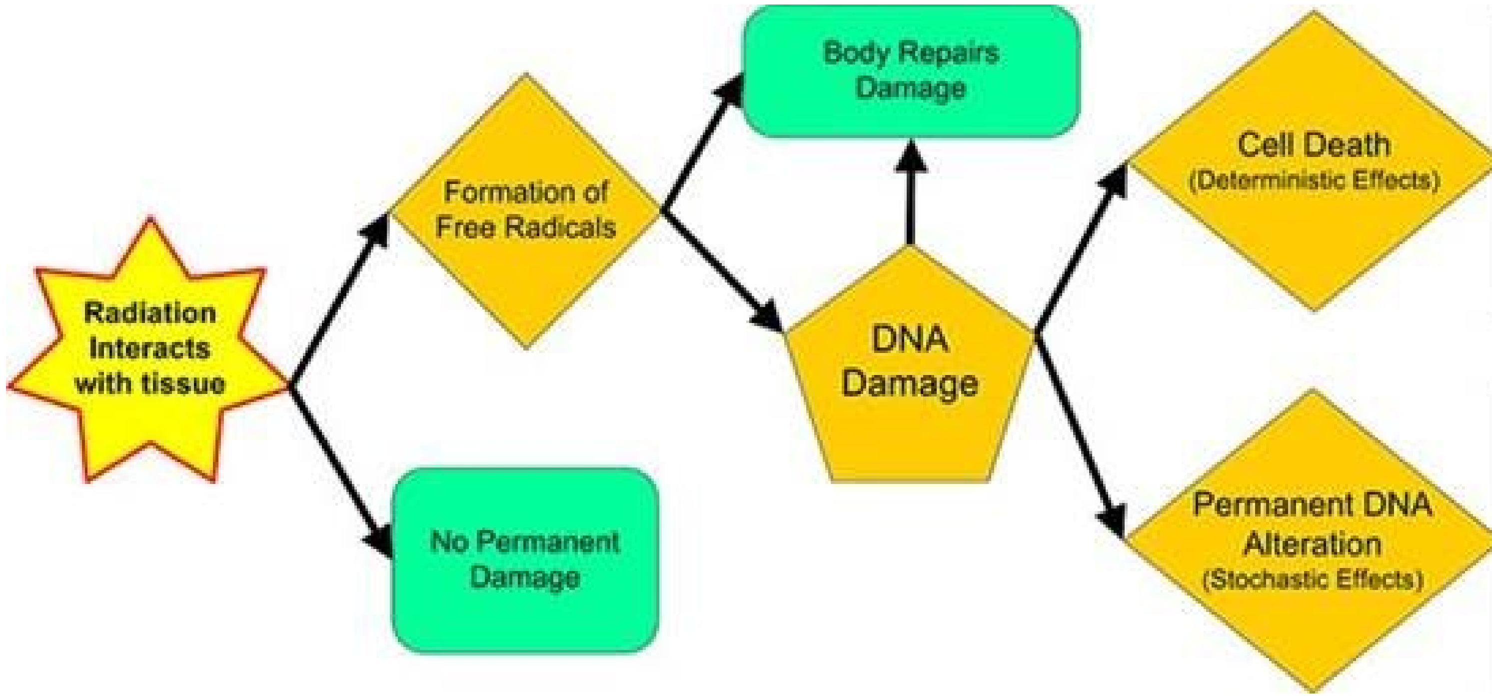


REMPLEX
CENTER FOR THE REMEDIATION OF COMPLEX SITES
@PNNL

Dose vs. Risk Endpoint in Radiation Risk Assessments

For radionuclides, concern is focused on health effects from radiation

- Dose is amount of energy absorbed by a person per unit mass
  - Biological dose or dose equivalent is a measure of biological damage to living tissue as a result of radiation exposure
  - Units are rems or sieverts (Sv)
    - ✓ 1 rem = 0.01 Sv
    - ✓ 1 mrem = 0.00001 Sv = 10 µSv
    - ✓ 1 µSv = 0.1 mrem



Source: https://www.imagewisely.org/Imaging-Modalities/Computed-Tomography/How-to-Understand-and-Communicate-Radiation-Risk

- Conversion of dose to risk for evaluation to regulation
  - Acceptable range 1 in 10,000 (10^{-4}) to 1 in 1,000,000 (10^{-6})
  - For US Federal drinking water standards (40 CFR 141.16):
    - ✓ 4 mrem/yr (40 µSv)

REMPLEX CENTER FOR THE REMEDIATION OF COMPLEX SITES @PNNL

Pacific Northwest
NATIONAL LABORATORY

Thank you

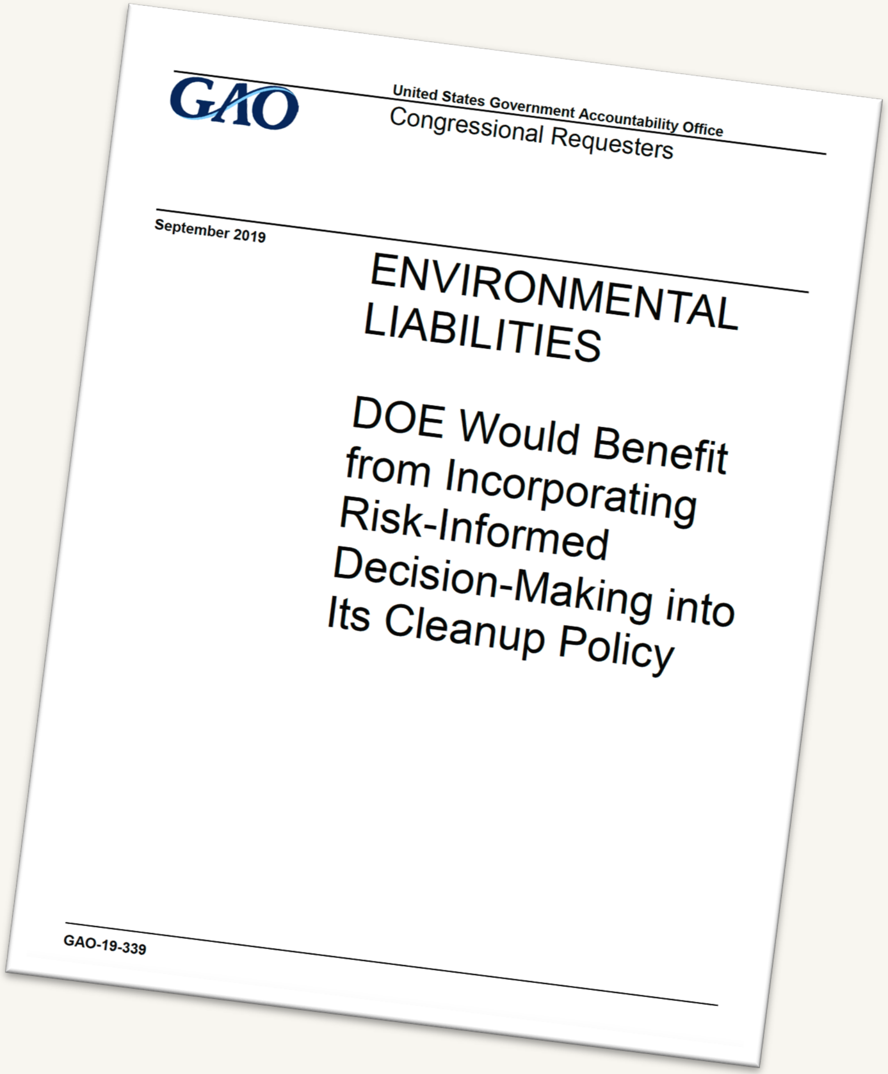
Technical Basis for Risk-Informed Decision-Making

A Historical Perspective on Radiation Protection Guidance

Vicky Freedman

GAO Report on Risk-Informed Decision-Making

- 2019 GAO report recommended that DOE adopt a risk-informed approach
- Facilitate decision-making approach that considers trade-offs
  - Risks to human health and the environment
  - Cost
  - Uncertainty
  - Diverse stakeholder perspectives


GAO

United States Government Accountability Office
Congressional Requesters

September 2019

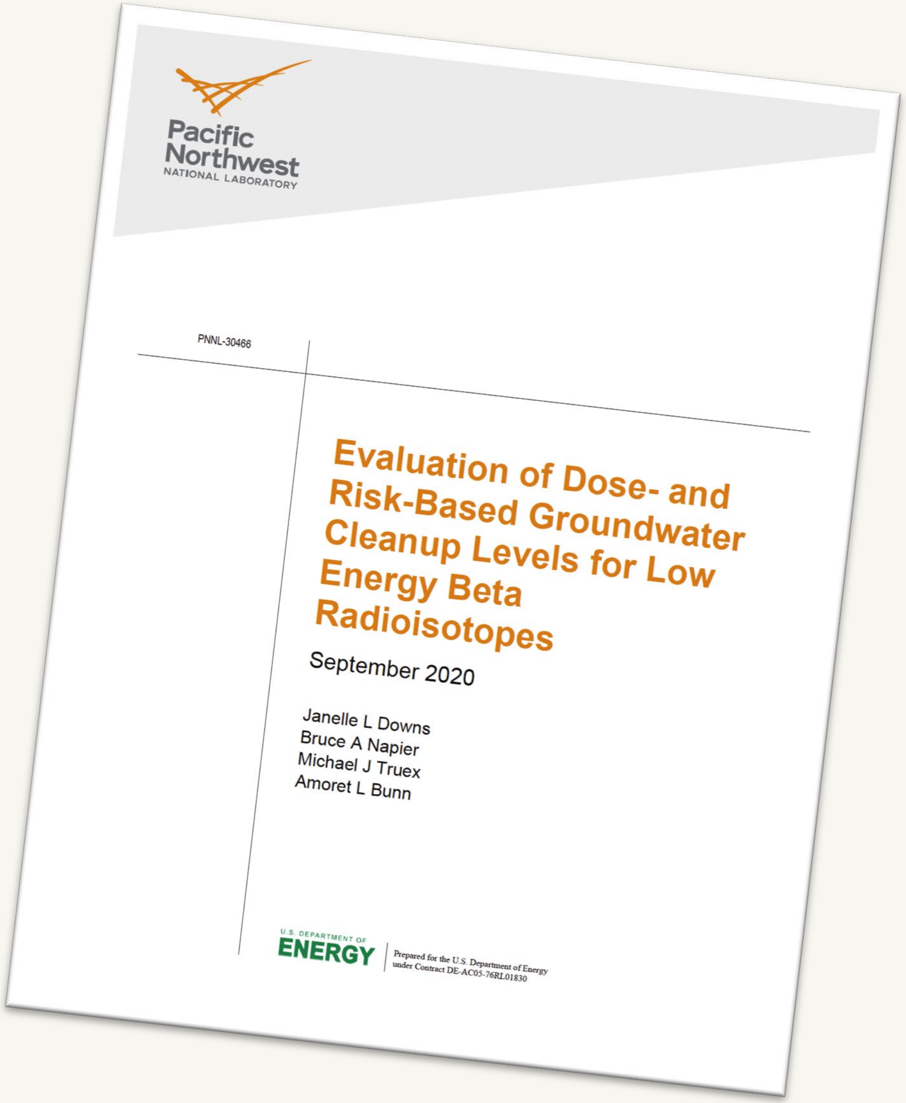
ENVIRONMENTAL LIABILITIES

DOE Would Benefit from Incorporating Risk-Informed Decision-Making into Its Cleanup Policy

GAO-19-339

Risk Evaluation Approach for Low Beta Emitters

- Identify ***risk-based factors*** relevant for ***remedy decisions*** *for* five low-energy beta radioisotopes
  - Based on updated information on dosimetry, effective dose, and biokinetics, determine derived concentrations that correspond to a 4 mrem/yr (40 µSv) dose limit for using tap water scenario
  - Support management strategies where cleanup to drinking water standards (DWS) may not be attainable within a reasonable timeframe using currently available treatment technologies


Pacific Northwest
NATIONAL LABORATORY

PNNL-30466

Evaluation of Dose- and Risk-Based Groundwater Cleanup Levels for Low Energy Beta Radioisotopes

September 2020

Janelle L Downs
Bruce A Napier
Michael J Truex
Amoret L Bunn

U.S. DEPARTMENT OF ENERGY

Prepared for the U.S. Department of Energy under Contract DE-AC05-76RL01830

Groundwater Risk Assessment

Contaminant Fate & Transport

Contaminant concentrations are predicted at point(s) of compliance. For complex sites, this step may require the use of physically-based fate and transport models with high computational demands, which can limit the ability to assess uncertainty.

Model Abstraction

Physically-based models may be abstracted to less complex models that can assess uncertainty associated with groundwater concentrations at points of compliance

Dose Calculations

Support the development of maximum concentrations through different exposure scenarios (e.g., farmer, resident, outdoor worker, etc.) to different media (e.g., soil, air, tap water) using tools such as PRG Calculator, RESRAD, GENII, etc.

Risk Estimates

Exposure scenarios are analyzed to produce guidelines for remediation and cleanup actions using different assumptions; Superfund requires that the selected remedy will meet the one in 10,000 to one in a million cancer (10^{-4} to 10^{-6}) risk range for all carcinogens

Barriers to Cleanup

I-129

- Relatively mobile
- Complex speciation
- Presence of iodine-127 can interfere with treatment
- Long half-life limits natural attenuation
- Potential technologies likely species specific

Tc-99

- Highly mobile
- Long half-life limits natural attenuation
- Potential technologies need to be identified to limit flux to groundwater

H-3

- Highly mobile

C-14

- P&T not effective due to low mobility and interaction with natural carbonates
- GW treatment may not be practicable

Cl-36

- Often major impediment to cleanup of reactors

Standards Based on Radiation Protection Guidance

The Health Physics Society

Nonprofit scientific organization chartered in U.S. that develops position statements and recommendations on radiation protection

National Council on Radiation Protection and Measurements (NCRP)

National nonprofit chartered by Congress in 1964 to collect, analyze, and disseminate information on rad protection (Public Law 88-376)

Different agencies rely on different sources for technical guidance published over the last 60 years

The International Commission on Radiological Protection (ICRP)

Principal international, not-for-profit, independent organization concerned with radiation protection, providing recommendations and guidance on all aspects of protection against ionizing radiation

Other International Organizations

International Atomic Energy Agency (IAEA) and the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) also provide unbiased international consensus on the risks of radiation exposure

Definitions and Terms

Threshold

Maximum permissible dose for worker protection

- Early radiation protection philosophy centered on radiation doses below a protective threshold
- Environmental Protection Agency (EPA) apportioned dose limit separately to the drinking water pathway –
- Extension of **critical organ** approach

Critical Organ

Dose regulated based on organ receiving the highest dose

- Radionuclide treated as a point source inside of a spherical organ or body
- Simplified approach, suitable for hand calculations
- Need to select an organ and calculate dose

Effective Dose Equivalent

Weighted approach equivalent to whole body irradiation

- Different organs have different sensitivities to radiation
- This knowledge eventually was used to develop the concept of **effective dose** or **effective dose equivalent**
- Uses sophisticated biokinetic models of radionuclide retention and distribution, including organ specific risks and weighting factors

Equivalent Dose

Absorbed radiation multiplied by radiation weighting factor

- **Equivalent dose** is a measure of the radiation dose to tissue
- Accounts for relative biological effects of different types of ionizing radiation
- Measured using the sievert but rem is still commonly used (1 Sv = 100 rem)

Technical Guidance and Regulations

1960

ICRP Publication 2

Basis for EPA and NRC regulations, 4 mrem/y drinking water only, critical organ and total body approach

1963

National Bureau of Standards Handbook 69

Initial basis for dose conversion factors for ingested radioactivity

1976

National Interim Primary Drinking Water Regulations

EPA establishes DWS for all public water supplies

1977

ICRP Publication 26

Supplanted maximum permissible body burden with the *effective dose*

1979

ICRP Publication 30

First major revision that is now used by the NRC, incorporating methods of ICRP Publication 26 with dose per unit intake published in multiple volumes (1979 – 1982)

EPA Proposed Rule

Base regulatory limit on effective dose equivalent (ede) (ICRP 1977)

1991

ICRP Publication 60

DOE adopted the approach outlined in ICRP 60 (1991) for worker exposure. Adopted "effective dose" term and updated weighting factors

1995

HEAST (EPA)

Included slope factors for inhalation, ingestion, and external exposure to soil contamination

1999

Federal Guidance Report (FGR)-13

EPA document using gender specific dose assessment based on ICRP Pub 72 (1996); EPA Blue Book (2011) based on risk and dose coefficients in FGR-13

2000

EPA Proposed Rule

Proposed rule never finalized due to concerns over the most effective way to regulate radon and other considerations

2011

DOE 1196-2011

Derived concentrations based on effective dose limit of 100 mrem/y (all pathways), FGR-13 and ICRP Pubs 60 and 107

Advancements in Dosimetry and Biokinetics

2002

ICRP Publication 89

Provided gender-specific physiological parameters for the Reference Man

2007

ICRP Publication 103

Provided updated information on the energies and intensities of radiation emitted by radionuclides, including the radiation and tissue weighting factors and radiation detriment using latest available scientific information of the biology and physics of radiation exposure.

2011

EPA Blue Book

Revision of the EPA methodology for estimating cancer risks from radiation exposure based on the 2006 National Research Council report and EPA Science Advisory Board, providing basis for future updates to radiation protection rules and guidance.

2014

IAEA Radiation Protection

International guidance for radioactive contaminants in drinking water is based on calculations that apply more recent dosimetric methods, parameters, and guidance based largely on ICRP Pub 103

2015+

ICRP Occupational Intakes of Radionuclides (OIR)

Provide updated information on chemical forms, decay parameters, biokinetics, and tables of committed effective dose for inhalation and ingestion [Parts 1 – 4 (2015 – 2019), and Part 5 (in preparation)].Organ equivalent doses is not yet available.

2019

Federal Guidance Report (FGR)-15

Incorporates several updates, including expansion of age specific dose coefficients, six updated tissue weighting factors (ICRP Publication 103) and radionuclide decay data (ICRP Publication 107)

Regulation of Radiation Exposure

NRC, EPA, OSHA, DOE

Oversight for exposure standards for the public and for workers

Total Body

US DOT

Oversight for transportation of radionuclides

ICRP, 1960

NBS, 1963

Critical Organ

Effective Dose

ICRP, 1979 – 1982

FGR, 1999

ICRP, 1991

NRC and US FDA

Primary regulatory authority over the use of ionizing radiation in medicine

Risk Evaluation

FGR-15, 2019

ICRP, 2007

IAEA, 2014

Federal and State Laws

States may regulate independently of federal guidance, with more conservative protections in place

Federal Drinking Water Standards

1

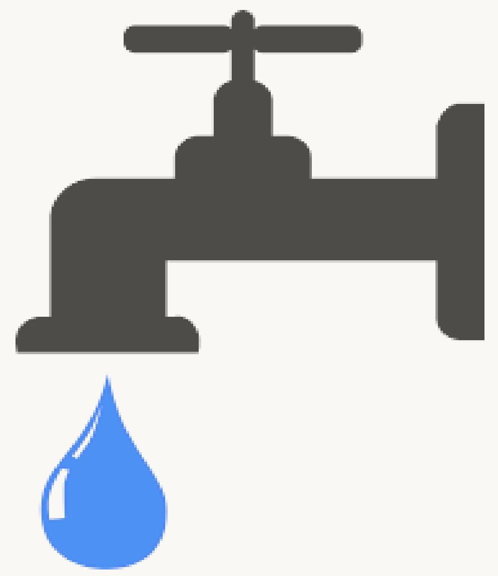
Technical Basis

Dose factors in ICRP 2 (1960), methodology in NBS 69 (1963), DWS based on 4 mrem/y to most sensitive (critical) organ from ingestion of drinking water in an adult resulting in risk coefficients ranging from 10^{-4} to 10^{-6}

2

Concentration Limits

Limits were established by the National Interim Primary Drinking Water Regulations (EPA 1976), becoming effective in 1977; public dose was set to a fraction of the worker dose limit because of the potential for enhanced effects in children or elderly



3

Critical Organ Approach

Dose regulated based on the organ receiving the highest dose (considered as a point source) Not based on risk of cancer, but on minimizing immediate and hereditary effects.

4

Final Rule

EPA intent was to review the 4 mrem/y dose limit for beta and photon emitters within 2 to 3 years of publication (EPA, 1976) to ensure that the MCL reflects the best available science, but review or changes to the standards have not been implemented to date

Health Physics Knowledge Updates

1 **Method Updates**

Updates based on methods published by the ICRP, the U.S. National Committee on Radiation Protection and Measurements and the National Council on Radiation Protection and Measurements (NCRP)

2 **Effective Dose**

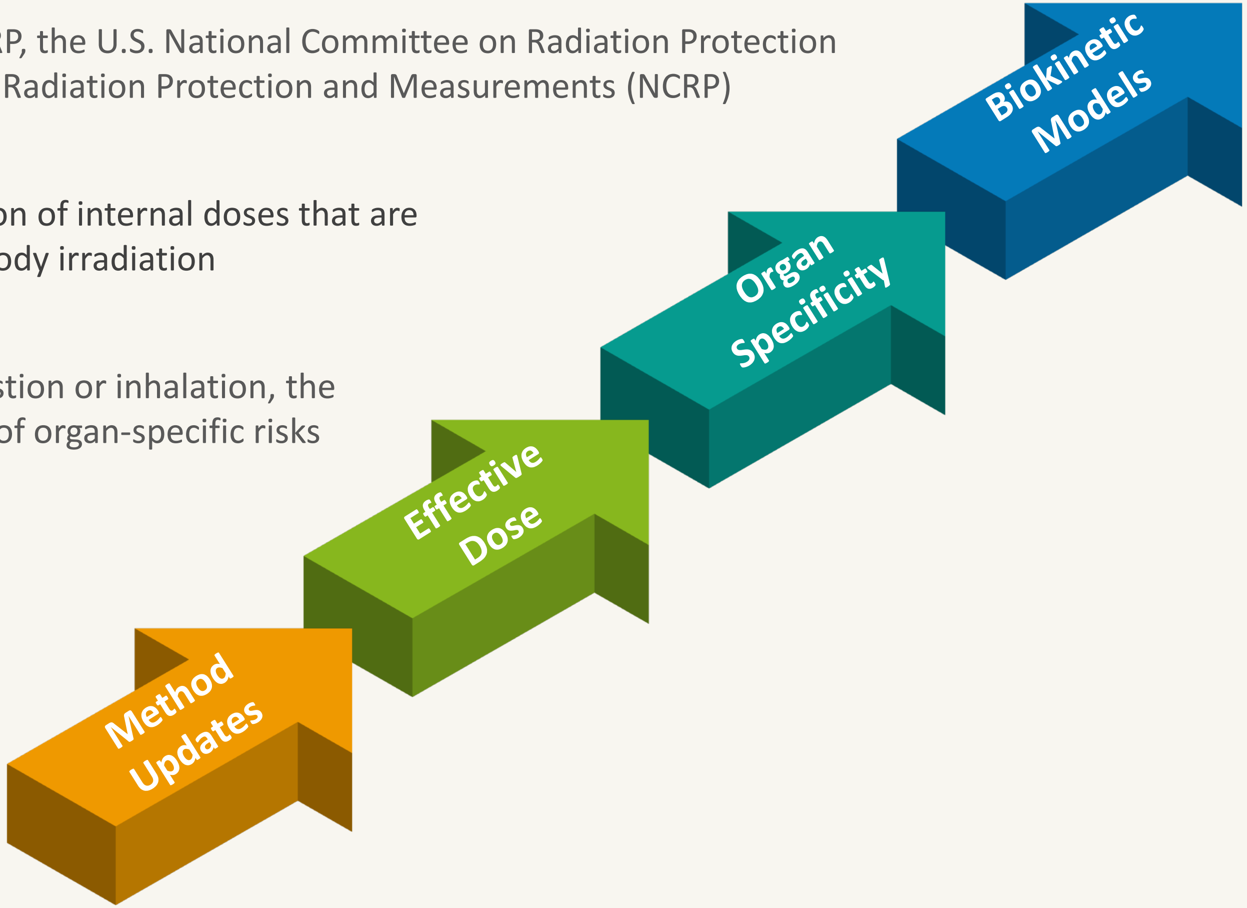
Use of **effective dose** uses weighted accumulation of internal doses that are "effectively" the same as an equivalent whole-body irradiation

3 **Organ Specificity**

Increased knowledge in the body following ingestion or inhalation, the irradiation of neighboring organs, and inclusion of organ-specific risks with organ/tissue weighting factors

4 **Biokinetic Models**

Refinements in biokinetic models has led to improvements in dosimetry and time factors (e.g., biological half-life)



Technical Basis for Exposure Limits

1	Based on 4 mrem/y (40 µSv) to any organ and basis for **EPA** DWS	**ICRP Pub 2 (1960)** **NBS 69 (1963)**
2	First major revision that is now used by the **NRC**, incorporating methods of ICRP Publication 26 with dose per unit intake	**ICRP Pub 26 (1977)** **ICRP Pub 30 (1978)**
3	**EPA Blue Book** supports organ weighting factors and includes cancer risk coefficients, and different age groups	**ICRP Pub 60 (1991)** **ICRP Pub 72 (1996)** **FGR-13 (1999)**
4	**DOE** derived concentration standards, gender-specific (not age-specific), with a single effective dose for each pathway	**ICRP Pub 72 (1996)** **ICRP Pub 89 (2002)** **ICRP Pub 107 (2008)** **FGR-13 (1999)**
5	**IAEA** guidance supports radiation and tissue weighting factors, radiation detriment using latest available scientific information of the biology and physics of radiation exposure	**ICRP Pub 103 (2007)** **IAEA (2014)** **ICRP OIR (2015 – 2019)**

Summary

- Improved knowledge in health physics result in different concentration limits
  - Critical organ to Total Organ/Effective Dose
  - Age-specific, gender-specific parameters
  - More advanced biokinetic models, tissue weighting factors, etc.
- Derived concentrations (based on EPA exposure limit of 4 mrem/y [40 µSv]) resulted in higher concentration limits for all five low-beta emitters
- Risk-based concentration limits support risk-informed decision-making
  - Can include other exposure pathways (e.g., inhalation, food ingestion)
  - Does not necessarily result in higher concentration limits

References

DOE-STD-1196-2011. 2011. DOE Standard-Derived Concentration Technical Standard. U.S. Department of Energy, Washington, D.C.

Eckerman KF, RW Leggett, CB Nelson, JS Puskin, and ACB. Richardson. 1999. Cancer Risk Coefficicents for Environmental Exposure to Radionuclides. Federal Guidance Report No. 13, EPA 402- R-99-001, Oak Ridge National Laboratory, Oak Ridge, TN.

Eckerman KF 2019. FGR15 External Dose Rate Coefficient Viewer. Oak Ridge National Laboratory, Oak Ridge, TN.

EPA. 1976. National Interim Primary Drinking Water Regulations. EPA-570/9-76-003, U.S. Environmental Protection Agency, Office of Water Supply, Washington, DC. EPA. 1988.

Letter from the Science Advisory Board to Lee M. Thomas, EPA Administrator on April 27, 1988. SAB-RAC-88-026, US Environmental Protection Agency, Washington, DC

EPA. 1991. National Primary Drinking Water Regulations; Radionuclides; Proposed Rule. 40 CFR Parts 141 and 142. U.S. Environmental Protection Agency, Washington, DC.

EPA 1993. Federal Guidance Report No. 12: External Exposure to Radionuclides in Air, Water, and Soil. EPA 402-R-93-081 , U.S. Environmental Protection Agency Office of Radiation and Indoor Washington, DC. https://www.epa.gov/radiation/federal-guidance-report-no-12-external-exposure-radionuclides-airwater-and-soil

EPA 1995. Health Effects Assessment Summary Tables, FY-1995 Annual. EPA 540/R-95/036, U.S. Environmental Protection Agency Office of Research and Development, Washington, DC.

EPA. 1997. Memorandum: Establishment of Cleanup Levels for CERCLA Sites with Radioactive Contamination. OSWER No. 9200.4-18, Office of Solid Waste and Emergency Response, US Environmental Protection Agency, Washington, DC.

EPA 2000. 40 CFR Part 141 National Primary Drinking Water Regulations, and 40 CFR Part 142, National Primary Drinking Water Regulations Implementation. U.S. Environmental Protection Agency, Washington, DC.

References

EPA. 2002. Federal Guidance Report 13 CD Supplement, Cancer Risk Coefficients for Environmental Exposure to Radionuclides, Rev. 1, 2002, U.S. Environmental Protection Agency, Washington, DC.

EPA 2011. EPA Radiogenic Cancer Risk Models and Projections for the U.S. Population EPA 402-R-11- 001, U.S. Environmental Protection Agency Office of Radiation and Indoor Air, Washington, DC https://www.epa.gov/sites/production/files/2015-05/documents/bbfinalversion.pdf

EPA 2019. Federal Guidance Report No. 15: External Exposure to Radionuclides in Air, Water, and Soil. EPA 402-R-19-002, U.S. Environmental Protection Agency Office of Radiation and Indoor Washington, DC

GAO. 2019. DOE Would Benefit from Incorporating Risk-Informed Decision-Making into Its Cleanup Policy. GAO-19-339, U.S. Government Accountability Office, Washington D.C.

ICRP. 1960. Report of Committee II on Permissible Dose for Internal Radiation. ICRP Publication 2, Pergamon Press, London.

ICRP. 1977. Recommendations of the International Commission on Radiological Protection. ICRP Publication 26, Ann. ICRP 1(3). ICRP. 1978. “Statement from the 1978 Stockholm meeting.” In: Annals of the ICRP 1(3), Pergamon Press, Oxford.

ICRP. 1979a. Limits for Intakes of Radionuclides by Workers. ICRP Publication 30, Part 1, Pergamon Press Ltd, Oxford, U.K.

ICRP. 1979b. Limits for Intakes of Radionuclides by Workers. ICRP Publication 30, Supplement to Part 1, Pergamon Press Ltd, Oxford, U.K.

ICRP. 1980. Limits for Intakes of Radionuclides by Workers. Statement and Recommendations of the 1980 Brighton Meeting of the ICRP.

ICRP Publication 30, Part 2, Pergamon Press Ltd, Oxford, U.K. ICRP. 1981a. Limits for Intakes of Radionuclides by Workers. ICRP Publication 30, Supplement to Part 2, Pergamon Press Ltd, Oxford, U.K.

References

ICRP. 1981b. Limits for Intakes of Radionuclides by Workers. ICRP Publication 30, Part 3. Pergamon Press Ltd, Oxford, U.K.

ICRP. 1982a. Limits for Intakes of Radionuclides by Workers. ICRP Publication 30, Supplement A to Part 3, Pergamon Press Ltd, Oxford, U.K.

ICRP. 1982b. Limits for Intakes of Radionuclides by Workers. ICRP Publication 30, Supplement B to Part 3, Pergamon Press Ltd, Oxford, U.K.

ICRP. 1991. 1990 Recommendations of the International Commission on Radiological Protection. ICRP Publication 60, Ann. ICRP 21(1–3).

ICRP. 1996. Age-dependent Doses to Members of the Public from Intake of Radionuclides: Part 5 Compilation of Ingestion and Inhalation Dose Coefficients. ICRP Publication 72, Elsevier Science Ltd, Oxford, U.K.

ICRP. 1988. Limits for Intakes of Radionuclides by Workers an Addendum. ICRP Publication 30, Part 4. Pergamon Press Ltd, Oxford, U.K.

ICRP. 2000. Protection of the Public in Situations of Prolonged Radiation Exposure. Recommendations of the International Commission on Radiological Protection. ICRP Publication 82, Annals of the ICRP, 29(1–2).

ICRP. 2002. Basic Anatomical and Physiological Data for Use in Radiological Protection Reference Values. ICRP Publication 89. Ann.

ICRP 32(3-4). ICRP. 2007. The 2007 Recommendations of the International Commission on Radiological Protection. ICRP Publication 103. Ann. ICRP 37(2-4).

ICRP. 2008. Nuclear Decay Data for Dosimetric Calculations. ICRP Publication 107, Ann. ICRP 38(3). ICRP. 2015. Occupational Intakes of Radionuclides: Part 1. ICRP Publication 130, Ann. ICRP 44(2)

ICRP 2016. ICRP Publication 134: Occupational Intakes of Radionuclides: Part 2. Ann ICRP 45(3-4):7- 349.

ICRP 2017. Occupational Intakes of Radionuclides: Part 3. ICRP Publication 137, Ann. ICRP 46(3/4). ICRP 2019. ICRP Publication 141: Occupational Intakes of Radionuclides: Part 4. Annals of the ICRP (2-3):9-501. doi: 10.1177/0146645319834139.

References

NCRP. 2004. Approaches to risk Management in Remediation of Radioactively Contaminated Sites. NCRP Report No. 146, National Council on Radiation Protection and Measurements, Bethesda, MD

Napier BA, RA Peloquin, DL Strenge, and JV Ramsdell. 1988. GENII – The Hanford Environmental Radiation Dosimetry Software System. PNL-6584, Vols. 1-3, Pacific Northwest Laboratory, Richland, WA.

National Research Council. 1999. Evaluation of Guidelines for Exposures to Technologically Enhanced Naturally Occurring Radioactive Materials. The National Academies Press, Washington, DC. https://doi.org/10.17226/6360.

NBS. 1963. Addendum 1 to Handbook 69, Maximum Permissible Body Burdens and Maximum Permissible Concentrations of Radionuclides in air and in Water for Occupational Exposure. Originally issued in 1959 by the U.S. Department of Commerce.

NRC. 1997. U.S. Nuclear Regulatory Commission. “10 CFR Parts 20, 30, 40, 50, 51, 70 and 72— Radiological Criteria for License Termination.” Final rule, 62 FR 39058-39095. US Government Printing Office, Washington DC.

NRCS. 1997. National Engineering Handbook, Part 652, Irrigation Guide. National Cartography and Geospatial Center, Fort Worth, TX.

WHO. 2017. Guidelines for Drinking-Water Quality. Fourth Edition incorporating the First Addendum. World Health Organization.

Thank you!

Risk-Informed Groundwater Cleanup Levels:
Hanford Case Study for Low Energy Beta Emitters

July 26, 2022

Amoret Bunn, PNNL

REMPLEX
CENTER FOR THE REMEDIATION OF COMPLEX SITES
@PNNL

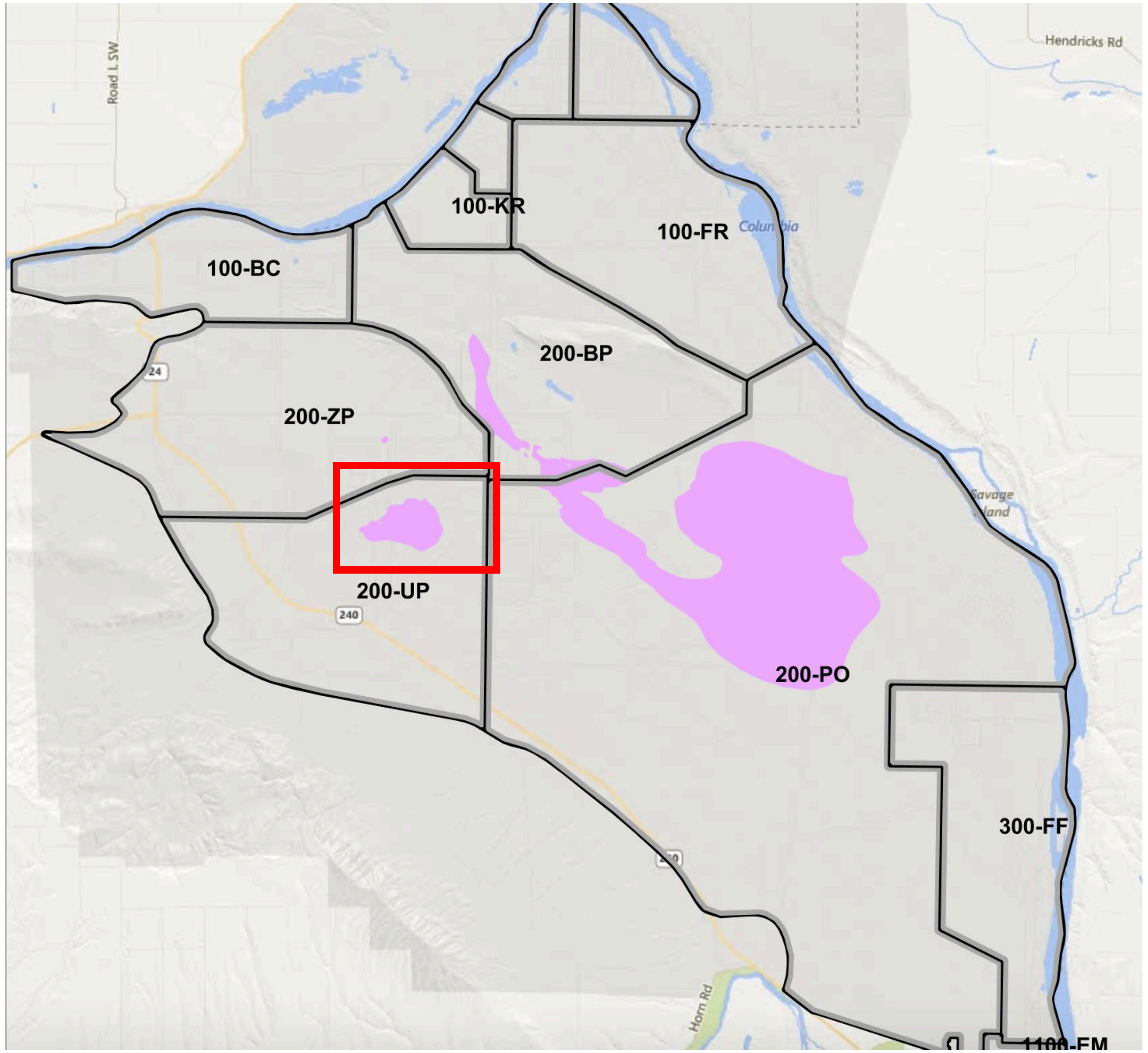
U.S. DEPARTMENT OF ENERGY   BATTELLE

PNNL is operated by Battelle for the U.S. Department of Energy

PNNL-SA-175596

Motivation: 200-UP-1 Interim ROD at Hanford

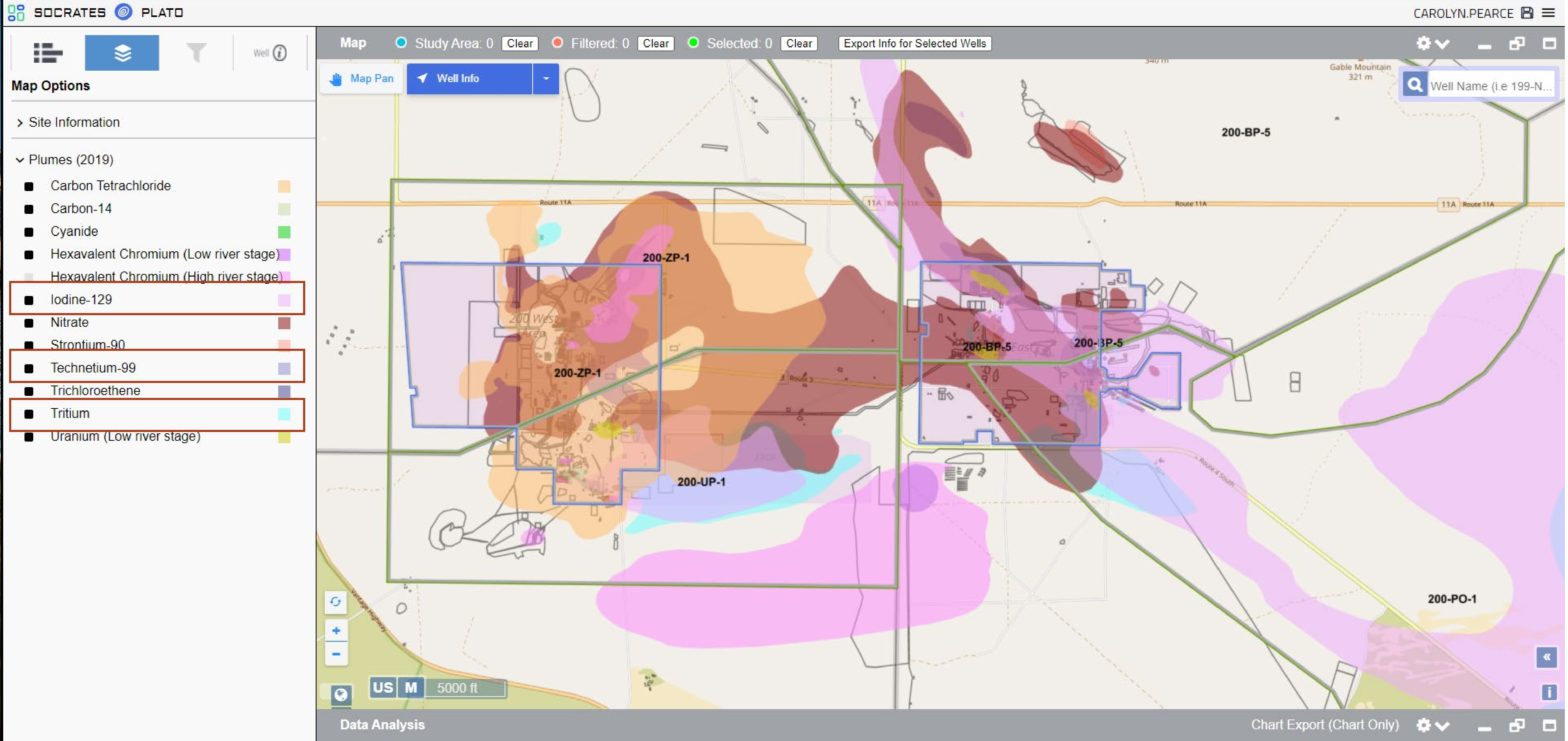
- Interim ROD (2012)
- Hydraulic control for ^{129}I plume
  - concentration range of 1 to 16 pCi/L [0.037 to 0.592 Bq/L])
- Three information gaps for ^{129}I
  - Geochemical conceptual model
  - Potential technologies
  - Applicability of Applicable or Relevant and Appropriate Requirements (**ARARs**) and Technical Impracticability (**TI**) waiver for final remedy



I-129 in groundwater at concentration exceeding Drinking Water Standard, 1 pCi/L (0.037 Bq/L)

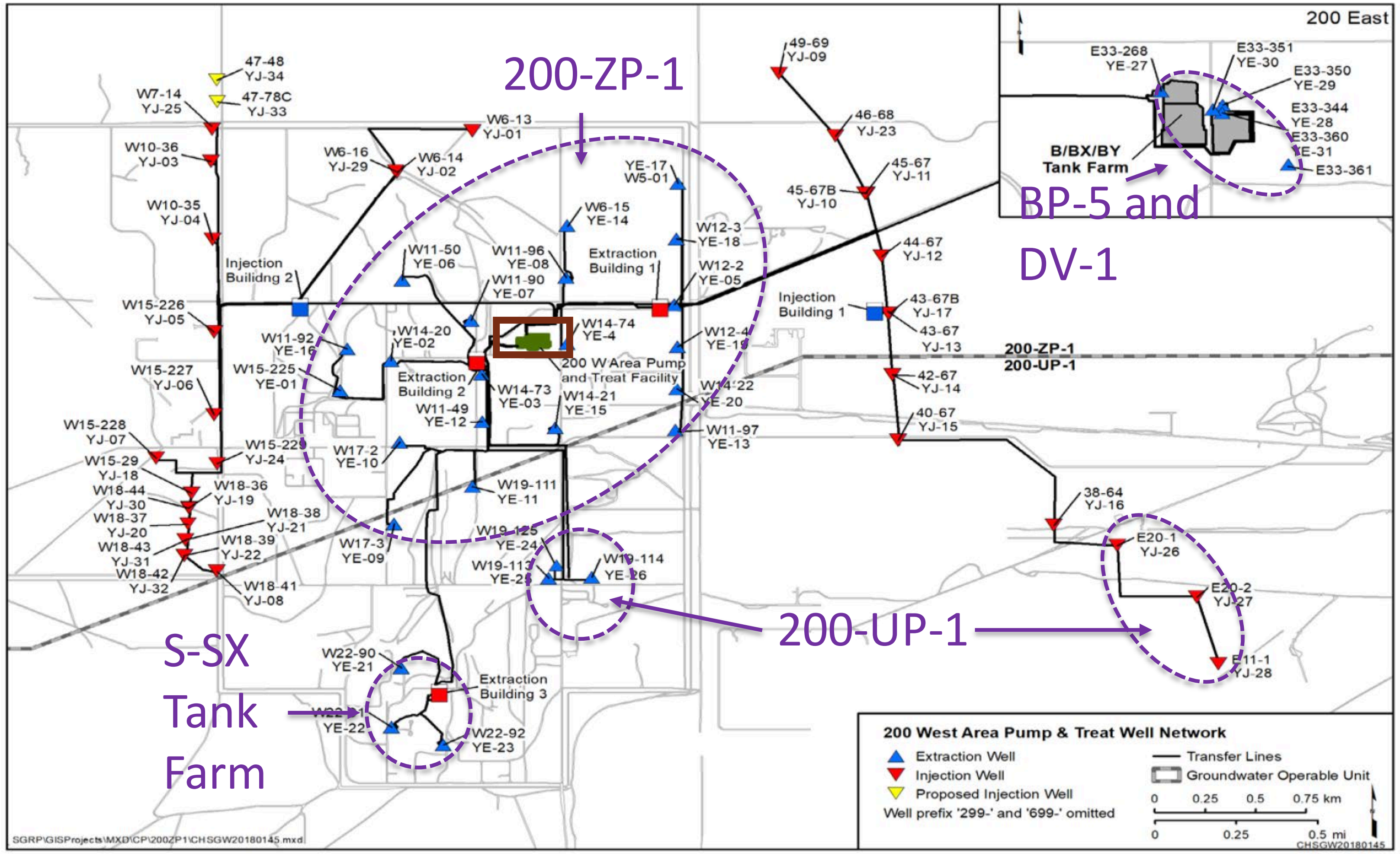
REMPLEX
CENTER FOR THE REMEDIATION OF COMPLEX SITES
@PNNL

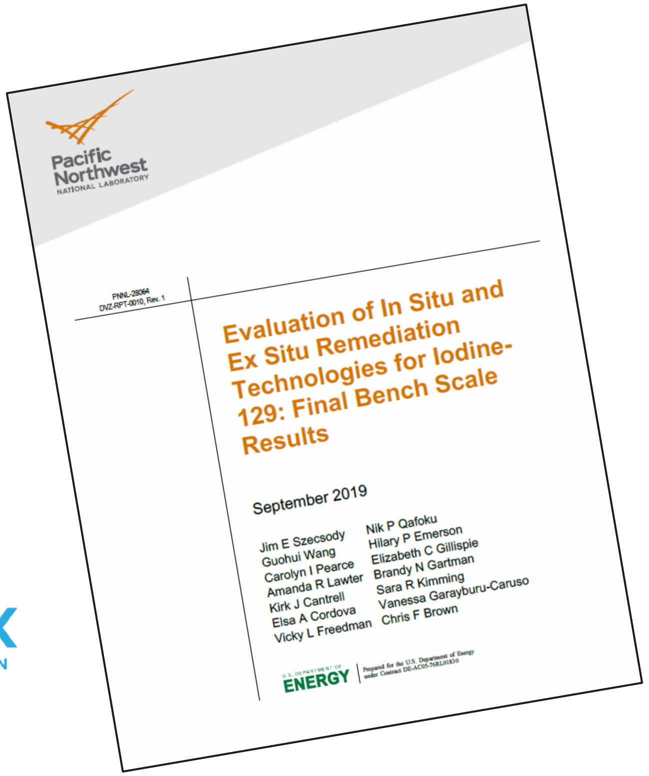
Co-mingled Contaminant Plumes at 200-UP-1



200 West Area Pump-and-Treat Remedy

- Network of extraction/injection wells to prevent spread of contaminants to Columbia River
- Ex-situ treatment technologies still under evaluation for I-129





Pacific Northwest
NATIONAL LABORATORY

PNNL-28064
DVZ-RPT-0010, Rev. 1

Evaluation of In Situ and Ex Situ Remediation Technologies for Iodine-129: Final Bench Scale Results

September 2019

Jim E Szecsody
Guohui Wang
Carolyn I Pearce
Amanda R Lawter
Kirk J Cantrell
Elsa A Cordova
Vicky L Freedman
Nik P Qafoku
Hilary P Emerson
Elizabeth C Gillispie
Brandy N Gartman
Sara R Kimming
Vanessa Garayburu-Caruso
Chris F Brown

U.S. DEPARTMENT OF ENERGY
Prepared for the U.S. Department of Energy under Contract DE-AC05-76RL01830

REMPLEX
CENTER FOR THE REMEDIATION OF COMPLEX SITES
@PNNL

Hanford Low Beta Emitter Plumes

Carbon -14
DWS: 2000 pCi/L

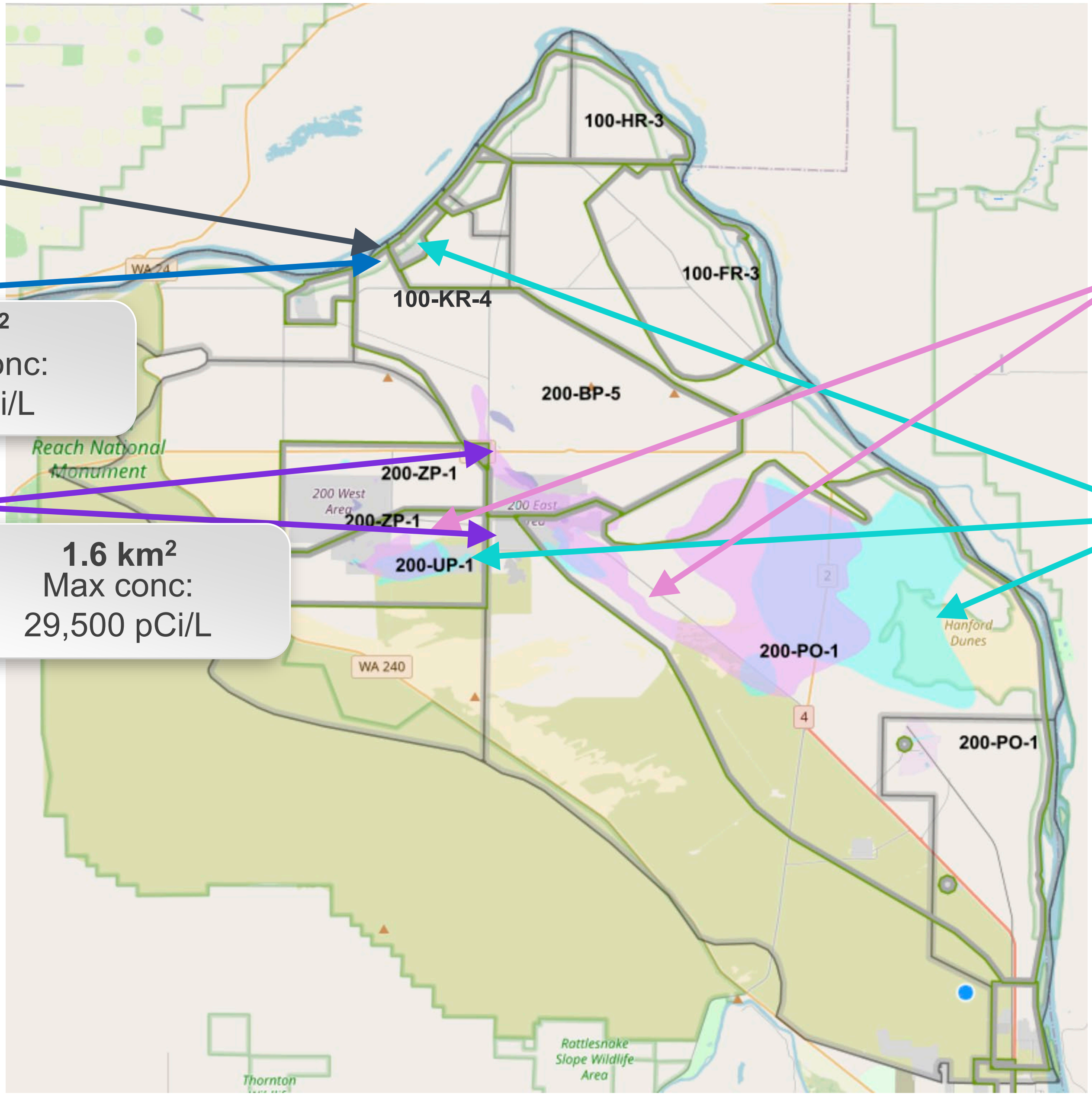
0.05 km²
Max conc:
27,200 pCi/L

Chlorine-36
DWS: 200 pCi/L

0 km²
Max conc:
31 pCi/L

Technetium-99
DWS: 900 pCi/L

1.6 km²
Max conc:
29,500 pCi/L



Iodine-129
DWS: 1 pCi/L

68 km²
Max conc:
16.4 pCi/L

Tritium
DWS: 20000 pCi/L

71 km²
Max conc:
428,000 pCi/L

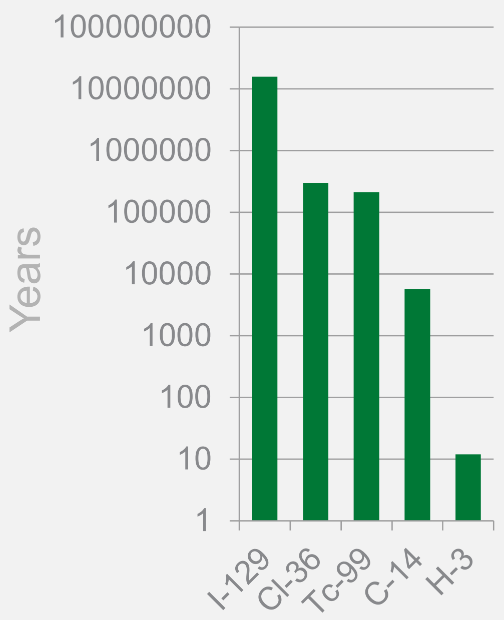
1 pCi = 0.037 Bq

Maximum concentrations based on Annual GW Monitoring Report (2020), except for Chlorine-36 which was last reported in the Annual GW Monitoring Report (2018)

Low Energy Beta Emitters

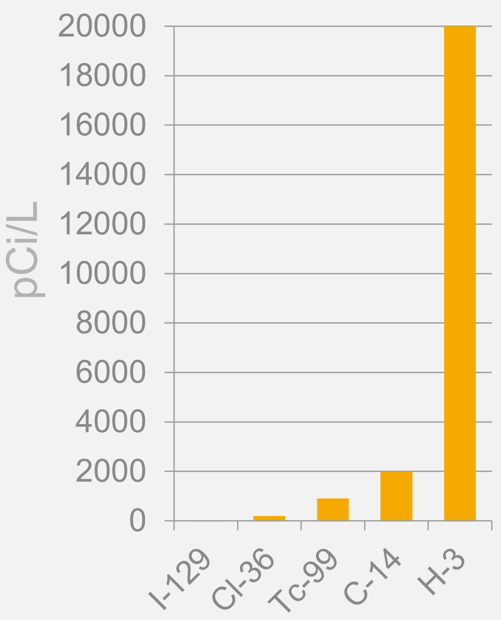
Half-Lives

Except for tritium, low energy beta emitters are long-lived radionuclides



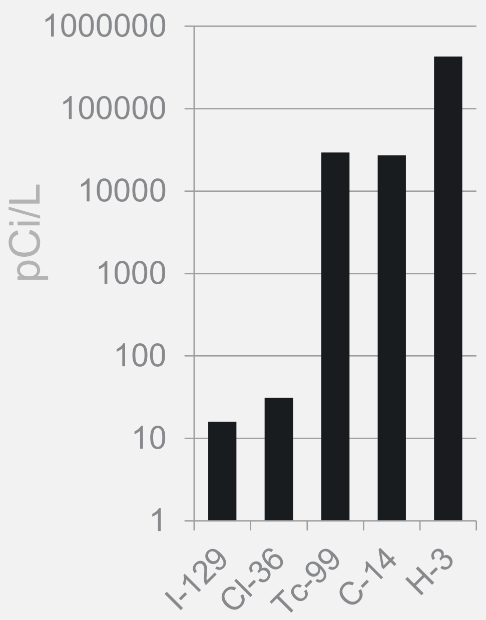
Drinking Water Standard

Federal (DWS) based upon 4 mrem/y dose standard (NBS Handbook 69 1963



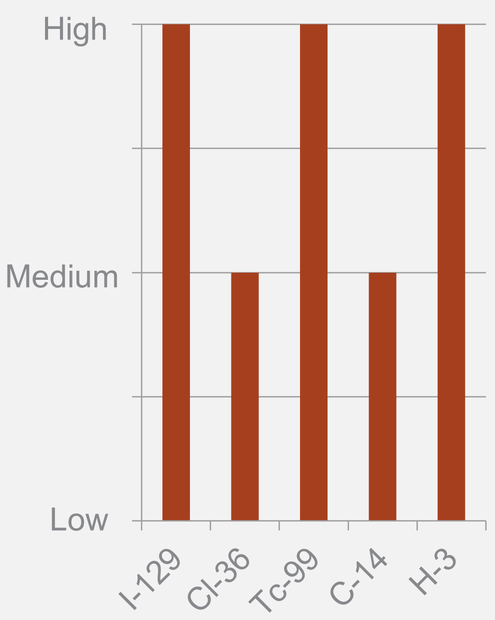
Hanford Max Groundwater Conc

Except for chlorine, maximum groundwater concentrations are 13-32 times higher than DWS



Mobility

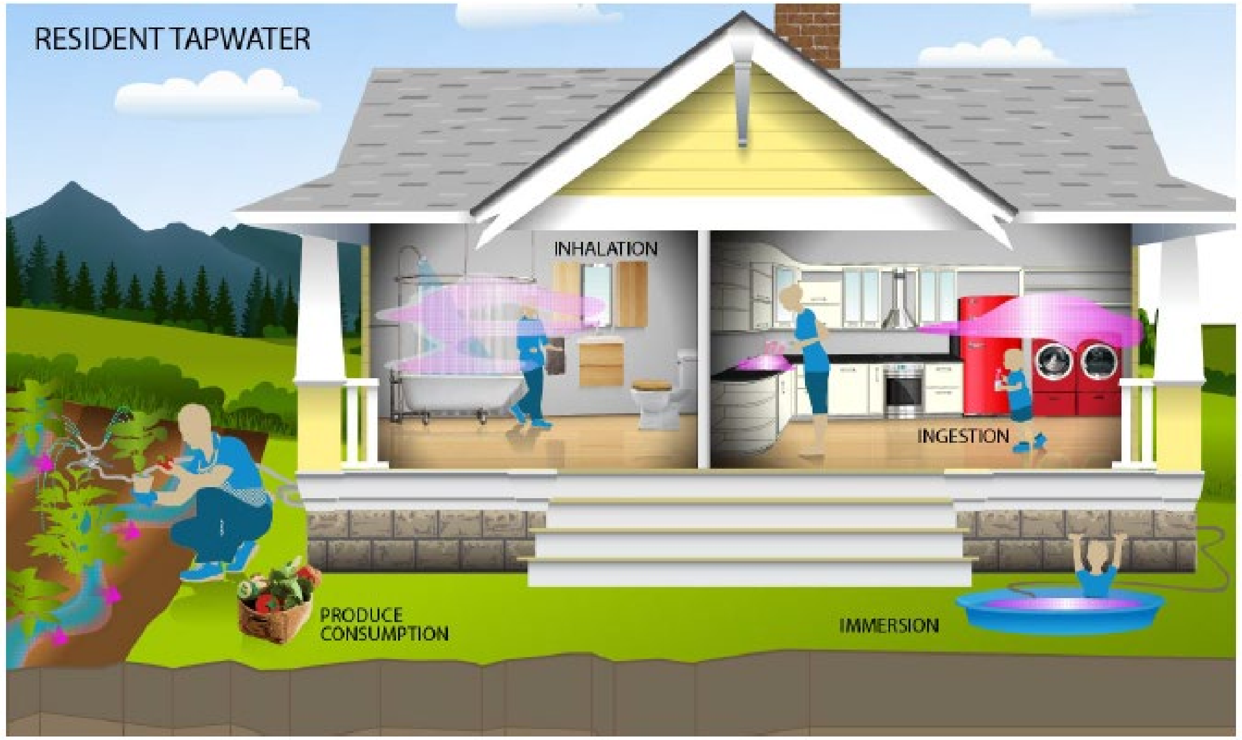
All of the low energy beta emitter are relatively mobile in the environment



1 pCi = 0.037 Bq

Risk-Based Concentration Calculations

- Calculate risk-based cleanup levels based on different technical guidance documents using
- **Resident Tap Water Scenario**
  - Drinking water ingestion
  - Bathing
  - Watering vegetable garden
  - In-house use releases volatile components, leading to a subsequent inhalation pathway (for H-3 and C-14 only)
  - Uses constant well-water concentration (1 pCi/L [0.037 Bq/L]) to quantify long-term radiation dose and risk
- Doses and risks are based on exposure parameters and factors that represent *reasonable maximum exposure* conditions



Exposure Pathways in the Risk Assessment Information System Resident Tap Water Scenario (https://rais.ornl.gov/tools/rais_rad_risk_guide.html)

Pacific Northwest NATIONAL LABORATORY

Technical Basis
Resident Tap Water Scenario

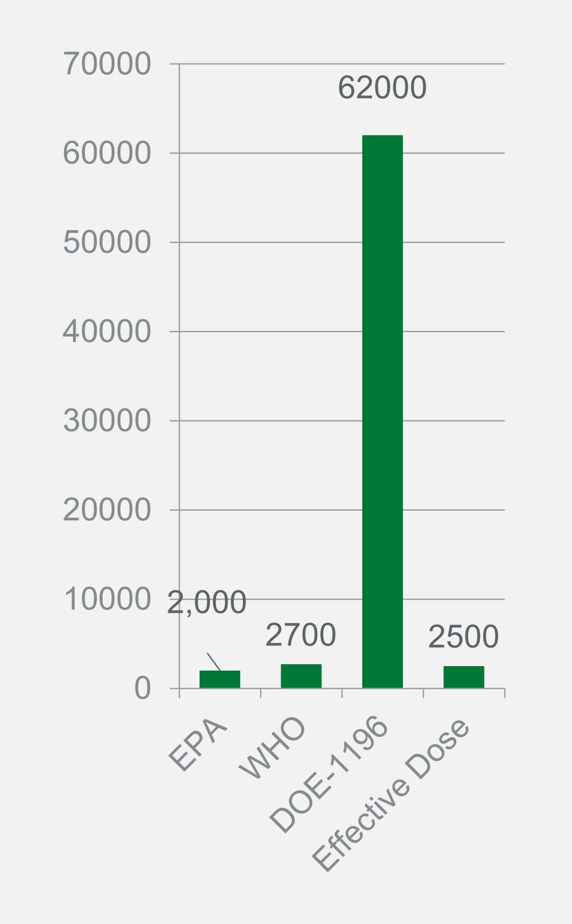
1	Based on 4 mrem/y (40 µSv/y)to any organ and basis for **EPA** DWS	ICRP Pub 2 (1960) NBS 69 (1963)
2	First major revision that is now used by the **NRC**, incorporating methods of ICRP Publication 26 with dose per unit intake	ICRP Pub 26 (1977) ICRP Pub 30 (1978)
3	**EPA Blue Book** supports organ weighting factors and includes cancer risk coefficients, and different age groups	ICRP Pub 60 (1991) ICRP Pub 72 (1996) FGR-13 (1999)
4	**DOE 1196-2011** derived concentration standards, gender-specific (not age-specific), with a single effective dose for each pathway	ICRP Pub 72 (1996) ICRP Pub 89 (2002) ICRP Pub 107 (2008) FGR-13 (1999)
5	**IAEA** guidance supports radiation and tissue weighting factors, radiation detriment using latest available scientific information of the biology and physics of radiation exposure	ICRP Pub 103 (2007) IAEA (2014) ICRP OIR (2015 – 2019)

Derived Concentration Limits

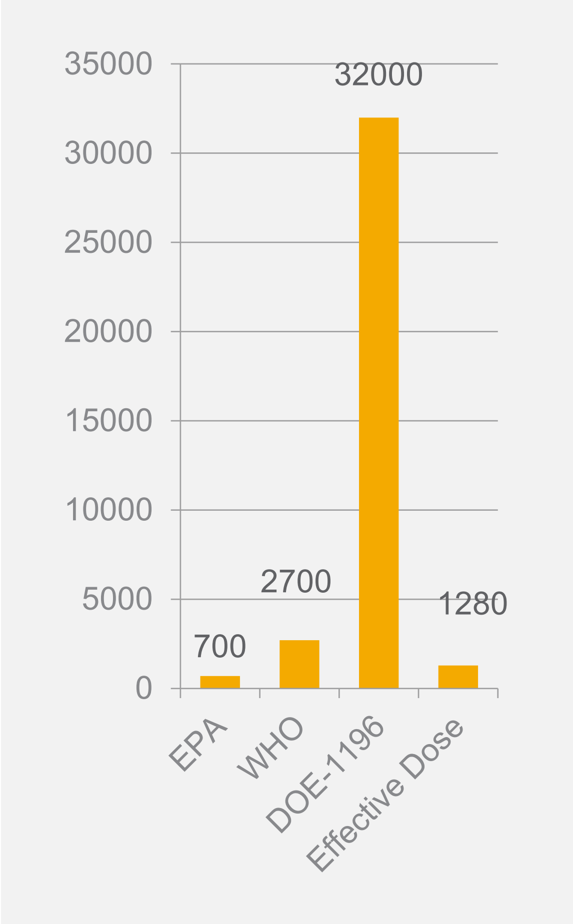
Based on Exposure Limits

1 pCi = 0.037 Bq

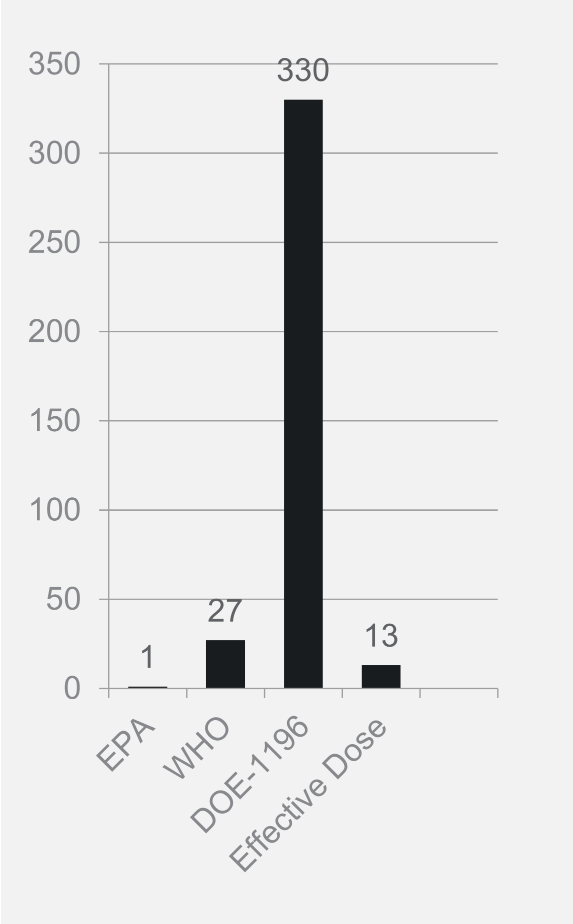
Carbon-14 (pCi/L)



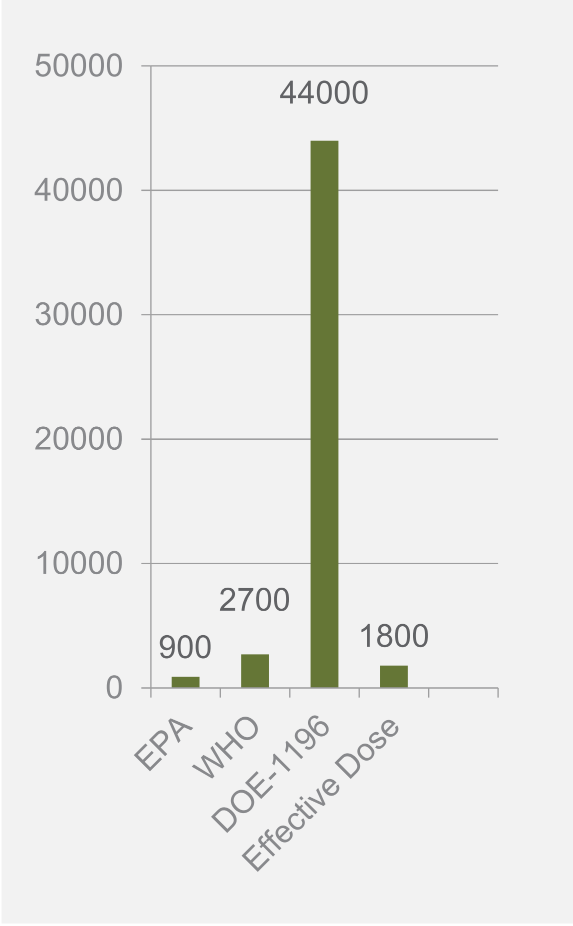
Chlorine-36 (pCi/L)



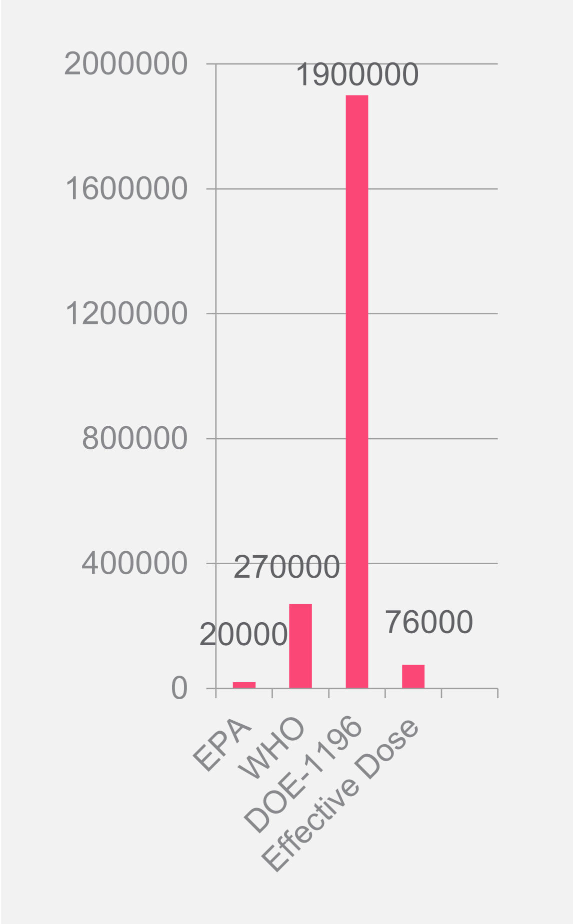
Iodine-129 (pCi/L)



Technetium-99 (pCi/L)



Tritium (pCi/L)



EPA = 4 mrem/y (40 µSv/yr)

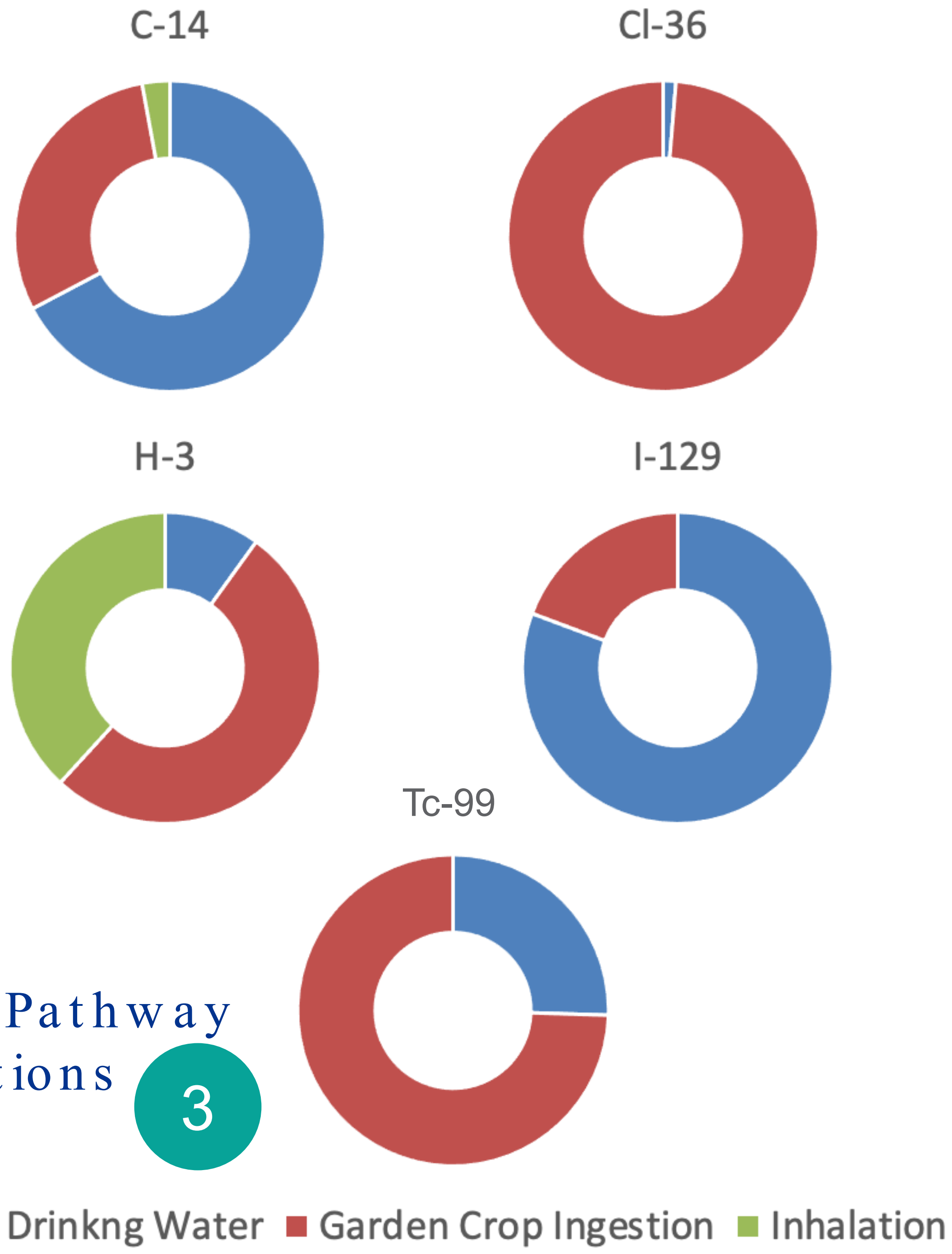
WHO = 10 mrem/y (100 µSv/yr)

DOE-1196 = 100 mrem/y (1000 µSv/yr)

Effective Dose (updated dosimetry) = 4 mrem/y (40 µSv/yr)

Dose Calculations
Resident Tap Water Scenario

- Calculated annual dose to organs and total body along four different pathways (mrem per pCi/L)
  - Drinking Water
  - Garden Crop Ingestion
  - Inhalation (C-14 and H only)
  - Bathing (estimated dose from immersion is negligible)
- Estimated dose varies due to differences in
  - Dose factors for each radionuclide
  - Radionuclide-specific parameters (e.g., solubility and soil to plant transfer)
- Need to understand pathways considered in dose/risk codes



Relative Pathway Contributions

3

Pacific Northwest NATIONAL LABORATORY

Critical Organ and Total Body Dose
Resident Tap Water Scenario

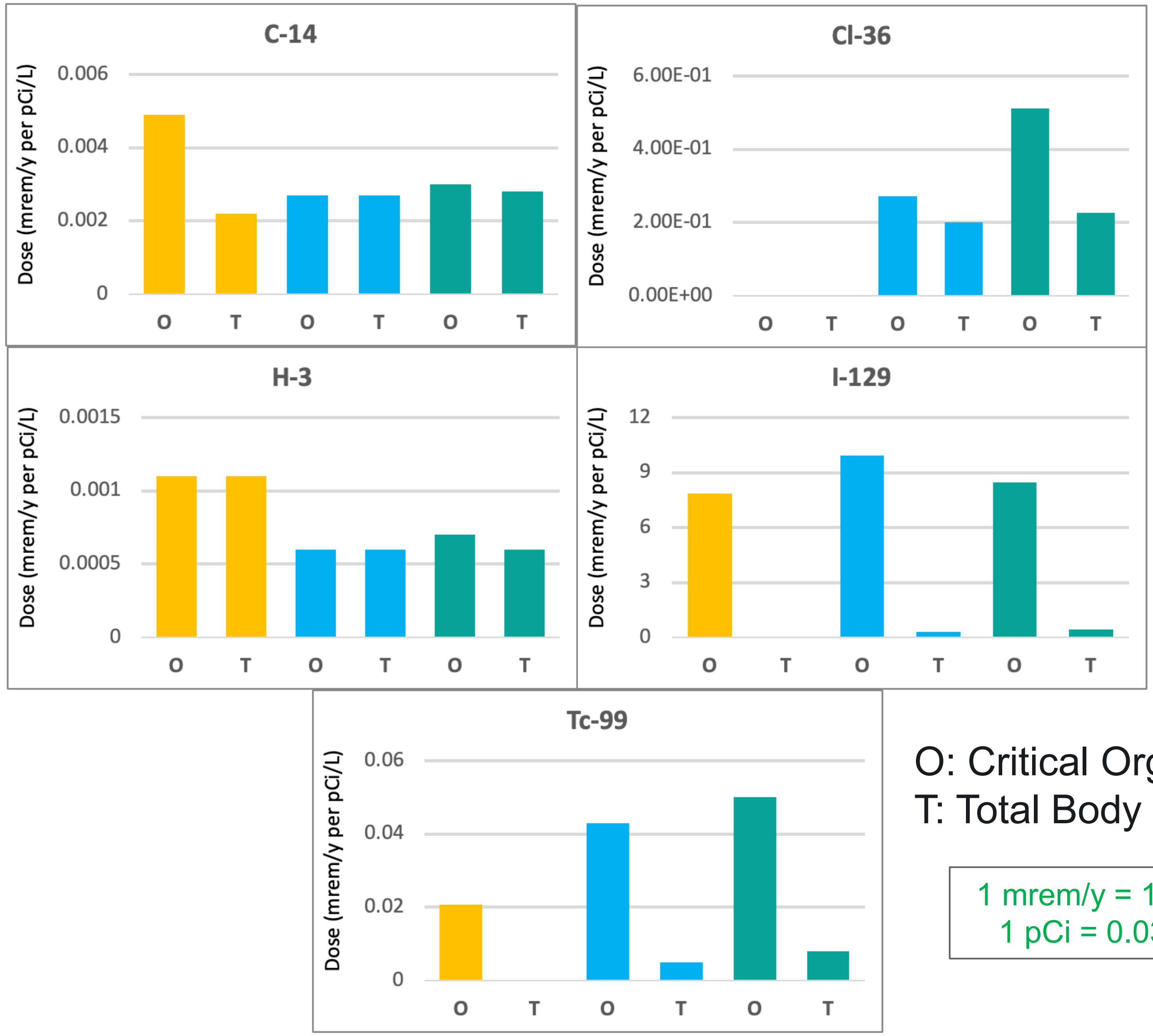
1 **EPA** (ICRP Pub 2 1960), no Cl-36 dose factors

2 **NRC** (ICRP Pub 30 1979)

3 **EPA Blue Book** (ICRP Pub 72 1996, FGR-13 1999)

Critical Organ vs.
Total Body Approach (ICRP Pub 2 1960)

- I-129 dose is nearly **800X** larger
- Tc-99 dose is **~100X** larger



O: Critical Organ Dose
T: Total Body Dose

1 mrem/y = 10 μSv/y
1 pCi = 0.037 Bq

Based on Table 4.12 (Downs et al. 2020)

REMPLEX CENTER FOR THE REMEDIATION OF COMPLEX SITES @PNNL

Pacific Northwest NATIONAL LABORATORY

Effective Dose
Resident Tap Water Scenario

1 **EPA** * (ICRP Pub 2 1960)

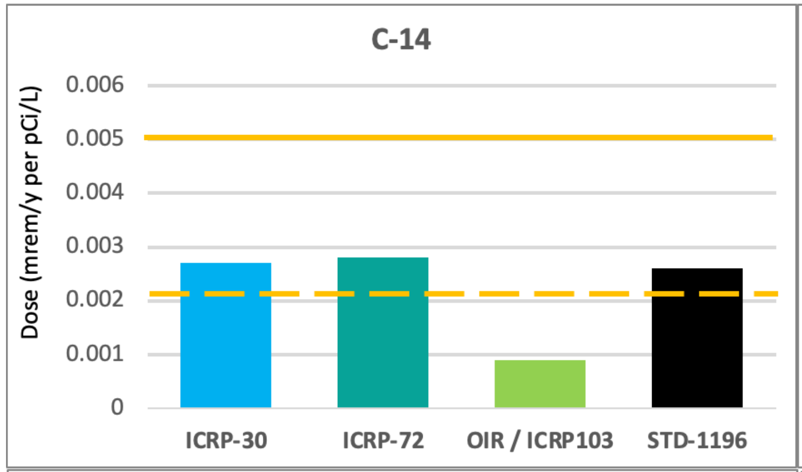
2 **NRC** (ICRP Pub 30 1979)

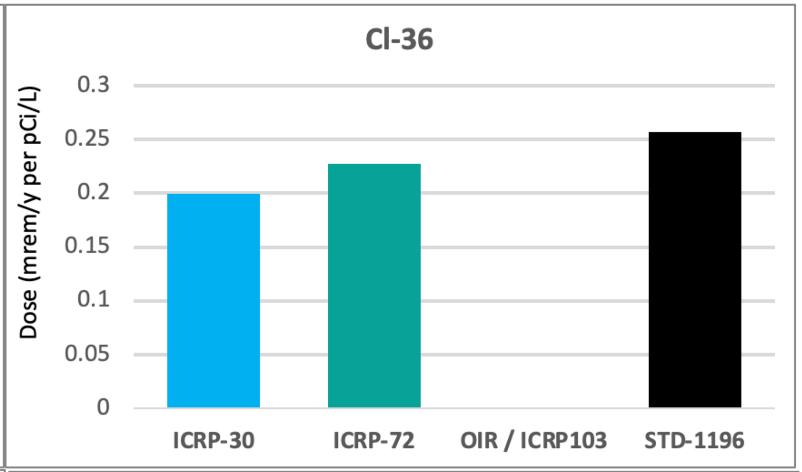
3 **EPA Blue Book** (ICRP Pub 72 1996, FGR-13 1999)

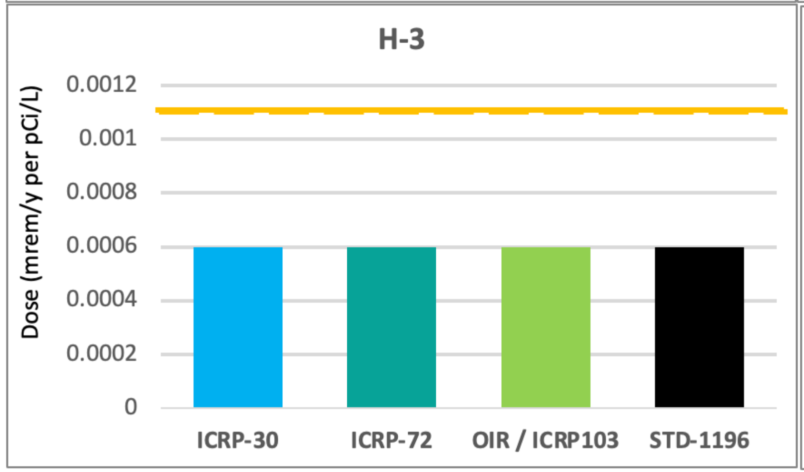
4 **DOE** * (DOE-STD-1196 2011)

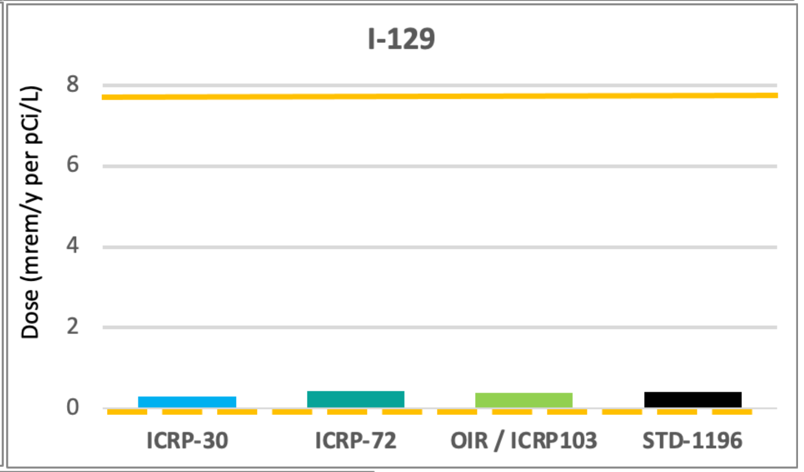
5 **IAEA** (ICRP Pub103 2007 and OIR Series 2015+)

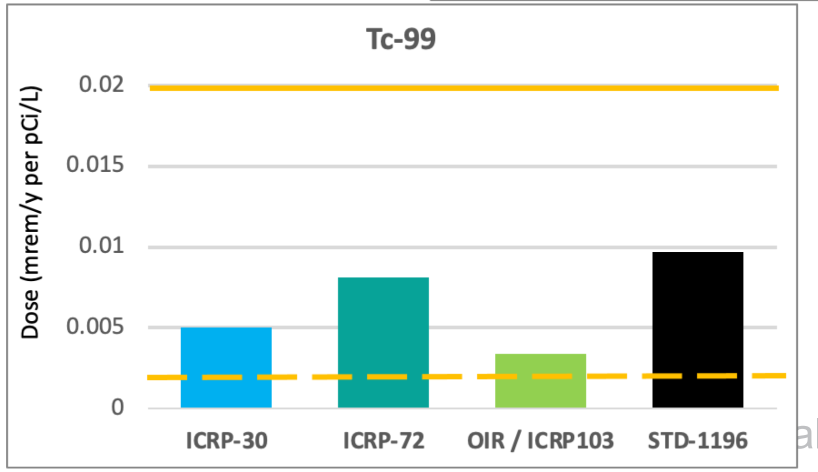
***no Cl-36 dose factors**











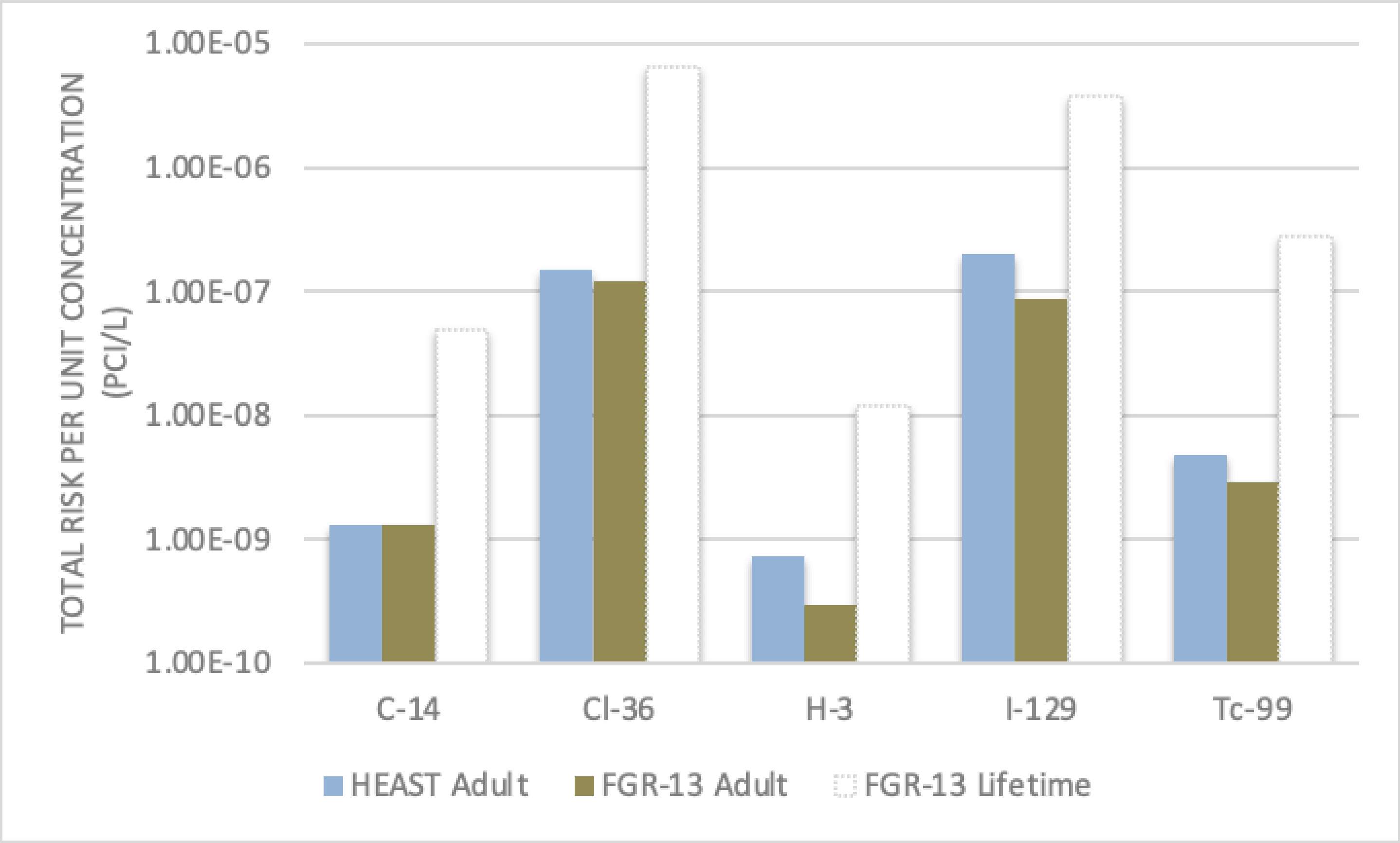
ICRP Pub 2 Crit Organ
ICRP Pub 2 Total Body

1 mrem/y = 10 μSv/y
1 pCi = 0.037 Bq

al. 2020)

Dose to Risk Calculations
Resident Tap Water Scenario

- Generally accepted value used for dose to risk conversion ~5x10^{-4} per rem (5% per Sv)
- Health Effects Assessment Summary Tables (HEAST) provides updated slope factors (risk per unit exposure factors) for:
  - Inhalation
  - Ingestion
  - External exposure to soil contamination
- FGR-13 (Eckerman et al. 1999) updated HEAST (EPA 1995)



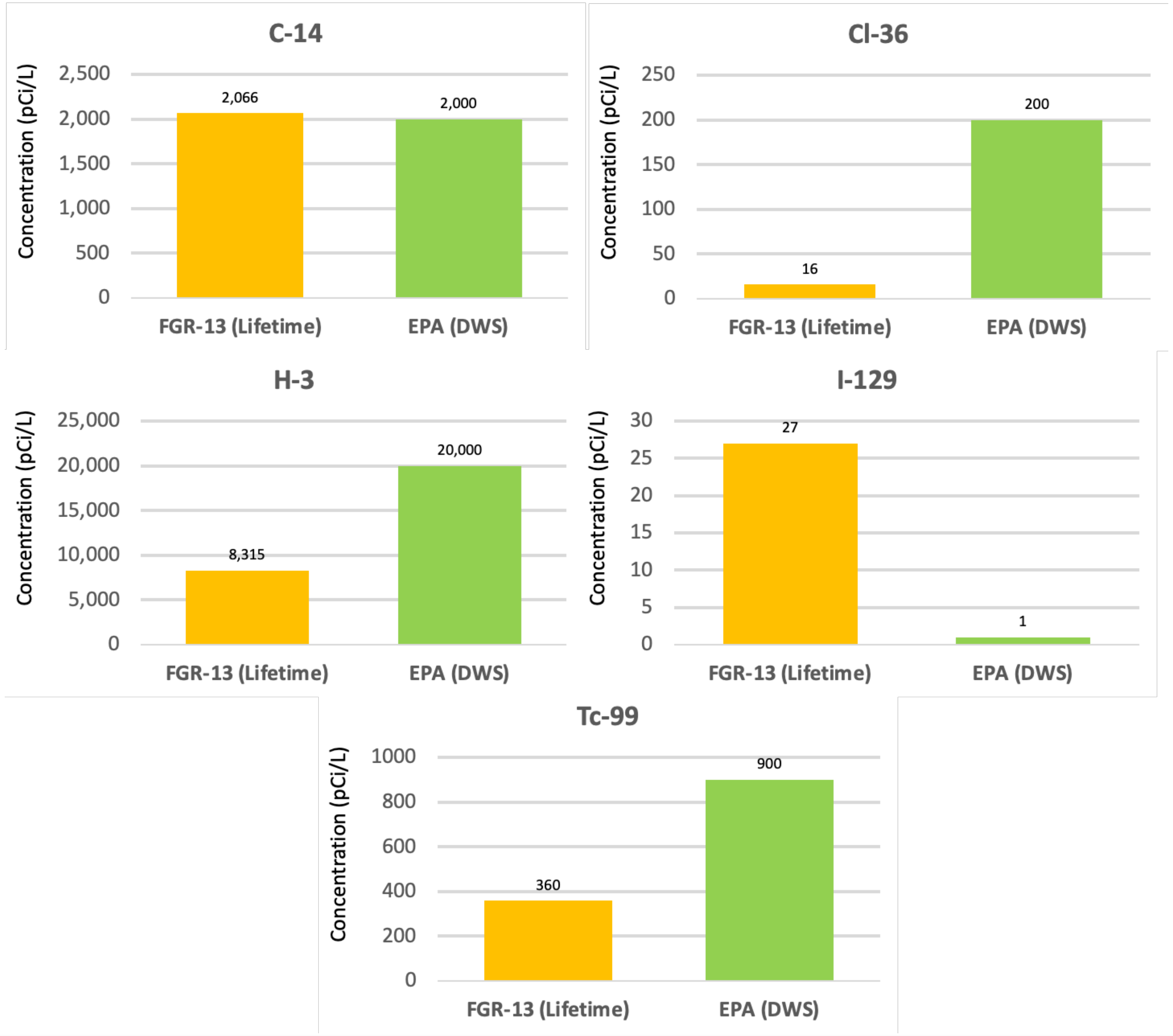
Based on Table 4.14 (Downs et al. 2020)

Concentration Limits

Tap Water Scenario

- Risk-based I-129 concentrations are up to 27 times higher than DWS
- Risk-based Tc-99 concentrations are up to 2.5 times lower than DWS

1 pCi = 0.037 Bq



Low Beta Emitter DWS Relative to Risk-based and Derived Concentrations

Pacific Northwest NATIONAL LABORATORY

REMPLEX CENTER FOR THE REMEDIATION OF COMPLEX SITES @PNNL

Draft Manuscript: Intercomparison of Dose and Risk Models to Inform Groundwater Remediation Planning for Low Energy Beta-Emitting Radionuclides

- Radiation risk assessment models do not have identical assumptions, scenarios or calculations
  - Inputs are parameters for relevant exposure scenario
  - Output is risk or dose
  - Uncertainties in scenarios and parameters
- Codes can assist with answering initial questions:
  - Are remedial actions warranted?
  - What are the preliminary remediation goals (PRGs) for contaminants?
  - What exposure levels are protective of human health and the environment?
- Manuscript compares different radiation risk assessment models/codes that calculate dose and risk

Draft Manuscript: Comparison of Radiation Risk Codes

Type of Code	Tool	Sponsor; Developer	Calculation Type
Screening	Preliminary Remediation Goal (**PRG**) Calculator	EPA	Screening-level PRG corresponding to target risk, by applying a cancer slope factor to translate estimated exposure to risk
Screening	Risk Assessment and Information System (RAIS) Radionuclide Risk Calculator (**RRC**)	ORNL, University of Tennessee	Screening-level preliminary cleanup level corresponding to target risk
Screening	Dose Compliance Concentrations (**DCC**) Calculator	EPA	Screening-level preliminary cleanup level corresponding to target dose, by applying dose conversion factor (DCF) to translate estimated exposure to dose
Cleanup decision levels	**GENII** (Generation II) Code (V 2.10.1)	DOE, EPA, NRC; PNNL	Cleanup level corresponding to target dose & target risk from radionuclide released; models fate and transport processes, including environmental accumulation and removal from surface water, groundwater, and soil when radionuclide concentration in given medium is provided
Cleanup decision levels	(RESidual RADioactivity) **RESRAD-OFFSITE** Code (V 4.0)	DOE, NRC; ANL	Cleanup level corresponding to a dose limit and time-integrated dose and risk from specified radionuclide inventory; code models release, transport, accumulation and exposure processes; can output and/or read in releases and concentrations in well and surface water

Draft Manuscript: Conclusion

- Screening calculators:
  - Web-based calculators
  - Default parameters – conservative to extremely conservative
- Cleanup decision level codes:
  - Mechanistic modeling codes
  - Provide site-specific preliminary goals for remediation
  - Clearly delineate the dose and risk drivers that inform cleanup priorities.
- Overall, tools for estimating dose and health risk play a crucial role in developing cleanup levels for radioactively contaminated sites
  - Crucial that assumptions inherent in default parameter values and code calculations be understood to support the technical basis for informing cleanup decisions.

Collaborators

- PNNL:
  - Bruce Napier
  - Janelle Downs
  - Mike Truex
  - Vicky Friedman
- Groundwater and Remedy Options:
  - Mark Rockhold
  - Jim Szecody
  - Carolyn Pearce
- Argonne National Laboratory:
  - Emmanuel Gnanapragasm
  - Jing-Jy Cheng
  - Sunita Kamboj
  - Margaret MacDonell

Pacific Northwest
NATIONAL LABORATORY

Thank you

Risk and ARARs at Superfund Sites, A Regulator's Perspective

RemPlex Seminar

July 26, 2022

Laura Buelow, Ph.D.
EPA Region 10
Hanford Project Office

Outline

- CERCLA Background
- What Triggers Remedial Action?
- Setting Cleanup Levels
- Applicable or Relevant and Appropriate Requirements (ARAR) Waivers

Comprehensive Environmental Response, Compensation, and Liability Act, 1980 (CERCLA, aka Superfund)

Love Canal, Niagara NY

Statutory and Regulatory Framework

CERCLA

SARA

Regulation:

National Contingency Plan (NCP)

Superfund Policy and Guidance

CERCLA Remedial Process

Remedial Investigation
- Nature and Extent of Contamination
- Baseline Risk Assessments

Feasibility Study
- Cleanup Alternatives Based on Preliminary Remediation Goals

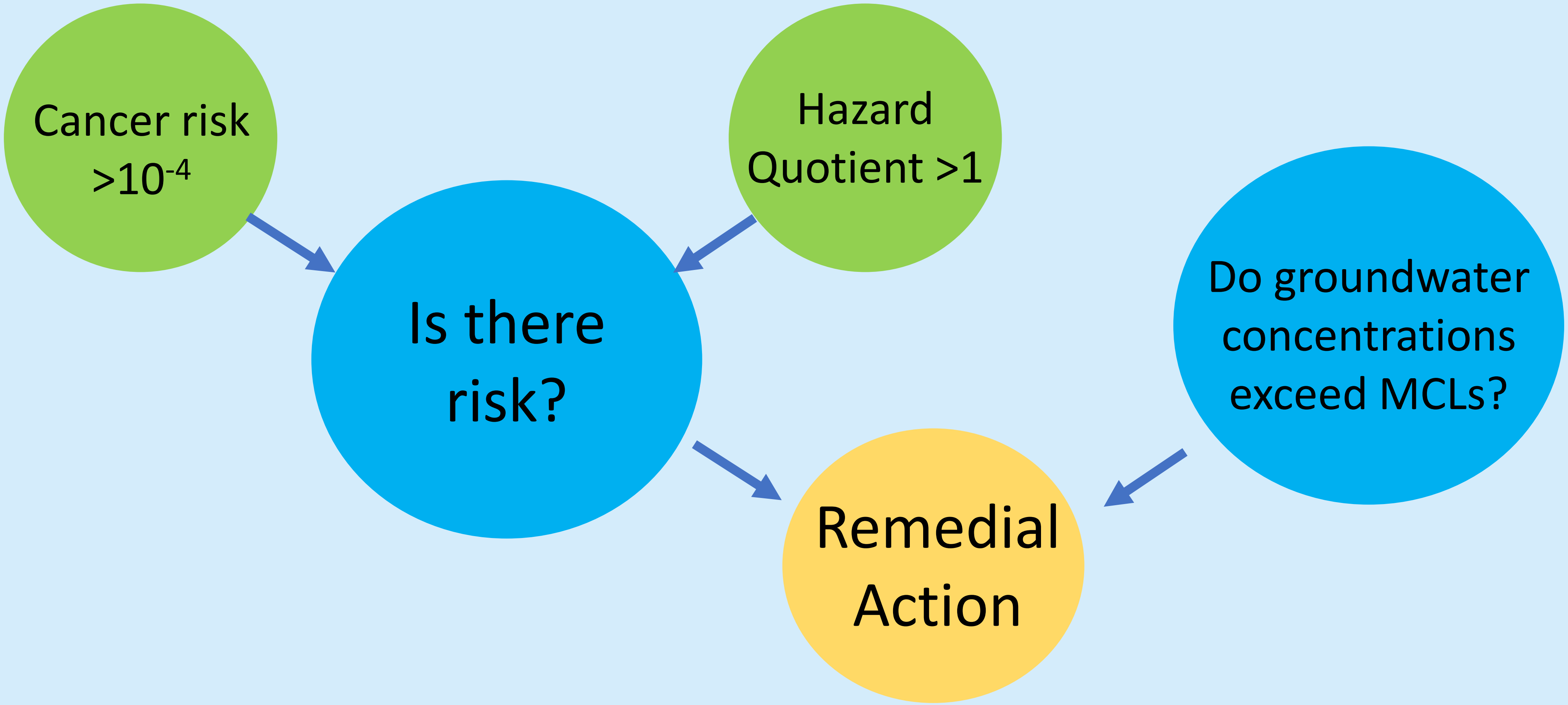
Proposed Plan
- Public Comment on Proposed Cleanup Approach

Record of Decision
- Legal Document Identifying Cleanup Technology and Cleanup Levels (Risk-Based and ARARs)

Remedial Action
- Cleanup

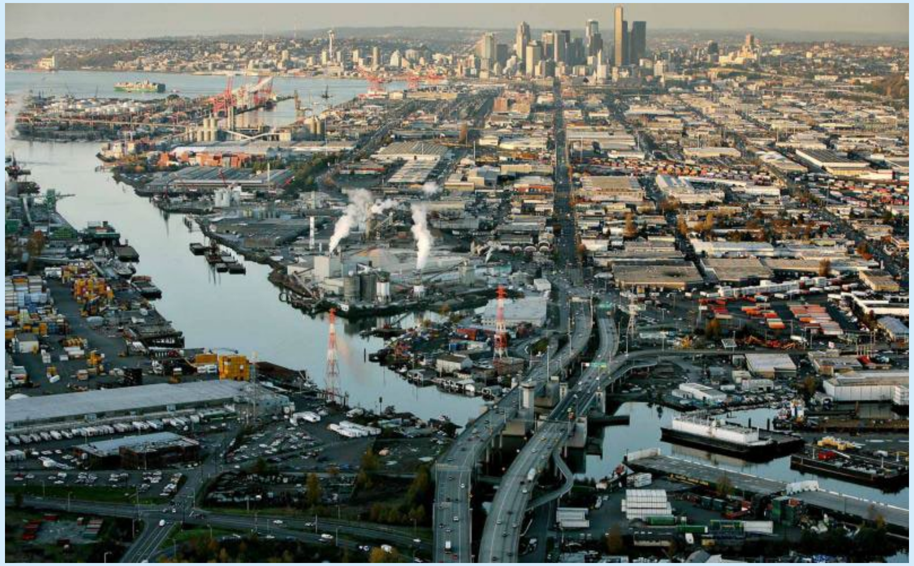
Closeout
- Five-Year Reviews at Most Sites

What Triggers Remedial Action at Superfund Sites?



Current and Future Land Use

Tribal Use, Residential, Industrial, Recreational, etc.



Lower Duwamish Waterway, Seattle

St. Maries Creosote Site
St. Maries, ID
Within Coeur d'Alene
Tribe Reservation

Upper Columbia River
Residential Soil Cleanup

Henry Mine
Idaho

Groundwater in CERCLA and the NCP

- 40 CFR §300.430(a)(1)(iii)(F) EPA expects to return usable ground waters to their **beneficial uses wherever practicable, within a timeframe that is reasonable given the particular circumstances** of the site. When restoration of ground water to beneficial uses is **not practicable**, EPA expects to prevent further migration of the plume, prevent exposure to the contaminated ground water, and evaluate further risk reduction.
- 40 CFR §300.430(e)(2)(i)(B) **Maximum contaminant level goals (MCLGs),** established under the Safe Drinking Water Act, **that are set at levels above zero, shall be attained by remedial actions for ground or surface waters that are current or potential sources of drinking water**, where the MCLGs are relevant and appropriate under the circumstances of the release based on the factors in § 300.400(g)(2). If an MCLG is determined not to be relevant and appropriate, the corresponding maximum contaminant level (MCL) shall be attained where relevant and appropriate to the circumstances of the release.

Groundwater Classification

- In states that have an EPA-endorsed Comprehensive State Ground Water Protection Program (CSGWPP), EPA will defer to the State's determination of current and future GW uses (with some exceptions)
- Class I- Special Groundwater
  - Highly vulnerable
  - Irreplaceable source of drinking water for a substantial population
  - Ecologically vital
- Class II- Current and Potential Sources of Drinking Water and Groundwater Having Other Beneficial Uses
- Class III- Groundwater Not a Potential Source of Drinking Water and/or Limited Beneficial Use
  - TDS concentration ≥ 10,000 mg/L
  - Contaminated by naturally occuring conditions or broad-scale human activity
  - Yields are insufficient to meet minimum needs to an average household (150 gal/day)

CERCLA Remedial Process

- **Remedial Investigation**
  - Nature and Extent of Contamination
  - Baseline Risk Assessments
- **Feasibility Study**
  - Cleanup Alternatives Based on Preliminary Remediation Goals
- **Proposed Plan**
  - Public Comment on Proposed Cleanup Approach
- **Record of Decision**
  - Legal Document Identifying Cleanup Technology and Cleanup Levels (Risk-Based and ARARs)
- **Remedial Action**
  - Cleanup
- **Closeout**
  - Five-Year Reviews at Most Sites

Threshold Criteria Under the NCP

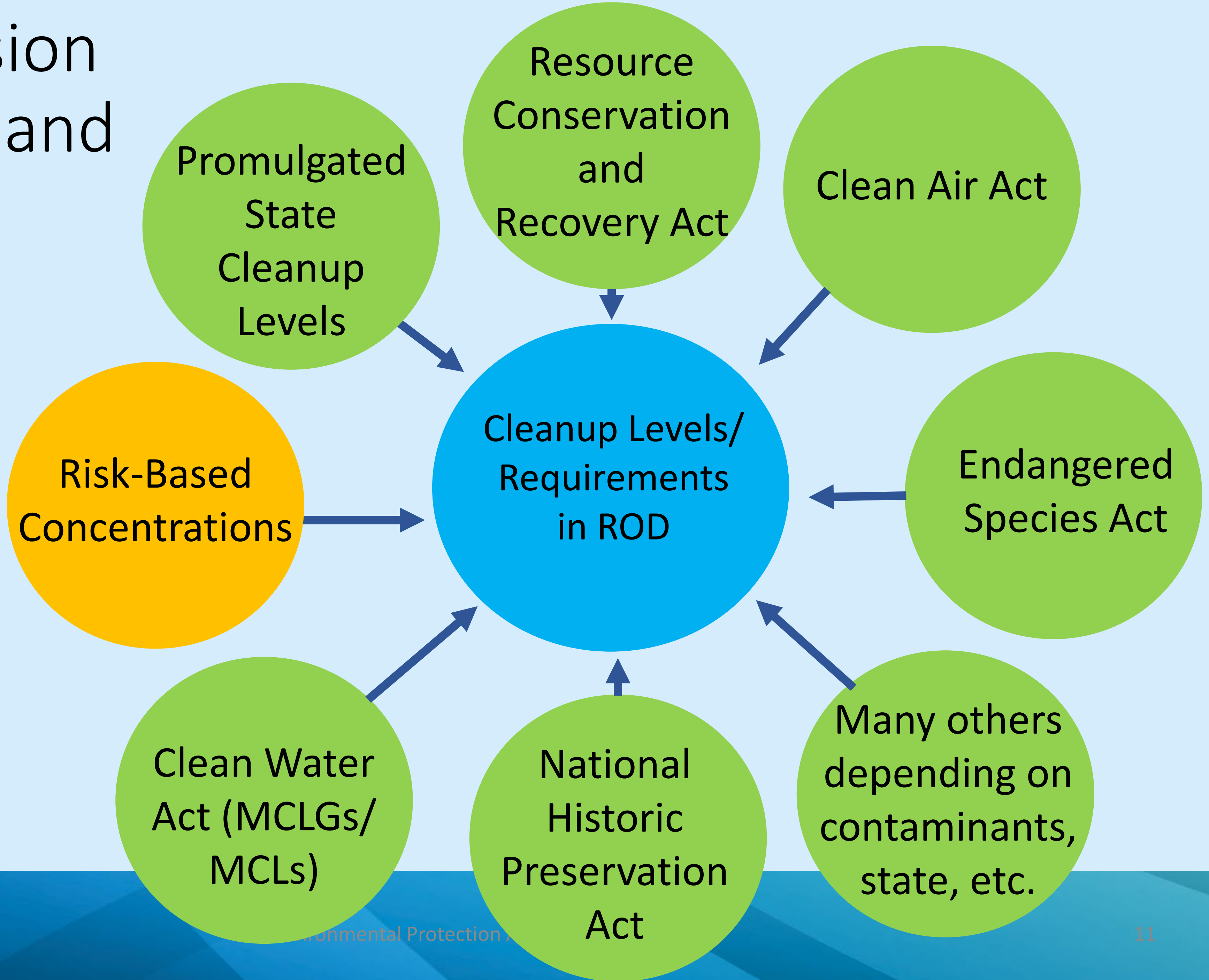
- *Overall protection of human health and the environment*
  - Multiple contaminants can drive cleanup levels below MCLs

- *Compliance with Applicable or Relevant and Appropriate Requirements (ARARs)*
  - Other Federal environmental laws, as well as more stringent state environmental and siting laws
  - Unless invoking ARAR waiver

Record of Decision Cleanup Levels and Requirements

- State ARARs must be **more** protective than federal levels, they cannot be less protective.

ARAR Examples



Can Cleanup Levels Change?

- Pre-Record of Decision
  - MCLs go through Six-Year Review by EPA Drinking Water Program
  - EPA Regional Screening Levels can be updated
  - State ARARs updates
- Post-Record of Decision
  - Cleanup levels are “frozen” at time of signature
  - CERCLA Five-Year Reviews done to determine if remedy is “protective”
  - ARARs may need to be updated if remedy is no longer protective, usually requires a ROD Amendment

Example of RSL Change Pre-ROD

- Original Proposed Plan had dig and dispose in a landfill as the preferred alternative
- Before ROD was completed, updated benzo(a)pyrene toxicity values in IRIS increased screening levels and the site no longer exceeded screening levels
- New Proposed Plan issued that changed from dig and dispose in landfill to No Action

How are ARARs Waived?

40 CFR §300.430(f)(1)(ii)(B)(2) An alternative that does not meet an ARAR under federal environmental or state environmental or facility siting laws may be selected under the following circumstances:

- (*1*) The alternative is an **interim measure** and will become part of a total remedial action that will attain the applicable or relevant and appropriate federal or state requirement;
- (*2*) Compliance with the requirement will result in **greater risk** to human health and the environment than other alternatives;
- (*3*) Compliance with the requirement is **technically impracticable** from an engineering perspective;
- (*4*) The alternative will attain a **standard of performance that is equivalent** to that required under the otherwise applicable standard, requirement, or limitation through use of another method or approach;
- (*5*) With respect to a state requirement, **the state has not consistently applied**, or demonstrated the intention to consistently apply, the promulgated requirement in similar circumstances at other remedial actions within the state; or
- (*6*) For **Fund-financed** response actions only, an alternative that attains the ARAR will not provide a balance between the need for protection of human health and the environment at the site and the availability of Fund monies to respond to other sites that may present a threat to human health and the environment.

Interim Actions- Hanford Waste Sites

- No full baseline risk assessment
- WA State MTCA residential cleanup levels for chemicals
- 15 mrem (150 μSv)/year dose for radionuclides
- Following up with “final” Records of Decision, using risk for radionuclides ($1x10^{-4}$)

Interim Actions- Hanford Groundwater

- 200-BP-5/PO-1
  - Uranium and Tc-99 COCs
  - Did not set cleanup levels for other co-contaminants that will be addressed in final ROD
  - Still need to address source contamination (Central Plateau waste sites)

- 200-UP-1
  - No technology to clean up I-129
  - Not enough information for TI waiver at time of Interim ROD

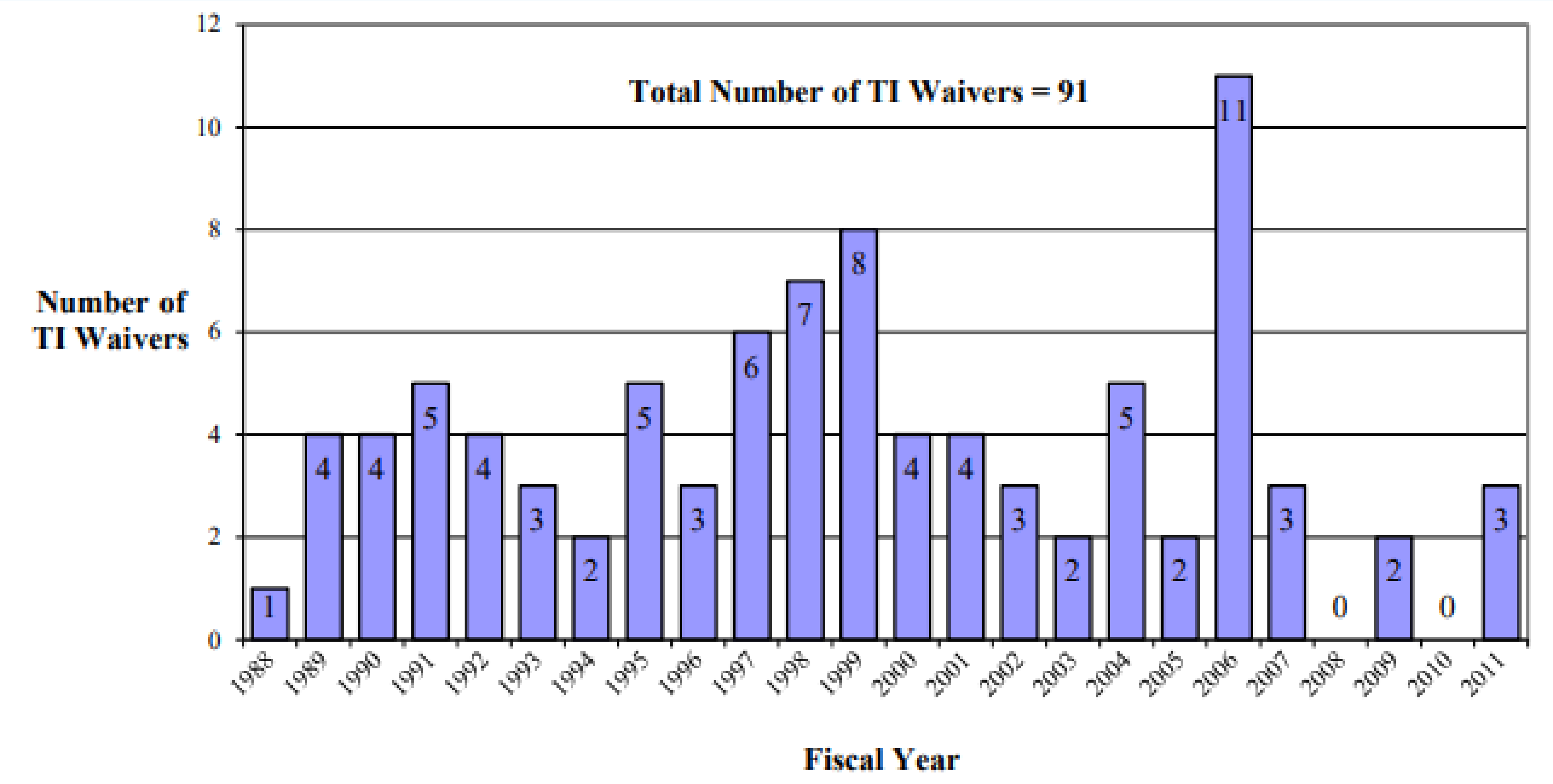
Greater Risk ARAR Waiver at Hanford ERDF

- ARAR in ERDF ROD identifies 40 CFR 268, "Land Disposal Restrictions," which specifies that treatment standards must be met **before** these wastes can be placed (land disposed) within the ERDF trench
- The in-trench macroencapsulation treatment alternative was shown to significantly reduce worker risk
- Waiver was only for “placement”, not for the treatment

Technical Impracticability Waiver (TI)

- As of 2012, 91 TI waivers have been issued, 81 of those are for groundwater
- Complex geology (fractured bedrock, karst terrain, heterogeneous soils with low permeability)
- Non-aqueous phase liquid (NAPL)
- Must still meet overall protectiveness of human health and the environment

TI Waivers Granted by EPA Nationwide (1988-2011)



Summary

- CERCLA action can be taken based on unacceptable risk **or** exceedance of MCLs
- Highest beneficial use for most aquifers is drinking water
- Cleanup levels are based on both risk-based concentrations and ARARs and are unique to each site
- ARARs must be met or waived

Questions?

Contact Info: Laura Buelow
Buelow.Laura@epa.gov

Want to Learn More?

- https://www.epa.gov/superfund
- https://trainex.org/
- https://clu-in.org/