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Environmental Dosimetry

Environmental Dosimetry Methods and New Developments

Tim Jannik
Principal Technical Advisor

Savannah River Chapter of Health Physics Society Seminar

May 16, 2014

Savannah River NUCLEAR SOLUTIONS℠

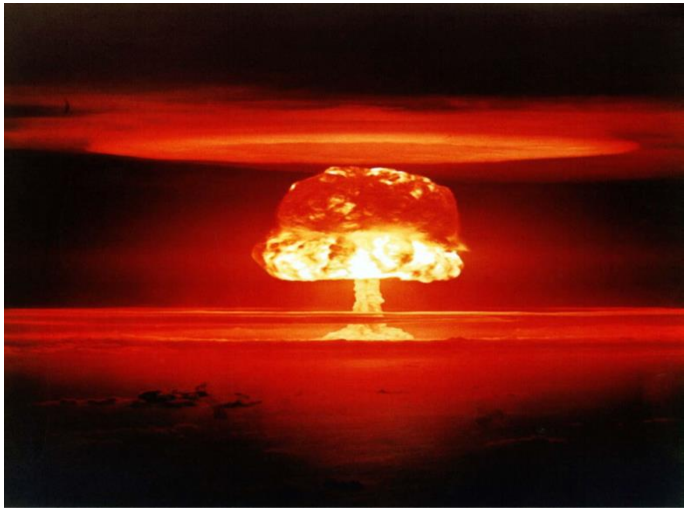
FLUOR • NEWPORT NEWS NUCLEAR • HONEYWELL

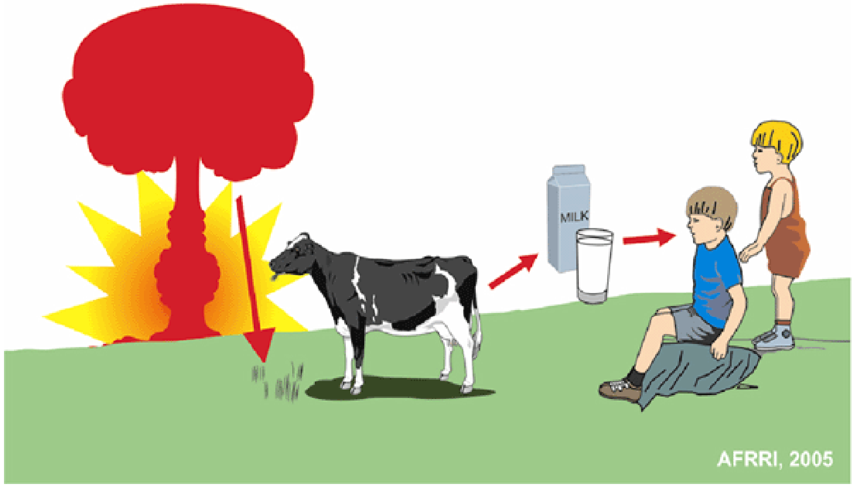
Outline

- **Introduction to Environmental Dosimetry**
- **Environmental Dosimetry Methods**
- **Representative Person**
  - Reference Person
- **USEPA's CAP88 PC Version 4.0**

1) Introduction to Environmental Dosimetry

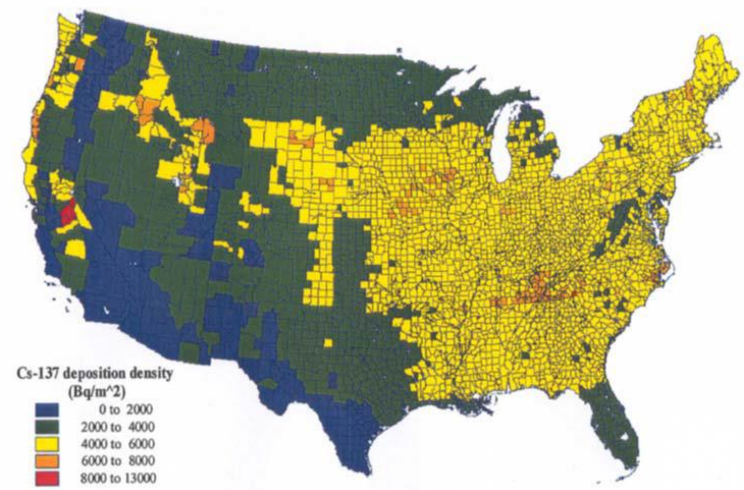
- **Fields of Environmental Dosimetry and Radioecology Grew Out of Societal Concerns Related to Activities Associated with the Cold War**
- **Concern about the Threat not only to Humans but to the Various Ecological Food Chains, Populations, and Ecosystems**
  - Airborne releases from atmospheric weapons testing (local and global scale)
    - *Cold War Production Facilities*
  - Critical pathways to humans discovered – enhanced exposures over time





Introduction - Cesium-137 from Global Fallout

Nation	Number of Above Tests	Years	Total Yield
United States	216	1945-1962	153.8 mt
U.S.S.R.	214	1949-1962	281.6 mt
United Kingdom	21	1952-1958	10.8 mt
France	46	1960-1974	11.4 mt
P.R.China	23	1964-1980	21.5 mt
South Africa	1	1979	0.003 mt



Cs-137 Deposition Density from CDC/NCI 2002

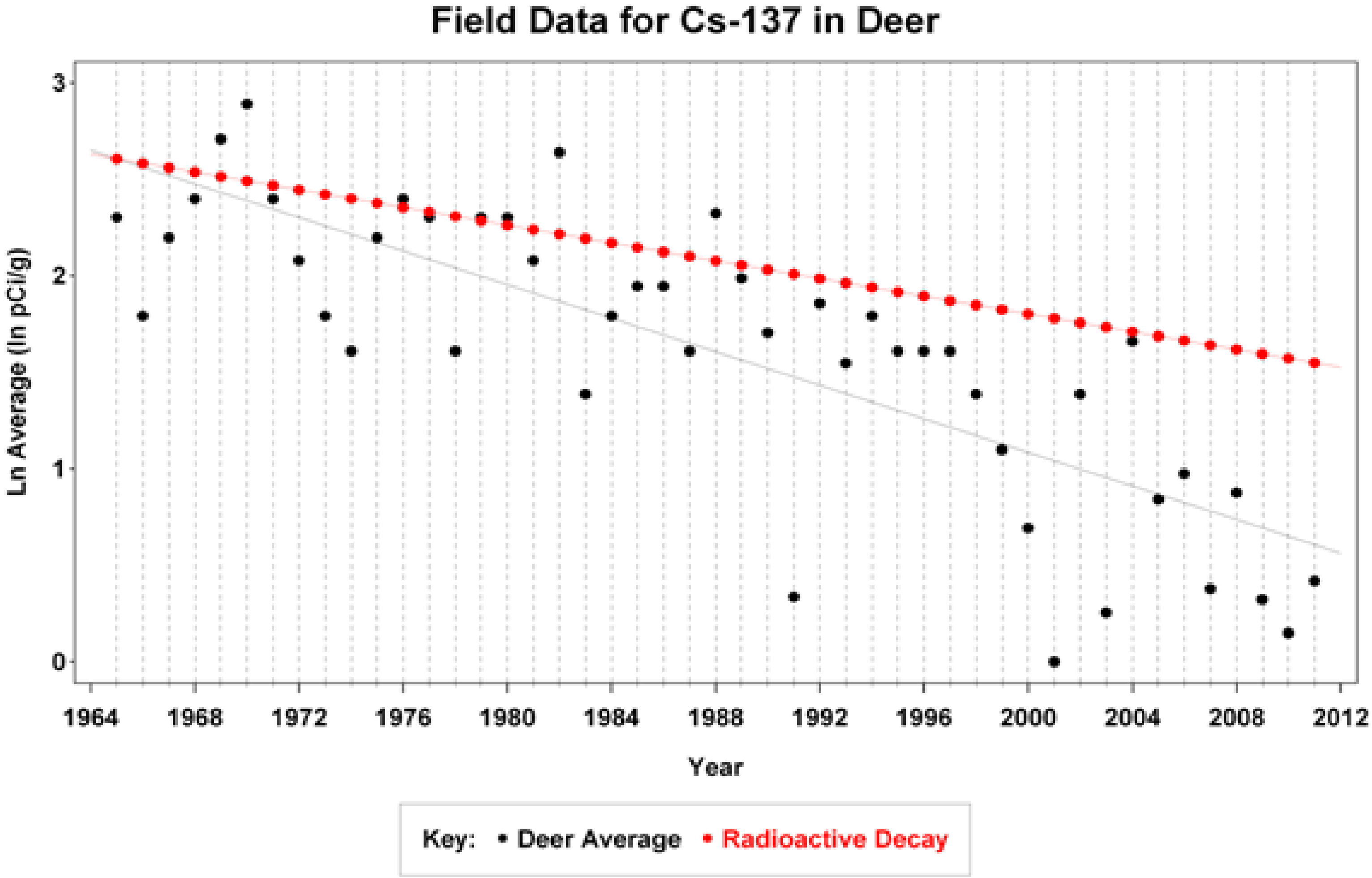
Environmental Dosimetry Introduction

- **After 50 years, there is still measurable fallout in the environment**
- **Especially in areas not impacted by anthropomorphic activities**

	Fort Stewart	Fort Gordon	Fort Jackson	SRS	Control Background
Cesium-137 Conc. in Deer (pCi/g)	15.6	3.3	2.6 (higher if outlier included)	2.1 (past 5 y)	0.1 – 1.0 (varies with weather and time of year)

Environmental Dosimetry Introduction – Effective Half Life

Effective ½ Life = 15.9 y



- **Atomic Energy Act of 1954**
  - Established authority for protecting the health and safety of the public
- **1960's to 1980's numerous environmental laws and regulations formalized Environmental Dosimetry**
  - Clean Air Act
  - Clean Water Act
  - NRC
    - *NUREG 1.109, Calculation of Annual Doses to Man from Routing Releases of Reactor Effluents for the Purpose of Evaluating Compliance with 10 CFR Part 50, App. 1*
  - DOE Orders
    - *5400.5 (now 458.1), Radiation Protection of the Public and the Environment*

- **Guidance on Environmental Dosimetry Methods**

2) Environmental Dosimetry Methods

- **Definition of Environmental Dosimetry is from Dr. John Till**

- **"Radiological Risk Assessment and Environmental Analysis"**
  - Bible for Environmental Dosimetry

Environmental Dose/Risk = (S • T • E • D• R)uvcp

- S = source term (characterization of the quantity and type of material released)
- T = environmental transport and fate of the material released
- E = exposure and usage factors
- D = conversion to dose
- R= dose conversion to risk

- u = uncertainty
- v = validation
- c = communication of results
- p = public participation

Dose/Risk = (S • T • E • D• R)uvcp

- **First key element is the source term (S) it defines the characteristics and quantity of material that is released to the environment**
  - Measured or calculated at the point of discharge
    - *Airborne pathways*
    - *Liquid pathways*
- **Requires the most resources relative to other steps**
  - Sampling
  - Flow measurements
  - Radiochemistry
  - Radioanalyses
  - Compilation
  - Quality control and assurance
- **Should follow a Data Life Cycle Process**
  - Optimize the quantity and quality of the data – Data Quality Objectives
  - The only good data are used data
  - The only used data are good data

Source Term Guidance

- **“Design of Effective Radiological Effluent Monitoring and Environmental Surveillance Programs”**
  – NCRP Report No. 169 (2011)
- **"Environmental Radiological Effluent Monitoring and Environmental Surveillance“**
  – DOE/EH-0173T (1991)
  – DOE Technical Standards Program (TSP) Handbook (Draft in DOE RevCom 2014)
- **“Sampling and Monitoring Releases of Airborne Radioactive Substances from the Stacks and Ducts of Nuclear Facilities,”**
  – ANSI N13.1 (2011)
- **"Offsite Dose Calculation Manual Guidance: Standard Radiological Effluent Controls for Pressurized Water Reactors“**
  – NUREG-1301 (1991)
- **"Offsite Dose Calculation Manual Guidance: Standard Radiological Effluent Controls for Boiling Water Reactors“**
  – NUREG-1302 (1991)

- **Batch Release Sampling**
  - Ideal Sampling
    - *Known volumes and concentrations*

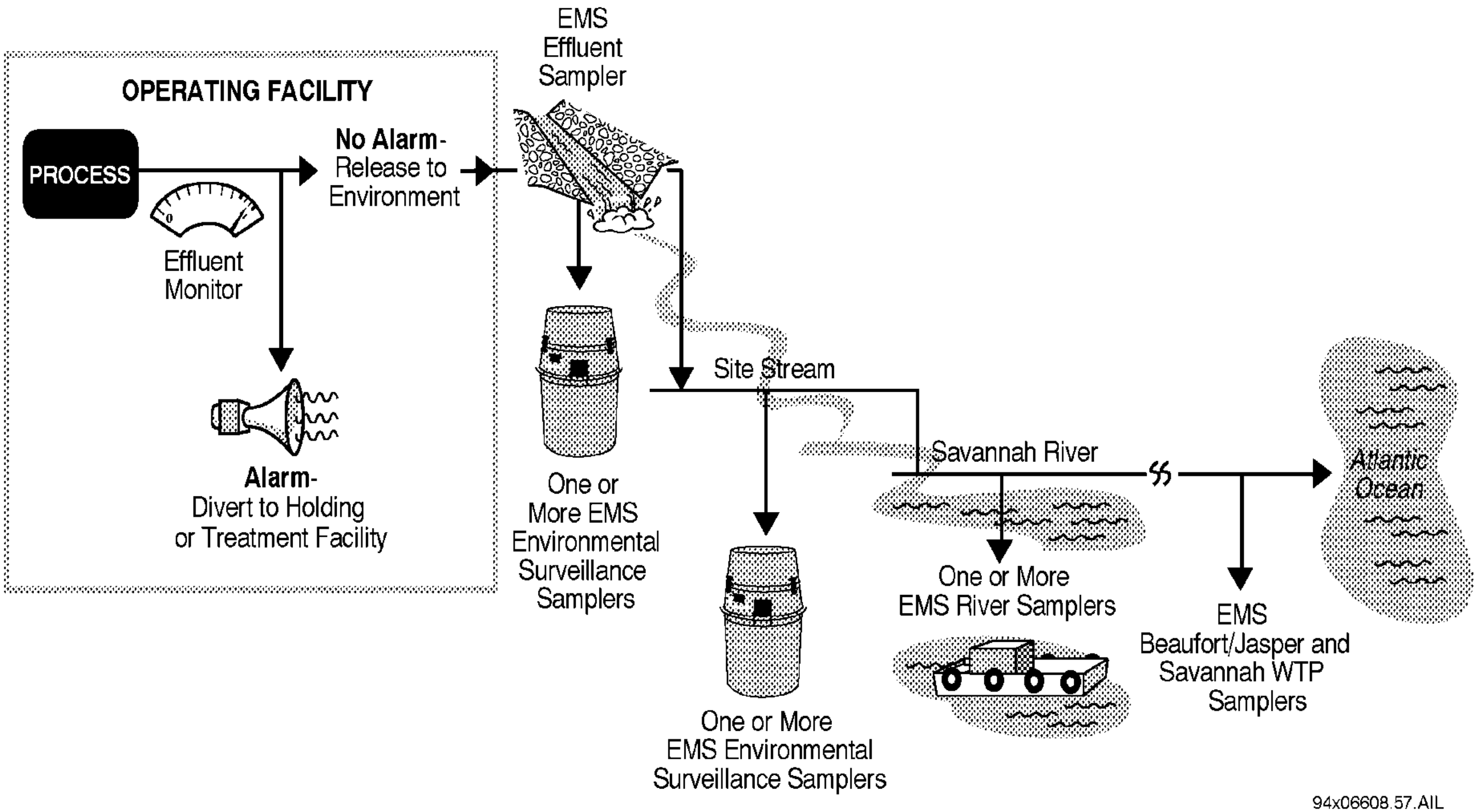
- **Timed Integrated Sampling**
  - Samples collected on a specific schedule
  - Composited over a specific sampling period
  - Separate Flow Measurements

- **Flow Proportional Sampling**
  - Requires continuous flow measurement and timed sampling
  - Sample taken is programmed to be proportional to the effluent flow volume

Source Term – Batch Release Sampling

Flow Proportional Sampling

Source Term Verification - Liquid



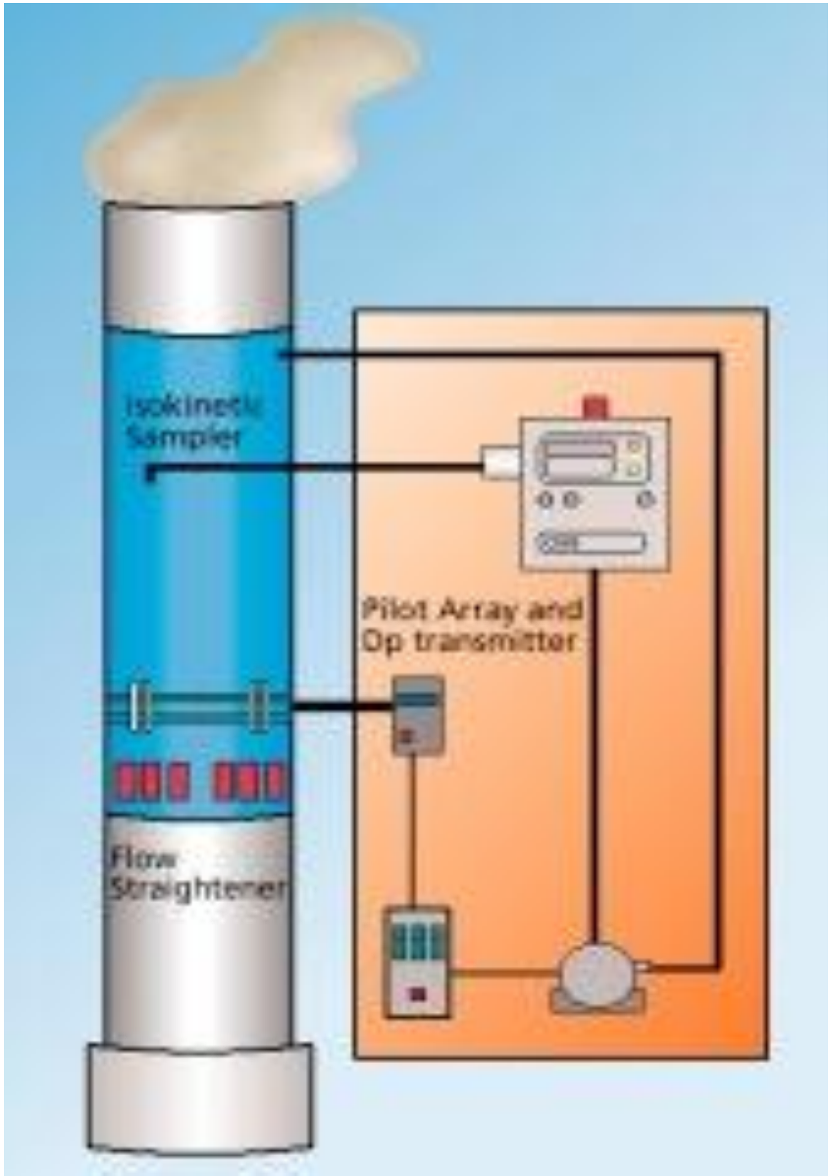
Source Term Determination – Airborne Effluents

- **National Emissions Standards for Hazardous Air Pollutants**
  - *NESHAPS Subpart H (EPA 1991)*
  - Requires Evaluation
    - *Potential Airborne Emissions*
      - Potential Effective Dose (PED)
    - *Normal Operations*
      - Including System Upsets
      - No Control Devices or Filtration Operating
- **Results of PED Evaluations**
  - Used to Determine Potential Impact Categories (PIC)
- **PIC Levels used to Determine Monitoring Requirements**

Source Term Verification - Atmospheric

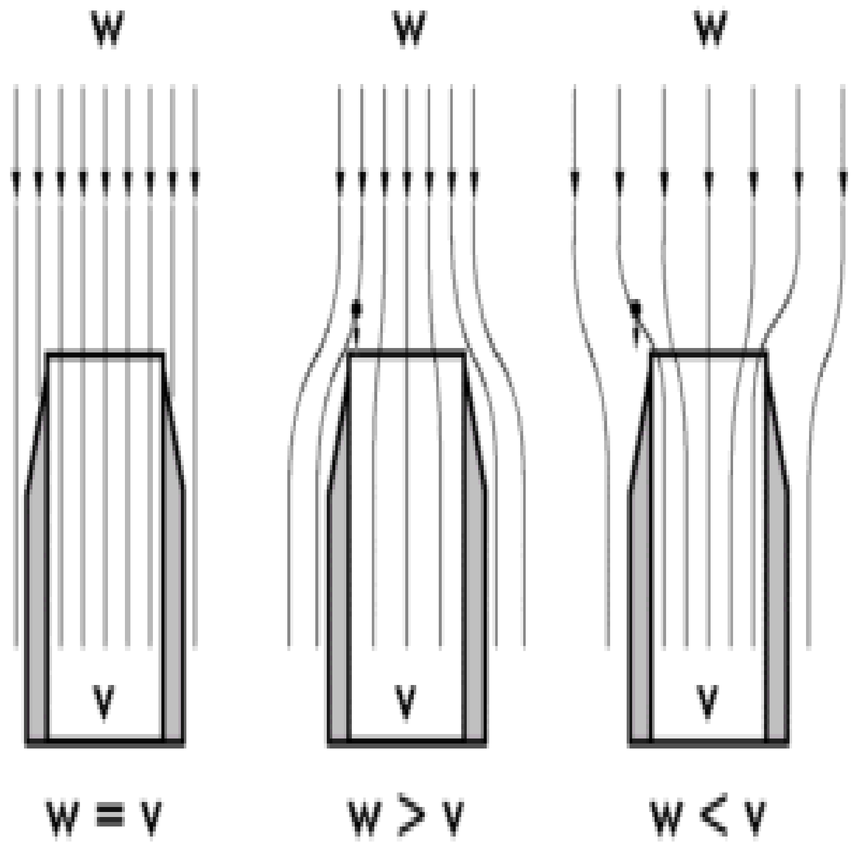
Potential Impact Category (PIC Level)	Monitoring and Sampling Criteria	PED (mrem/y)	Actual ED (mrem/y)
1	Continuous sampling to include a real time monitor and alarm	>0.1	>1E-02
2	Continuous sampling with off-line periodic analysis	>0.1	≤1E-02
3	Periodic quarterly or annual sampling and off-line analysis	≤0.1	>1E-05
4	Annual administrative review of facility to confirm absence of radioactive materials	≤0.1	≤1E-05

Isokinetic Sampling – ANSI N13.1



Isokinetic Sampling

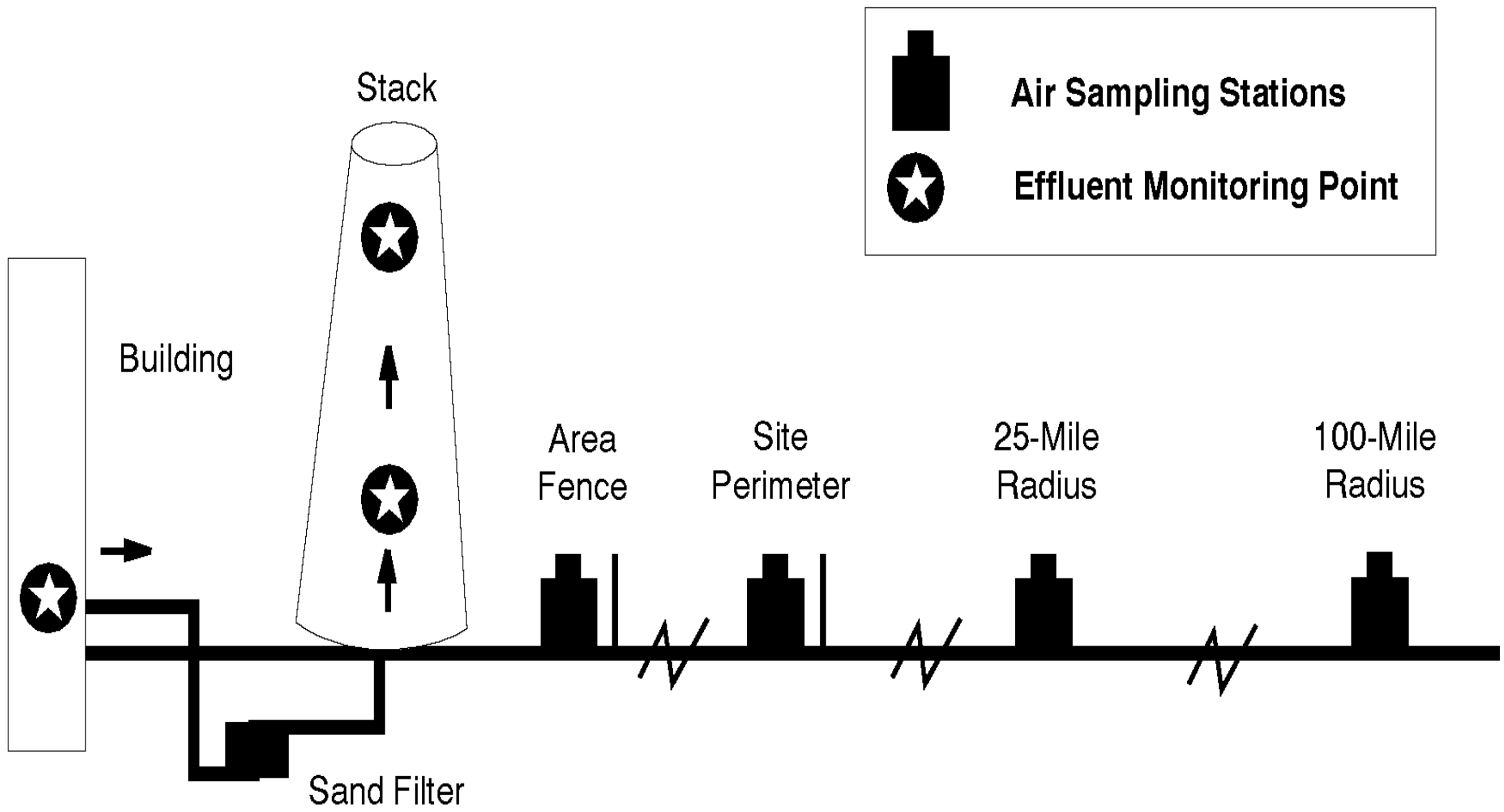
- **Isokinetic**
  - W=V
  - Uniform Particulate Sampling
- **Sample Velocity Lower**
  - W>V
  - Biased to Large Particles
- **Sample Velocity Higher**
  - W<V
  - Biased to Smaller Particles



Source Term Determination – Airborne Effluents Sample Collection Media

- **Air Filter Paper**
  - Particulates
- **Charcoal**
  - Radioiodine
- **Silica Gel**
  - Vapors
- **Gases (Noble)**
  - Real Time Gamma Monitoring
  - Periodic Grab

Source Term Verification - Atmospheric

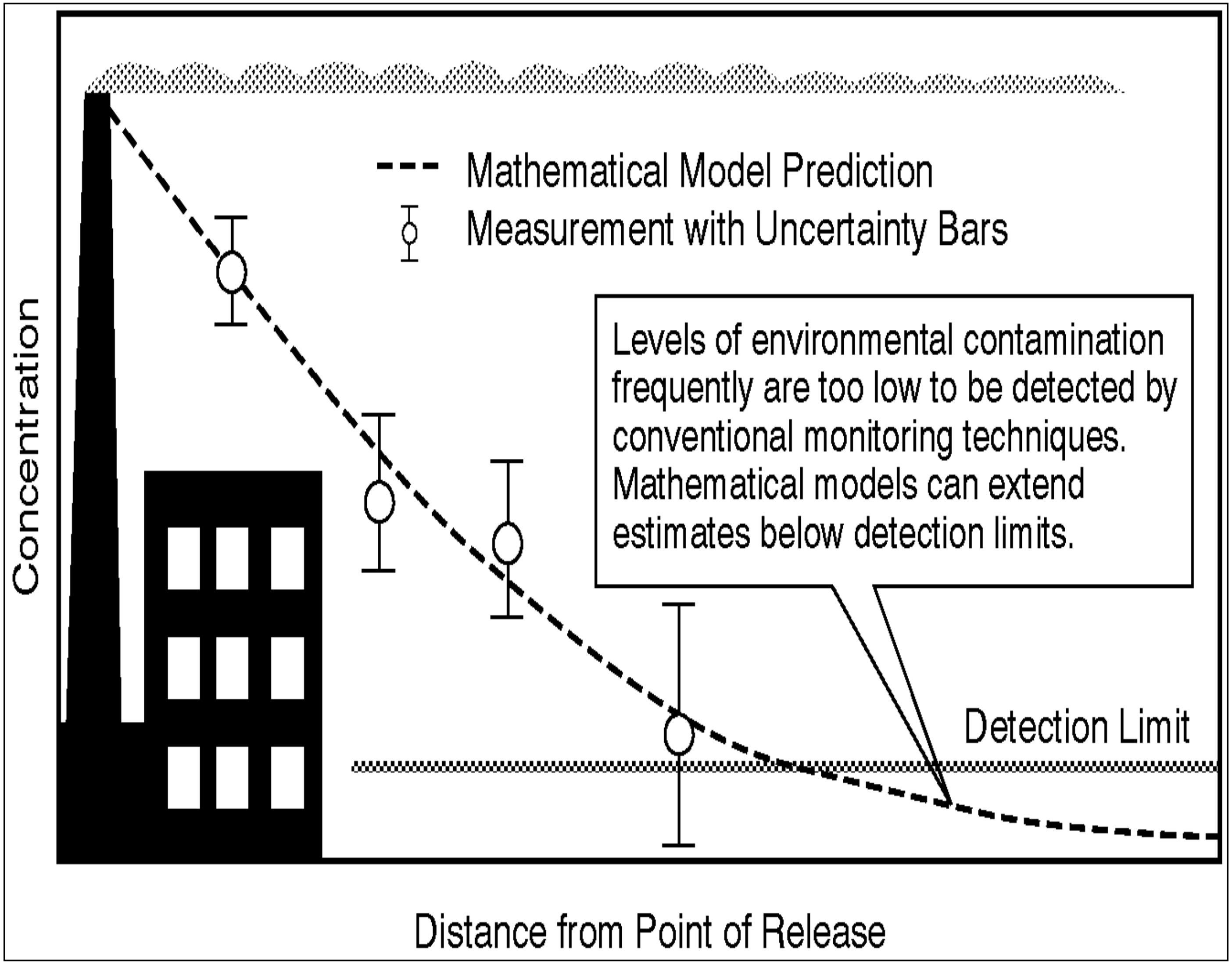


Transport

Dose/Risk = (S • T • E • D• R)uvcp

- **Transport (T) of contaminants as they move through the environment**
  - Estimates the concentration of contaminants in the environment at the point of exposure or compliance

Transport



Mathematical Model Prediction
Measurement with Uncertainty Bars
Levels of environmental contamination frequently are too low to be detected by conventional monitoring techniques. Mathematical models can extend estimates below detection limits.
Detection Limit
Concentration
Distance from Point of Release

Transport

- **Environmental Transport Models**

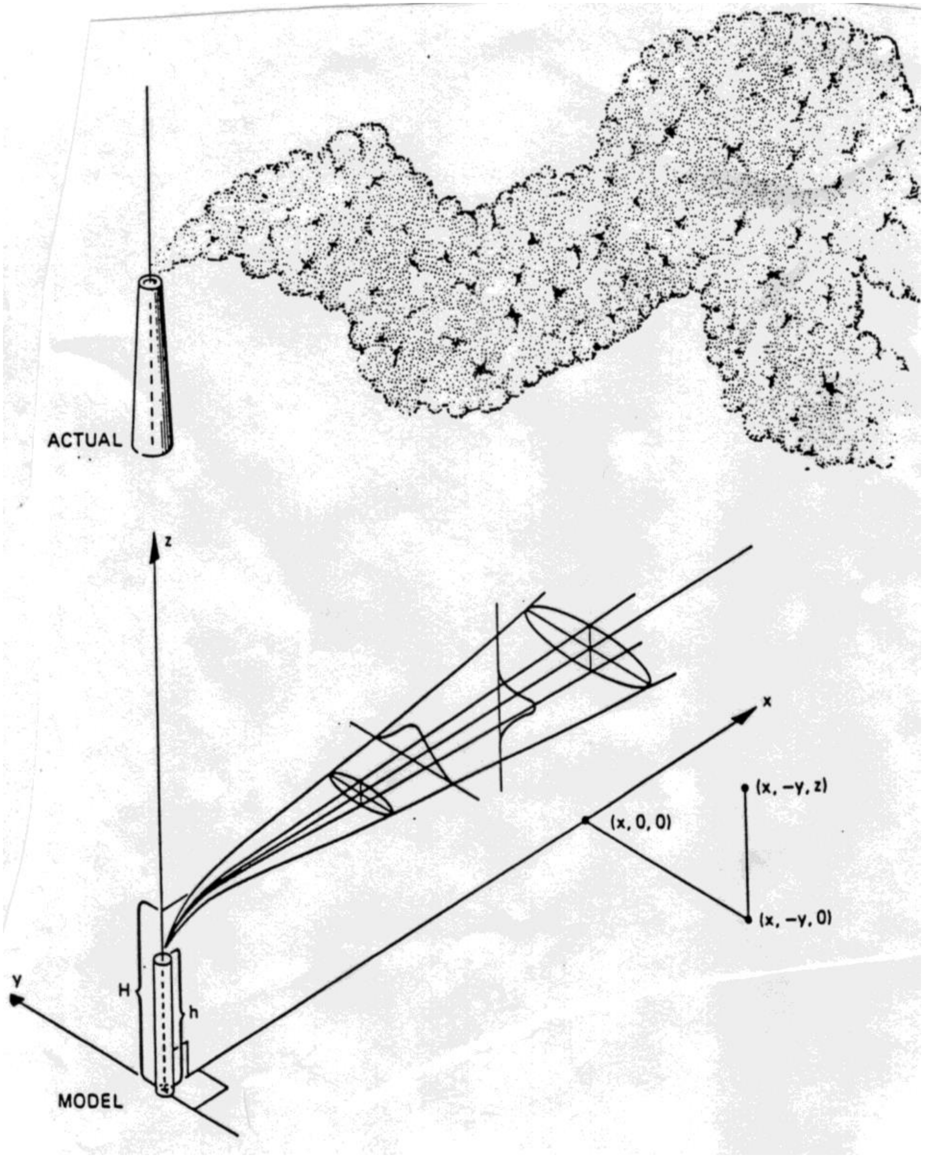
- **Simulate Complex Transport Phenomena**
  - Physical
  - Chemical
  - Biological
  - Progressive Dilution or Bioaccumulation

Transport – Air (Straight line Gaussian Plume Model)

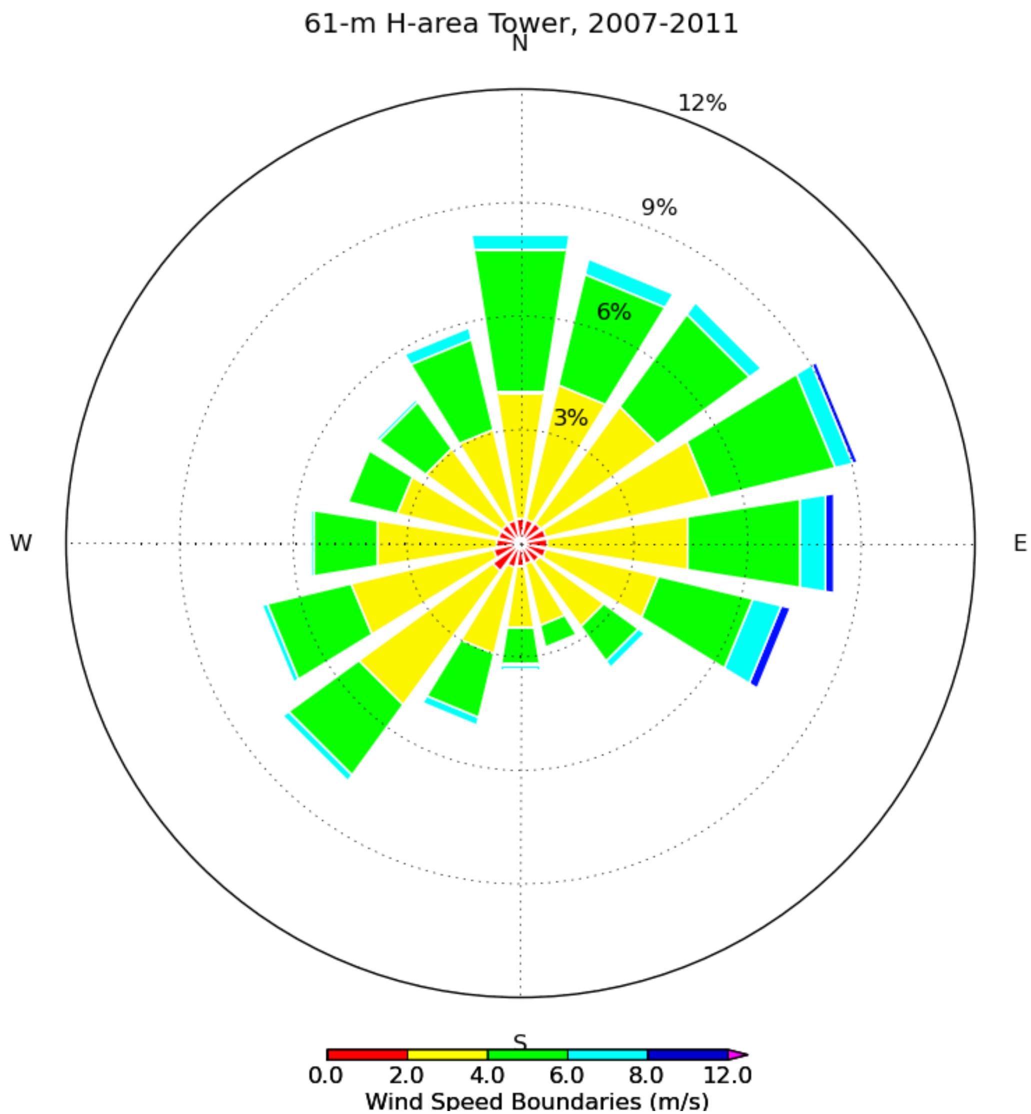
$$\left(\frac{\chi}{Q}\right)_i = \frac{2.032e^{-\left(\frac{(h_e)^2}{2\sigma_z^2}\right)}}{\sigma_z U x}$$

χ/Q - sector arc average relative air concentration (s/m^3);
x - downwind distance (m);
h_e - effective release height (m);
U - wind speed (m/s);
σ_z - standard deviation of the concentration distribution in the vertical direction(m)

Normal Distribution
Straight Line



Transport – Meteorological Data



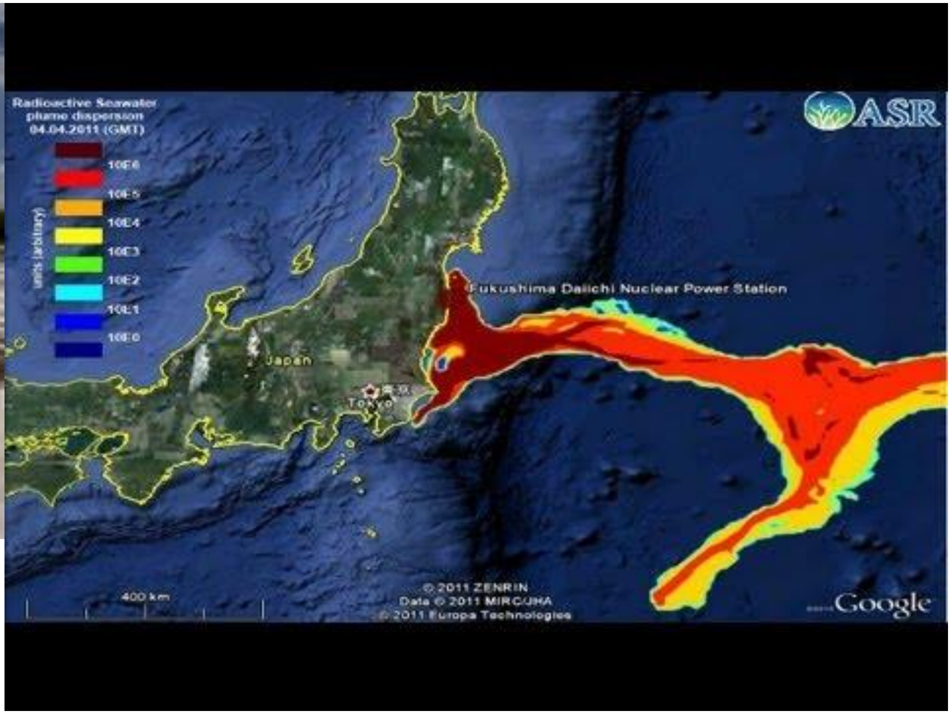
Transport – Model Concentration Comparisons

	pCi/m^3	
	Average Concentration	Maximum Sector
Measured at SRS Boundary (10)	5.2	9.5
Calculated:		
MAXDOSE-SR	9.9	20.2
CAP88-PC Version 4.0	7.6	11.0

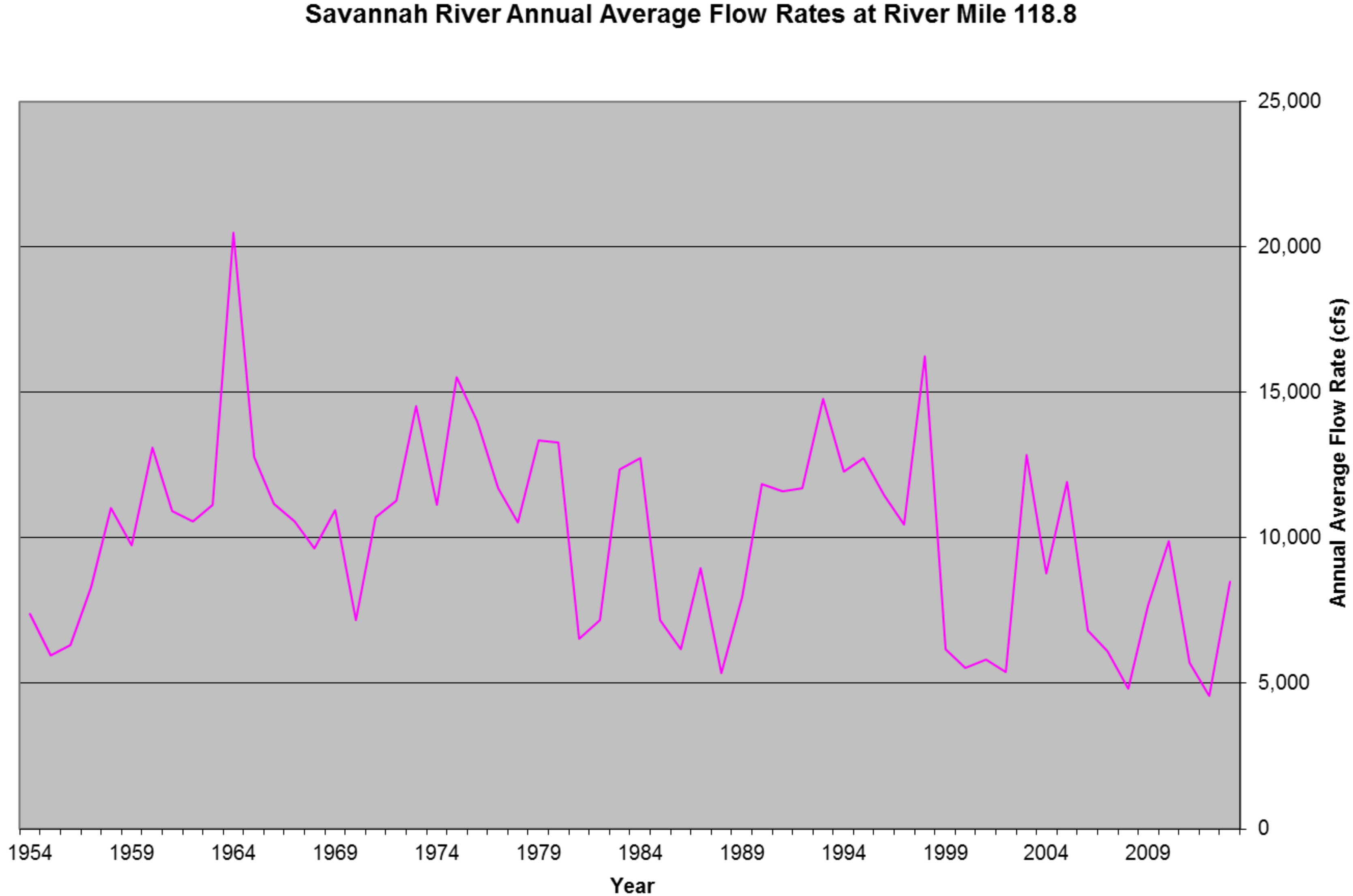
Transport – Liquid Releases

- Liquid Releases to rivers
  - Simple volume dilution
  - Assume Complete Mixing

- Liquid Releases to oceans and lakes
  - Not so Simple!
  - Empirical Data Needed



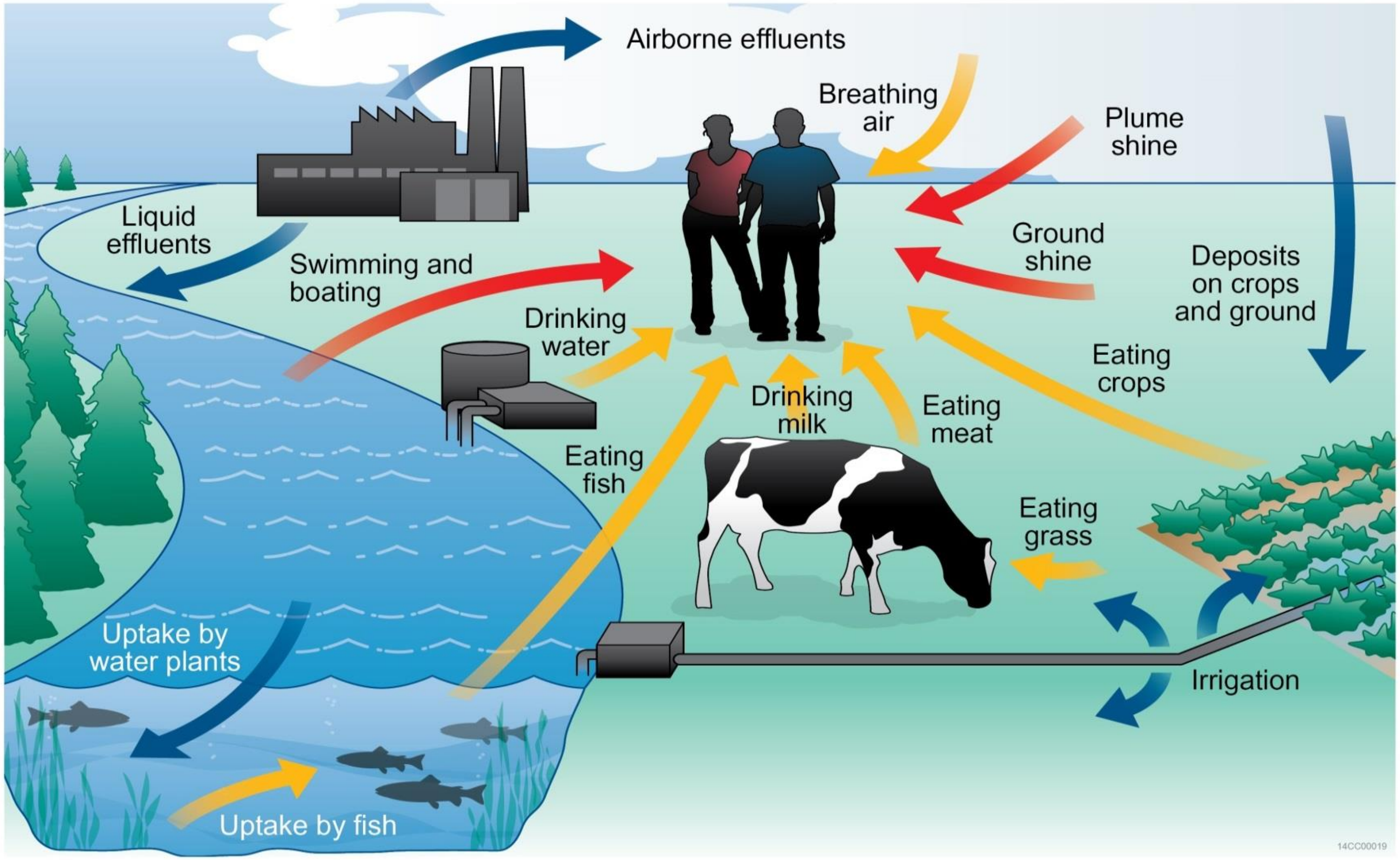
Transport – Liquid - Volumetric Dilution



Exposure and Environmental Pathways to Man

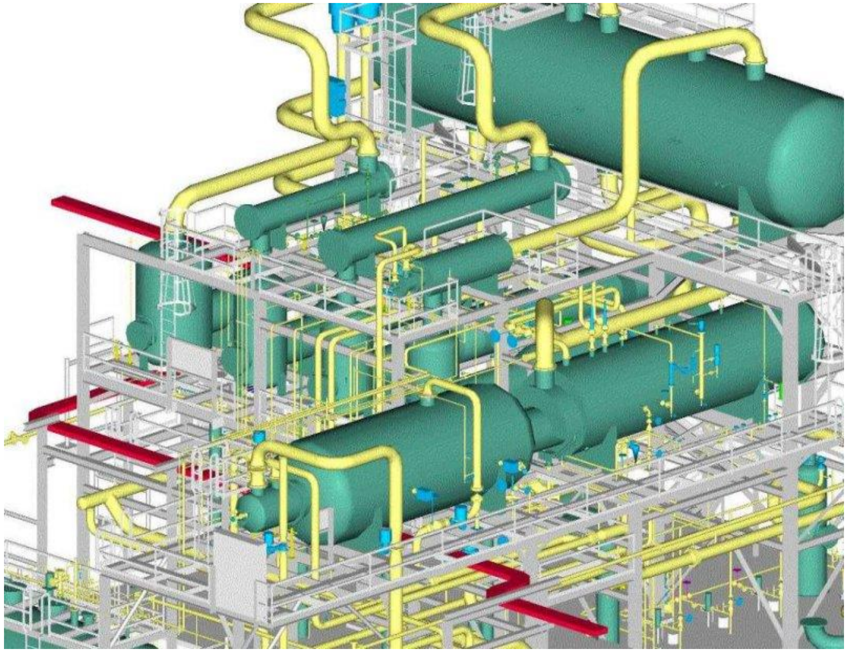
Dose/Risk = (S • T • E • D• R)uvcp

- **Exposure term (E) – amount of contamination taken up by humans/biota**

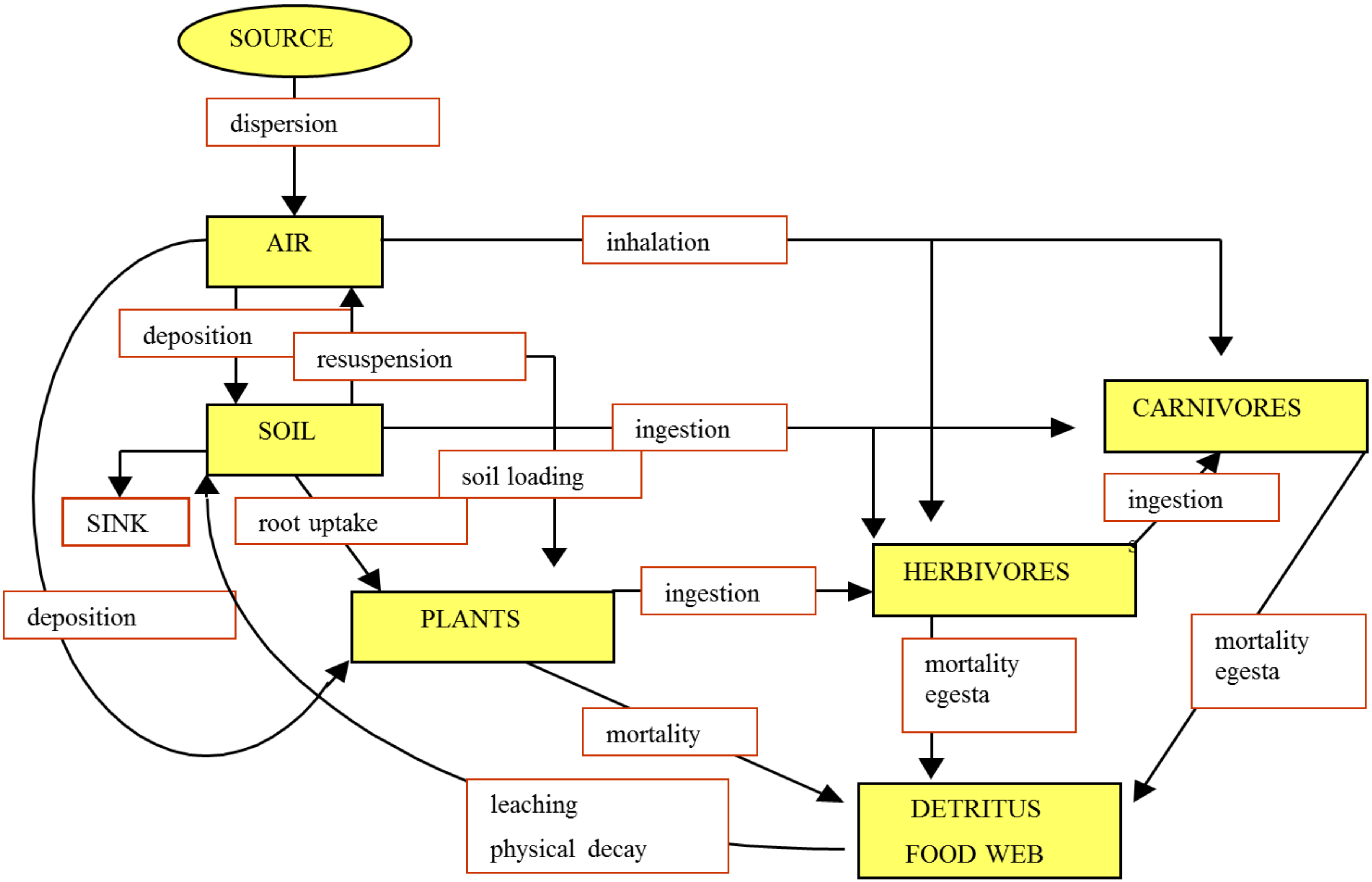


Exposure Term

- **Exposure (E) term accounts for how much material ends up in biota and humans**
  - Ecological systems dilute, remove, or bioaccumulate contaminants
  - Series of “buckets and pipes” (Tom Hinton SREL/IRSN)
  - Different sized buckets
  - All are interconnected with different size pipes!



Exposure – Simplistic Model of Major Ecological Processes - Terrestrial



Dose Coefficients and Dose Terminology

Dose/Risk = (S • T • E • D• R)uvcp

- **If we know the amount of exposure, then we can estimate the dose using D.**
  - Internal Dose Coefficients
    - *Ingestion (water and food)*
    - *Inhalation*
  - External Dose Coefficients
    - *Ground Shine*
    - *Plume Shine*
    - *Air Immersion*
    - *Water Submersion*

- **There are 5 distinct dose terms**
  - Absorbed Dose (*D*)
  - Equivalent Dose (*H*)
  - Effective Dose (ED)
  - Committed Effective Dose (CED)
  - Total Effective Dose (TED)

Absorbed Dose (*D*)

- **Absorbed dose, *D*, is the total energy absorbed into a mass of any material**
  - It is a measurable quantity
  - Defined by ICRP as the quotient of the mean energy (dε) deposited into a volume of mass (dm)

$$D = d\varepsilon/dm$$

  - This quantity does not account for the type of radiation being absorbed or material type absorbing the radiation
  - Standard unit for absorbed dose is the gray (Gy) which is equivalent to 1 joule per kilogram
  - Conventional unit is the rad, which is equivalent to 0.01 Gy.

Equivalent Dose (H)

- **Equivalent dose, H, is a radiation weighted dose**
  - Different types of radiation have very different biological impacts. Alpha radiation can be more damaging than gamma rays if the alpha emitting radionuclide is distributed within the biological material.
  - To account for these differences, the absorbed dose *D* is multiplied by a radiation weighting factor.
  - Standard unit for H is the Sievert (Sv).
  - Conventional unit is Roentgen Equivalent Man (rem) or mrem.
  - 1 Sv is equivalent to 100 rem.

$$Equivalent\ Dose$$

$$H = \sum_{i=0}^{n} D * w_r$$

Type of Radiation	w_r
Photons	1
Electrons	1
Neutrons	
- Less than 10 keV	5
- 10 to 100 keV	10
- 100 keV to 2 MeV	20
- 2 MeV to 20 MeV	10
- Greater than 20 MeV	5
Alpha Particles	20

Effective Dose (ED)

- **Effective dose, ED, is a tissue weighted dose**
  - Different types of tissue respond differently to radiation.
  - Organs and tissues with fast cell cycles receive more damage.
  - ED is calculated by multiplying the equivalent dose by a tissue weighting factor.
  - Standard unit for ED is the Sievert (Sv).
  - Conventional unit is the Roentgen Equivalent Man (rem) or mrem.
  - 1 Sv is equivalent to 100 rem.

$$Effective\ Dose$$

$$ED = \sum H * w_t$$

Organ or Tissue	w_t
Gonads	0.2
Colon, red marrow, stomach, lungs	0.12
Bladder, Breast, Esophagus, Liver, Thyroid, Remainder	0.05
Bone surface and Skin	0.01

Committed Effective Dose (CED)

- **Committed effective dose, CED, is a tissue weighted dose over time**
  - Certain radionuclides have long biological and physical half-lives
  - CED is the effective dose to a person integrated over time.
  - Standard unit for CED is Sievert (Sv).
  - Conventional unit is Roentgen Equivalent Man (rem) or mrem.
  - 1 Sv is equivalent to 100 rem.

  - NOT applicable for external exposures

$$Committed\ Effective\ Dose$$

$$CED = \int_0^{\tau} ED_T(t)\, dt$$

Time (t) = 50 y for adults
Time (t) = 70 y for children/infants

Total Effective Dose (TED)

- **Total effective dose, TED, is the sum of the effective dose from external exposures and the CED from internal exposures**
- **TED is used to demonstrate compliance with required dose limits.**
- **Standard unit for TED is the Sievert (Sv)**
- **Conventional unit is the rem or mrem**
  - 1 Sv is equivalent to 100 rem.

Human Health Risk Conversion

Dose/Risk = (S • T • E • D• R)uvcp

- **Dose is converted to risk (R) using coefficients developed over many years**
  - Atomic bomb survivor studies
  - Medical radiation studies
  - Occupational studies
    - *Nuclear Industry*
    - *Mayak workers*
    - *Chernobyl cleanup workers*
    - *Airline*
    - *Medical/Dental*
  - Environmental Radiation studies
    - *High background*
    - *Fallout*

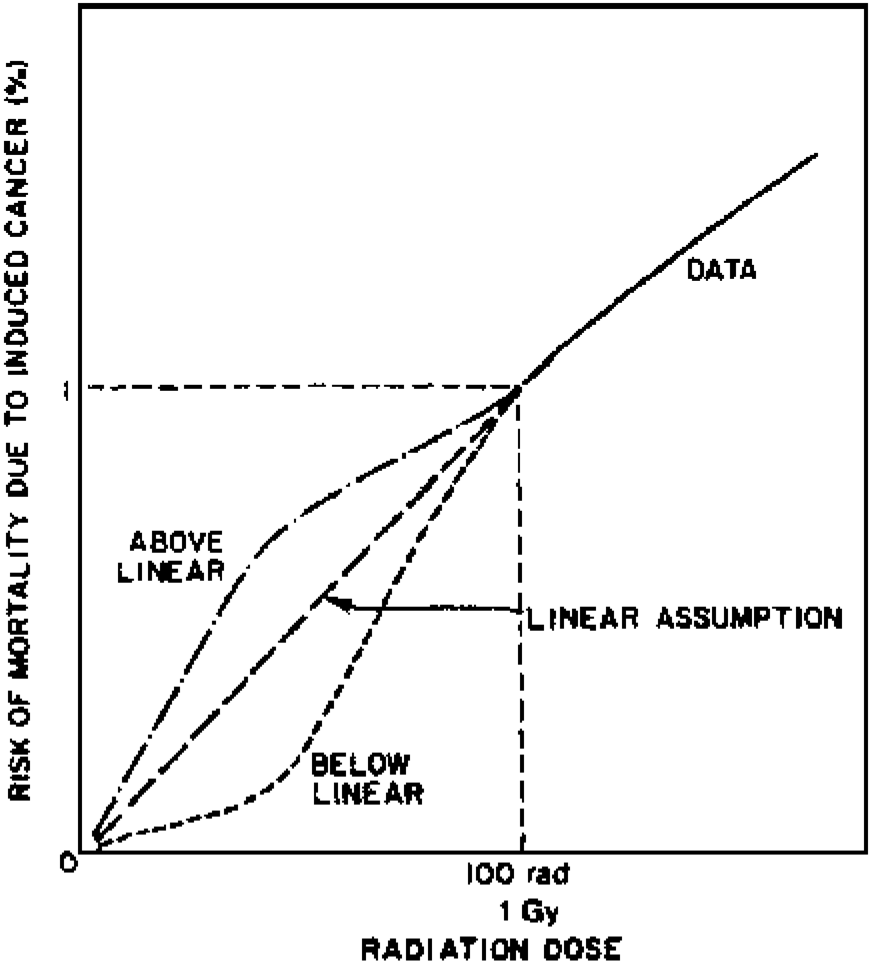
Human Health Risk Conversion

- **National Research Council's Biological Effects of Ionizing Radiation**
  - BEIR VII Report (phase 2 in 2006)
  - About 1,000 incidences per 100,000 exposed people (100 mSv) (10 rem)
  - About 500 deaths per 100,000 exposed people (100 mSv)

	All Solid Cancer		**Leukemia**	
Excess cases (including non-fatal cases) from exposure to 100 mSv	Males	Females	Males	Females
	800 (400–1600)	1300 (690–2500)	100 (30–300)	70 (20–250)
Number of cases in the absence of exposure	45,500	36,900	830	590
Excess deaths from exposure to 100 mSv	410 (200–830)	610 (300–1200)	70 (20–220)	50 (10–190)
Number of deaths in the absence of exposure	22,100	17,500	710	530

Human Health Risk Conversion – Linear No Threshold

- "in the presence of available data, it is neither sound statistical interpretation nor prudent risk evaluation to take the view that the risk should be 0 in some low-dose range…"



Human Health Risk Conversion – Linear Not Threshold

Dose (mSv)	Cancer Risk
100	1.0 E-02
10	1.0 E-03
1	1.0 E-04
0.1	1.0 E-05
0.01	1.0 E-06

1.0E-06 Risk / 1 mrem

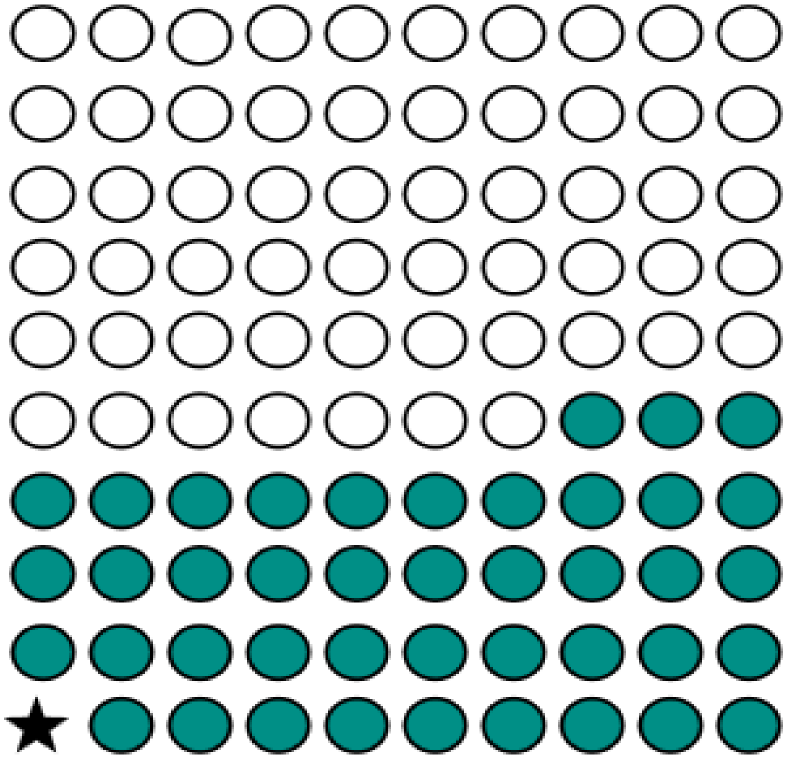


Figure 2. In a lifetime, approximately 42 (solid circles) of 100 people will be diagnosed with cancer[2] from causes unrelated to radiation. The calculations in this report suggest approximately one cancer (star) in 100 people could result from a single exposure 100 mSv of low-LET radiation.

Other Mitigating Factors

Dose/Risk = (S • T • E • D• R)uvcp

- **Uncertainty (u) is related to all of the basic elements in the risk assessment equation. Uncertainty calculations have changed this science in the last two decades more than anything.**
  - Most regulations and laws require deterministic calculations
    - *100 mrem/y public dose limit*

- **Validation (v) includes taking environmental measurement data and using these data to help confirm the model calculations.**
  - SRS is able to do this with tritium oxide measurements

- **Finally, communication (c) of what we do and participation (p) of stakeholders are important in helping people understand the meaning of risk estimates from exposure to radiation in the environment.**

Uncertainty in Dose Calculations

- **All of the Dose equation terms have a high degree of uncertainty**
  - Especially the exposure term based on environmental systems
- **Improving the input feels like "sharpening a marshmallow"**

3) SRS-Specific Reference Person - Outline

- The Reference Person History and Definition
- Dose Coefficients
- Intake Rates
- Dose Comparisons
- Conclusion and Discussion

Daniel Stone – Graduate Student at Oregon State University

2012 Summer Intern

Basis of his Masters Thesis

Published in most recent *HPS Operational Radiation Safety*

Department of Energy Order 458.1

- **Establishes an Annual Public Dose Limit of 100 mrem (1 mSv) and states that**:
  - "Compliance may be demonstrated by calculating dose to the *representative* person or to the maximally exposed individual (MEI)."

- **SRS historically used the MEI**
  - Adult Male Usage Factors
  - Adult Male/Female Dose Coefficients

- **This project was to develop a SRS Reference Person Usage Factors**
  - To be used for calculating a dose to the representative person

Reference Person History

- **Standard Man – 1960**
  - ICRP 2
  - Average biological and dosimetric parameters
  - Consistent and reproducible dose calculations to workers

- **Reference Man – 1974**
  - Updated, ICRP 23
  - Improved biokinetic models and dosimetric models
  - Adult worker
  - Data widely used

Representative Person History

- **Reference "persons" – 2002**
  - Updated in ICRP 89
  - Created male and female reference persons
  - Six age groups, each group with specific reference values
  - Provides the data for determining Reference Individual or Person
- **Representative Person – 2005**
  - ICRP 101
    - *Introduction of the representative person*
  - ICRP 103 (2007)
    - *formally recommended use of the representative person*
  - DOE Order 458.1 (2011)
    - *allows use of representative person*

- **Reference person**:
  - *A hypothetical aggregation of human (male and female) physical and physiological characteristics arrived at by international consensus for the purpose of standardizing radiation dose calculations*

- **Representative Person**:
  - *An individual receiving a dose that is representative of the more highly exposed individuals in the population. This term is equivalent of, and replaces, "average member of the critical group"*
  - *I*n ICRP 101 the definition is extended to include the *average value for the more highly exposed group* ***OR*** *the 95th percentile of appropriate national or regional data.*

- **Typical Person**:
  - A hypothetical reference person receiving a dose that is typical of the population group - established at 50th percentile or median - not the mean

Reference Person Dose Coefficients

- **DOE-STD-1196-2011, Dr. Keith Eckerman at ORNL**
- **Internal Reference Person Dose Coefficients**
  - First time age-weighted reference person used in US DOE regulations
  - Updated dose coefficients
  - Based on ICRP 107 Nuclear Data for dose coefficients and ICRP 89 reference values
    - *Age-Specific Dose coefficients updated from ICRP 72*
  - For Compliance - DOE-HQ recommended use of Water Ingestion dose coefficients for all ingestion pathways
  - Nearly all dose coefficients went up because of the incorporation of children

- **External Dose Coefficients used from EPA's DC_PAC3 toolbox**
  - Based on ICRP 107 Nuclear Data

- **In general, reference person DC's are higher than adult DC's**
  - DC's generally go up with decreasing age
    - *Not always linear with age*
    - *Depends on metabolism*

Ingestion DC's (Sv/Bq)

Nuclide	Newborn	1-year	5-year	10-year	15-year	Adult	Reference	ICRP-72
H-3	7.53E-11	5.51E-11	3.38E-11	2.45E-11	1.91E-11	1.91E-11	2.10E-11	1.80E-11
Sr-90	2.27E-07	7.23E-08	4.67E-08	5.96E-08	7.86E-08	2.76E-08	3.60E-08	2.80E-08
Cs-137	2.11E-08	1.24E-08	**9.71E-09**	**1.02E-08**	**1.34E-08**	**1.36E-08**	**1.33E-08**	**1.30E-08**
Pu-239	4.19E-06	4.22E-07	3.33E-07	2.71E-07	2.46E-07	2.51E-07	2.88E-07	2.50E-07

- **Several important parameters needed**
  - **Population fractions by age and sex**
    - *2010 US Census for SC and GA*
  - **Intake/Usage Rates for individuals by age and sex**
    - *2011 EPA Exposure Factors Handbook*
    - *ICRP 89 for Reference Person Physical Characteristics*

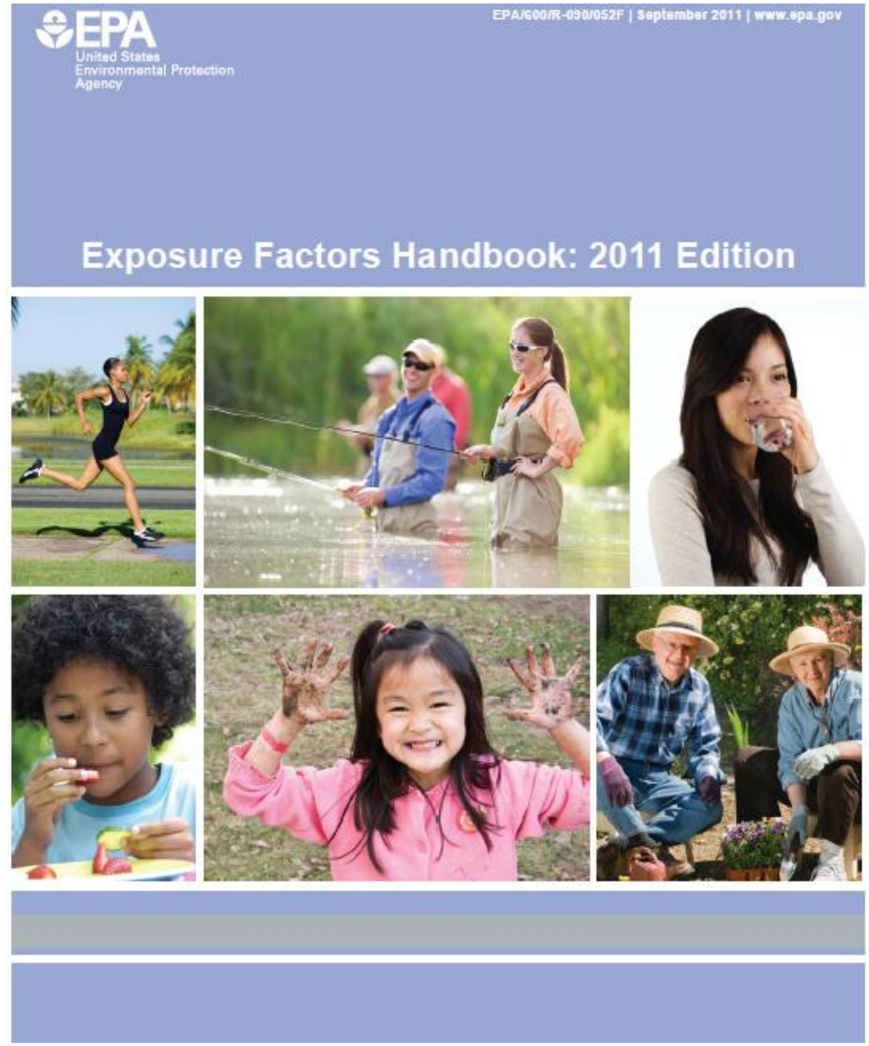
US Census for 2010 Population Fractions

Age Group	Age x, (y)	US 2010		SC/GA Counties 2010	
		Male	Female	Male	Female
new born	x<1	0.006524	0.006251	0.006770	0.006511
1 year	1≤x<3	0.013354	0.012800	0.013421	0.013240
5 year	3≤x<7	0.026979	0.025833	0.027484	0.026269
10 year	7≤x<12	0.033949	0.032489	0.034591	0.033192
15 year	12≤x<17	0.034765	0.033087	0.035017	0.033156
Adult	17 and older	0.376036	0.397933	0.369306	0.401043

Exposure Factors

- **New human health input parameters based on the EPA's Exposure Factors Handbook**
  - 95% for Representative Person
  - 50% for Typical Person

- **Previously, health input parameters were used from NRC and ICRP reports and other historical references**



Reference Person Intake Parameters – Water Ingestion

Age Group	Age x, (y)	Water Intake (L/d)			
		50%		95%	
		Male	Female	Male	Female
New Born	x<1	0.364	0.364	1.1195	1.1195
1 year	1≤x<3	0.3295	0.3295	0.98	0.98
5 year	3≤x<7	0.438	0.438	1.2	1.2
10 year	7≤x<12	0.503	0.503	1.409	1.409
15 year	12≤x<17	0.663	0.49725	1.96	1.47
Adult	17 and older	1.04175	0.781313	2.808	2.106
Reference Person (Age and Gender Combined)		0.81		2.2	

Reference Person Intake Parameters – Comparison

95%				
		Reference Person	**Pre 2012 MEI**	**Difference**
Air	m3/y	6400	8000	-20.0%
Water	L/y	800	730	9.6%
Total Meat	kg/y	81	81	0.0%
Leafy Vegetables	kg/y	31	43	-27.9%
Other Produce	kg/y	289	276	4.7%
Total Milk/Dairy	L/y	260	230	13%
Freshwater Fish	kg/y	24	19	26.3%
Saltwater Invertebrate	kg/y	9.0	8	12.5%
50%				
		Typical Person	**Pre 2012 Avg.**	**Difference**
Air	m3/y	5000	5548	-9.9%
Water	L/y	300	337	-11.0%
Total Meat	kg/y	32	43	-26.3%
Leafy Vegetables	kg/y	11	21	-47.6%
Other Produce	kg/y	89	163	-45.4%
Total Milk/Dairy	L/y	69	120	-42.3%
Freshwater Fish	kg/y	3.7	9	-58.9%
Saltwater Invertebrate	kg/y	1.5	2	-25.0%

Dose Comparison Using New Reference Person vs Old MEI Parameters

- **1 Bq/L or 1 Bq/kg of Tritium Oxide**

- **95th percentile Representative Person**
  – Dose increases for all Pathways except Air

- **50th percentile Typical Person**
  – Dose decreases with exception of Water

Representative Person Dose – Comparison

Pathway	95% Representative Dose (Sv)	Previous Dose (Sv)	Difference
Air	1.85E-07	2.16E-07	-14.22%
Water	1.68E-08	1.31E-08	27.85%
Meat	1.70E-09	1.46E-09	16.67%
Total Produce	6.72E-09	5.74E-09	17.03%
Milk/Dairy	5.46E-09	4.14E-09	31.88%
Freshwater Fish	5.04E-10	3.42E-10	47.37%
Saltwater Invertebrate	1.89E-10	1.44E-10	31.25%
	50%		
	Typical Dose (Sv)	Previous Dose (Sv)	Difference
Air	1.45E-07	1.50E-07	-3.37%
Water	6.30E-09	6.07E-09	3.86%
Meat	6.72E-10	7.74E-10	-13.18%
Total Produce	2.10E-09	3.31E-09	-36.59%
Milk/Dairy	1.45E-09	2.16E-09	-32.92%
Freshwater Fish	7.77E-11	1.62E-10	-52.04%
Saltwater Invertebrate	3.15E-11	3.60E-11	-12.50%

Reference Person Parameters - Conclusions

- **SRS-specific intake parameters developed for use**
- **Internal DC’s established based on DOE recommendation**
  - Reference Person
- **External DC’s only updated to new nuclear data in ICRP 107**
  - No age specific external DC’s
  -
- **Reference Person Parameters now being used for demonstrating compliance with DOE O 458.1**
  - 1mSv/year limit to the Representative Person

4) CAP88 PC Version 4.0 - Outline

- **CAP88 Background**
- **Comparison of Version 4.0 and 3.0**
- **Conclusions**

- **Georgia Regents University Nuclear Track Program 2013 interns**
  – Chris Sailors
  – Levi Johnson
  – Tammy Gussio
  – John O'Meara
  – Professor Joe Newton

CAP88 History

- **Clean Air Act Assessment Package – 1988**
  - Developed by USEPA for Clean Air Act compliance
    - National Emission Standards for Hazardous Air Pollutants (NESHAPs)
    - 40 CFR 61, subpart H (this is a LAW)
      - National Emission Standards for Emissions of Radionuclides Other Than Radon from Department of Energy Facilities
  - Modified Gaussian Plume Equation
  - Used by all DOE sites with air emissions
    - *Various versions allowed*

CAP88 History

- **CAP88 Mainframe 1988**
  - Used at SRS until 2012 when we lost our mainframe
- **CAP88-PC version 1.0**
  - 1992 DOS version
- **CAP88-PC version 2.0**
  - 1999 Windows version (was not Y2K compliant)
- **CAP88-PC version 2.1**
  - 2002 Compatible with Windows 95 and up
- **CAP88-PC version 3.0**
  - 11/2006 fixed errors
  - 3/2007 fixed errors
  - 10/2007 fixed errors
  - 12/2007 fixed errors
  - 2/2013 fixed errors discovered by SRNL
- **CAP88-PC version 4.0**
  - 1/2014 fixed most everything

CAP88-PC Version 4.0

- **Version 4.0 is a substantial upgrade to 3.0**
  - Updated code architecture and data formats
    - *Substantially improved simulation times*
  - Updated dose coefficients, decay data, and risk factors
    - *DCFPAK Version 2.2 (Eckerman and Leggett 2008)*
  - Changed (lowered!) human usage factors
    - *Decreased internal doses*
  - Updated ground surface buildup and depletion calculations
    - *Increased external doses due to 100 y buildup*
  - Adopts age dependent dose and risk factors
    - *No direction as to what to do with them yet*
    - *Assume we will have to calculate for all ages in the future*

CAP88-PC Version 4.0 (beta) versus 3.0

- **Version 4.0 beta version used in the comparison**
  - No changes in final version issued 01/2014
- **Standardized inputs**
  - Mostly default values for Individual only
  - One stack
  - SC “Rural” Agricultural data
  - Augusta/Bush Field Met data (default)
  - 3.7 E+10 Bq/y per radionuclide (1 Ci)
  - Progeny included
  - Version 3.0
    - *838 radionuclides*
  - Version 4.0
    - *1258 radionuclides*
      - IT IS GOOD TO HAVE INTERNS!

CAP88-PC Version 4.0 vs. 3.0 Human Usage Parameters

	Version 3.0	Version 4.0	% Change
Inhalation Rate (m^3/yr)	8.04E+03	5.26E+03	-35%
Human Food Utilization Factors			
Produce ingestion (kg/y)	1.76E+02	7.62E+01	-57%
Milk ingestion (L/y)	1.12E+02	5.30E+01	-53%
Meat ingestion (kg/y)	8.50E+01	8.40E+01	-1%
Leafy vegetable ingestion (kg/y)	1.80E+01	7.79E+00	-57%

CAP88-PC Version 4.0 vs. 3.0 Dose Coefficients

		Cs-137	H-3	I-129	Pu-239	Sr-90
Ingestion Dose Coefficient (mrem/pCi)	V3	5.02E-05	1.42E-07	3.91E-04	9.28E-04	1.02E-04
	V4	5.03E-05	7.10E-08	3.92E-04	9.29E-04	1.03E-04
	% Change	**0.20**	**-50.00**	**0.26**	**0.11**	**0.98**
Inhalation Dose Coefficient (mrem/pCi)	V3	1.73E-05	1.02E-07	1.33E-04	1.86E-01	1.32E-04
	V4	1.49E-05	6.79E-08	1.14E-04	1.79E-01	1.26E-04
	% Change	**-13.87**	**-33.43**	**-14.29**	**-3.76**	**-4.55**
Air Immersion Dose Coefficient (mrem-m^3/µCi-y)	V3	1.08E+07	0.00E+00	3.30E+07	4.07E+05	1.15E+07
	V4	1.10E+07	0.00E+00	3.33E+07	4.39E+05	1.15E+07
	% Change	**1.85**	**0.00**	**0.91**	**7.86**	**0.00**
Ground Shine Dose Coefficient (mrem-m^3/µCi-y)	V3	3.48E+03	0.00E+00	2.28E+04	3.31E+02	1.91E+03
	V4	3.65E+03	0.00E+00	2.32E+04	3.57E+02	1.91E+03
	% Change	**4.89**	**0.00**	**1.75**	**7.85**	**0.00**

CAP88-PC Version 4.0 vs. 3.0 Concentrations and Depositions – Small Change

		Cs-137	H-3	I-129	Pu-239	Sr-90
Air Concentration (pCi/m^3)	V3	3.52E-03	5.99E-03	2.07E-04	3.52E-03	3.52E-03
	V4	3.59E-03	5.99E-03	2.06E-04	3.59E-03	3.59E-03
	% Change	**1.99**	**0.00**	**-0.48**	**1.99**	**1.99**
Chi/Q (Sec/m^3)	V3	1.11E-07	1.89E-07	6.54E-09	1.11E-07	1.11E-07
	V4	1.13E-07	1.89E-07	6.51E-09	1.13E-07	1.13E-07
	% Change	**1.80**	**0.00**	**-0.46**	**1.80**	**1.80**
Dry Deposition (pCi/cm2s)	V3	6.34E-10	0.00E+00	7.26E-10	6.34E-10	6.34E-10
	V4	6.46E-10	0.00E+00	7.23E-10	6.46E-10	6.46E-10
	% Change	**1.89**	**0.00**	**-0.41**	**1.89**	**1.89**
Wet Depostion (pCi/cm2s)	V3	3.20E-10	0.00E+00	6.09E-11	3.18E-10	3.21E-10
	V4	3.21E-10	0.00E+00	5.94E-11	3.21E-10	3.21E-10
	% Change	**0.31**	**0.00**	**-2.46**	**0.94**	**0.00**
Ground Deposition (pCi/cm2s)	V3	9.54E-10	0.00E+00	7.87E-10	9.52E-10	9.54E-10
	V4	9.68E-10	0.00E+00	7.82E-10	9.68E-10	9.68E-10
	% Change	**1.47**	**0.00**	**-0.64**	**1.68**	**1.47**

CAP88-PC Version 4.0 vs. 3.0 Dose Comparison

		Cs-137	H-3	I-129	Pu-239	Sr-90
Total Effective Dose (mrem)	V3	2.50E-01	4.68E-05	6.82E-01	5.52E+00	3.99E-01
	V4	4.12E-01	1.66E-05	5.28E-01	3.51E+00	3.09E-01
	% Change	**64.80**	**-64.53**	**-22.58**	**-36.41**	**-22.56**
Ingestion Dose (mrem/yr)	V3	2.45E-01	4.19E-05	6.82E-01	2.72E-01	3.94E-01
	V4	1.88E-01	1.45E-05	5.16E-01	1.21E-01	2.62E-01
	% Change	**-23.27**	**-65.39**	**-24.34**	**-55.51**	**-33.50**
Inhalation Dose (mrem/yr)	V3	4.89E-04	4.89E-06	2.21E-04	5.25E+00	3.87E-03
	V4	2.81E-04	2.14E-06	1.24E-04	3.39E+00	2.45E-03
	% Change	**-42.54**	**-56.24**	**-43.89**	**-35.43**	**-36.69**
Air Immersion Dose (mrem/yr)	V3	1.05E-05	0.00E+00	6.84E-09	1.43E-09	3.66E-07
	V4	1.07E-05	0.00E+00	6.88E-09	1.58E-09	3.72E-07
	% Change	**1.90**	**0.00**	**0.58**	**10.49**	**1.64**
Ground Surface Dose (mrem/yr)	V3	4.36E-03	0.00E+00	1.29E-04	2.27E-06	8.86E-04
	V4	2.24E-01	0.00E+00	1.24E-02	2.35E-04	4.45E-02
	% Change	**5037.61**	**0.00**	**9512.40**	**10252.42**	**4922.57**

CAP88-PC Version 4.0 Conclusion

- **CAP88-PC Version 4.0 will be used at SRS for the 2013 Annual Report**
  – Much better than Version 3.0!
- **In general, the alpha and beta (internal doses) go down**
  – Consumption rates went down
- **In general, gamma doses go up**
  – 100 y buildup
  – No depletion from the environment
- **Overall SRS NESHAP doses will go down**
  – Dominated by tritium oxide