Dose Limits for Normal Emissions from the Nuclear Fuel Cycle: Understanding 40CFR190 and its Technical Basis

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Outline

Why is 40CFR190 Important?

Technical Bases for 40CFR190

- Dose and Health Effects
- Cost Analysis
- Risk Integration

Changes Since EPA's 1976 Final Environmental Statement

Observations and Summary

40CFR190

Subpart B—Environmental Standards for the Uranium Fuel Cycle

§ 190.10 Standards for normal operations.

Operations covered by this subpart shall be conducted in such a manner as to provide reasonable assurance that:

(a) The annual dose equivalent does not exceed 25 millirems to the whole body, 75 millirems to the thyroid, and 25 millirems to any other organ of any member of the public as the result of exposures to planned discharges of radioactive materials, radon and its daughters excepted, to the general environment from uranium fuel cycle operations and to radiation from these operations.

(b) The total quantity of radioactive materials entering the general environment from the entire uranium fuel cycle, per gigawatt-year of electrical energy produced by the fuel cycle, contains less than 50,000 curies of krypton-85, 5 millicuries of iodine-129, and 0.5 millicuries combined of plutonium-239 and other alpha-emitting transuranic radionuclides with half-lives greater than one year.

§ 190.11 Variances for unusual operations.

The standards specified in § 190.10 may be exceeded if:

(a) The regulatory agency has granted a variance based upon its determination that a temporary and unusual operating condition exists and continued operation is in the public interest, and

(b) Information is promptly made a matter of public record delineating the nature of unusual operating conditions, the degree to which this operation is expected to result in levels in excess of the standards, the basis of the variance, and the schedule for achieving

40CFR190: Environmental Protection Standards for Nuclear Power Operations

Limits for Normal Operations - Subpart A

Dose Limit

190.10(a): *"…annual dose equivalent dose not exceed 25 mrem to whole body, 75 mrem to thyroid and 25 mrem to any other organ of any member of public…"*

EPA concerned that the previous standard was unnecessarily high and concluded it could be reduced without burdening industry.

Operating experience suggests that this standard will not be difficult to meet

40CFR190: Environmental Protection Standards for Nuclear Power Operations

Limits for Normal Operations - Subpart B

Release Limit

190.10(b): *"…total quantity of radioactive materials entering general environment…per gigawatt-year of electrical energy…contains less than 50,000 Ci Kr-85, 5mCi I-129, and 0.5 mCi Pu-239…"*

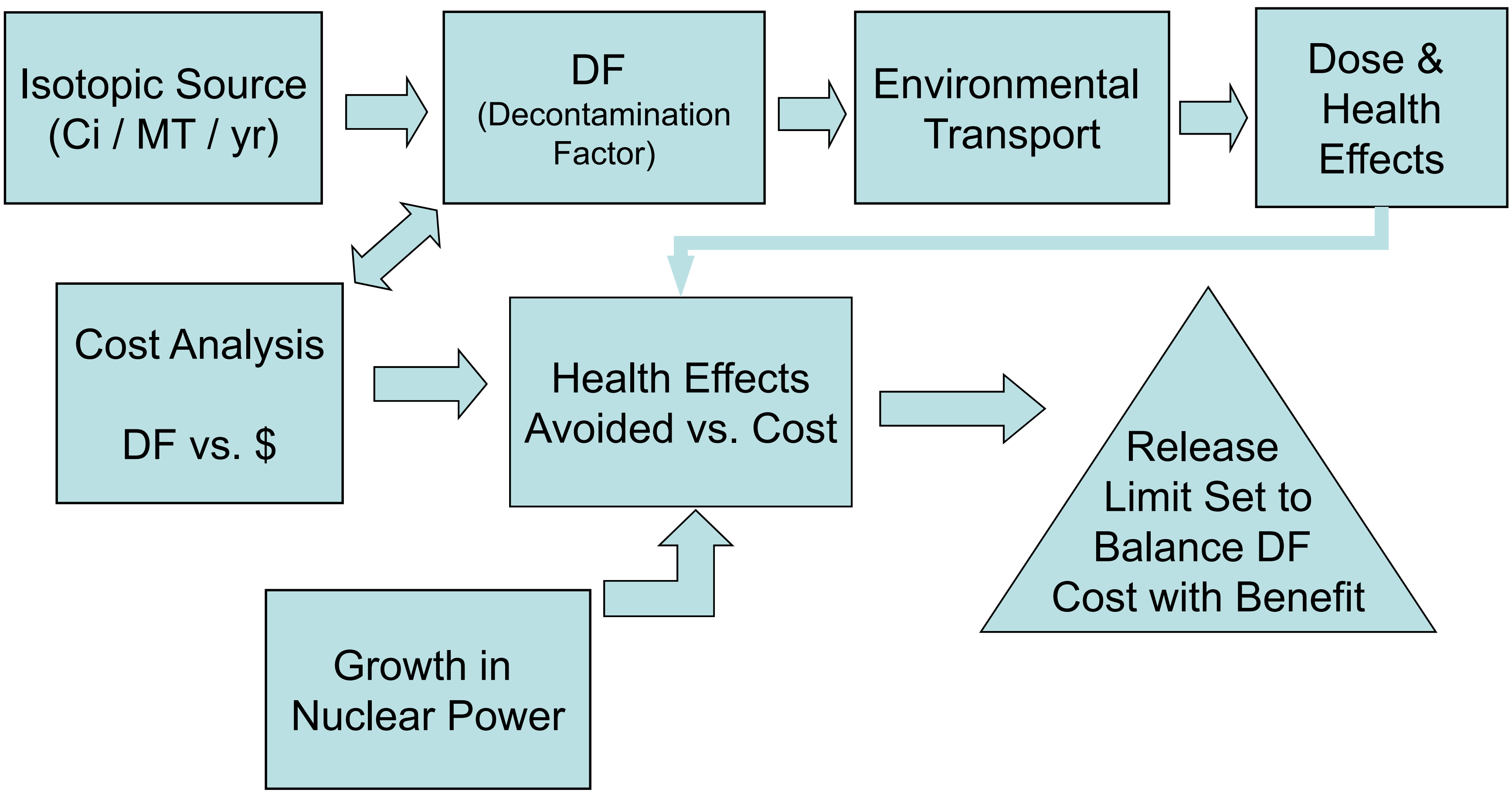
EPA concerned about build-up of persistent isotopes (I-129, Kr-85, etc) especially in light of growth projections for nuclear power

- ***I-129 produced – 1000mCi/GWe-yr***
- ***Kr-85 produced – 300,000Ci/GWe-yr***
- ***Release limits for I-129 & Kr-85 could be difficult to meet in a cost-effective manner***

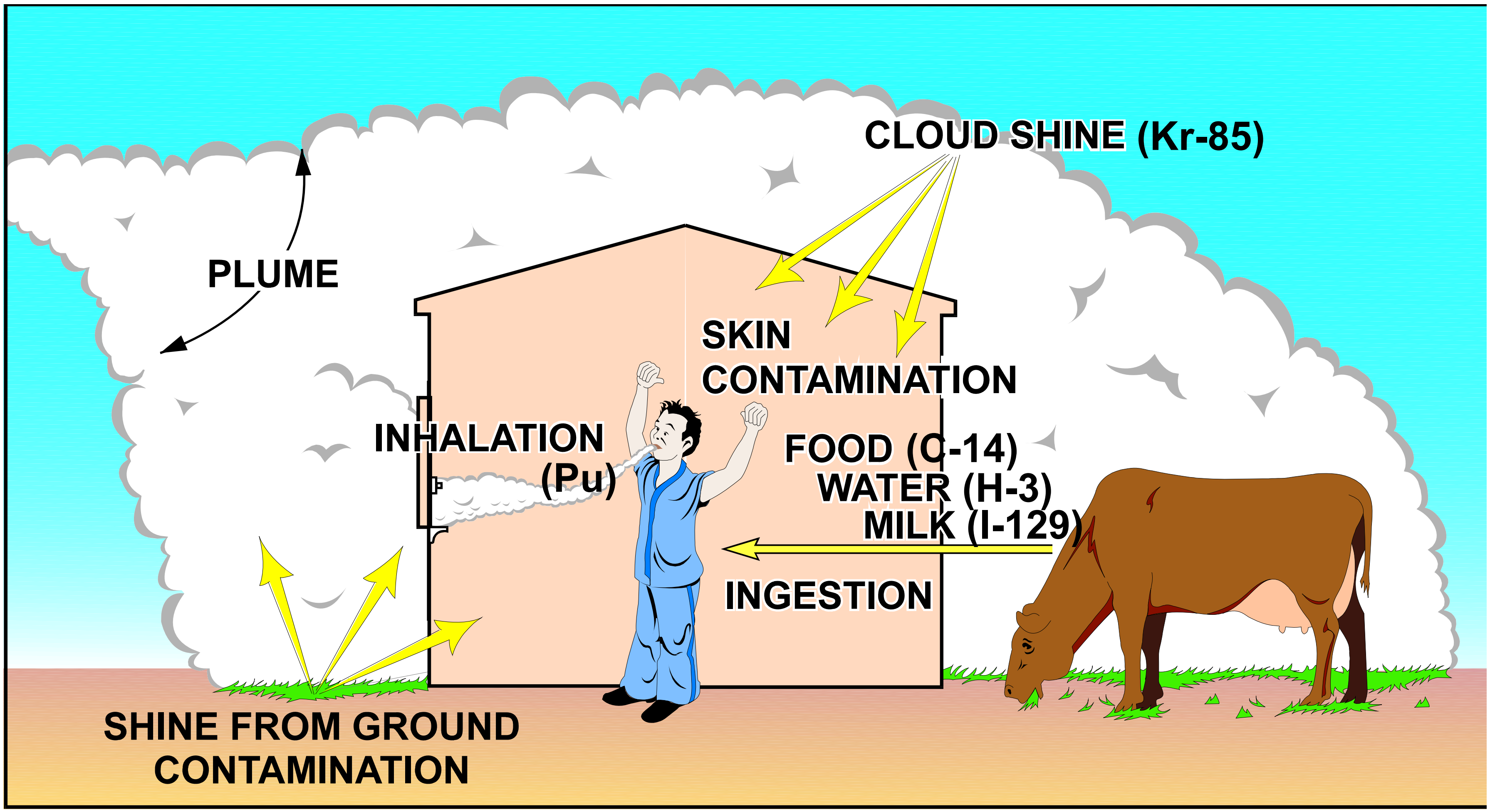
EPA Methodology

- **Final Environmental Statement and supporting technical documents provide basis for rule (1976)**
  - Assumed 2700 GWe in USA in 2020
- **EPA developed model for estimating health effect**
  - 1500 MT/yr reprocessing plant used as basic unit
  - Developed release, transport, and health effects model for isotopes of interest
    - Parametrically varied decontamination factors
- **Determined cost of decontamination systems**
  - Wide range of technologies assessed
- **Evaluated cost versus effectiveness (as measured by health effects avoided)**

Overview of EPA Methodology

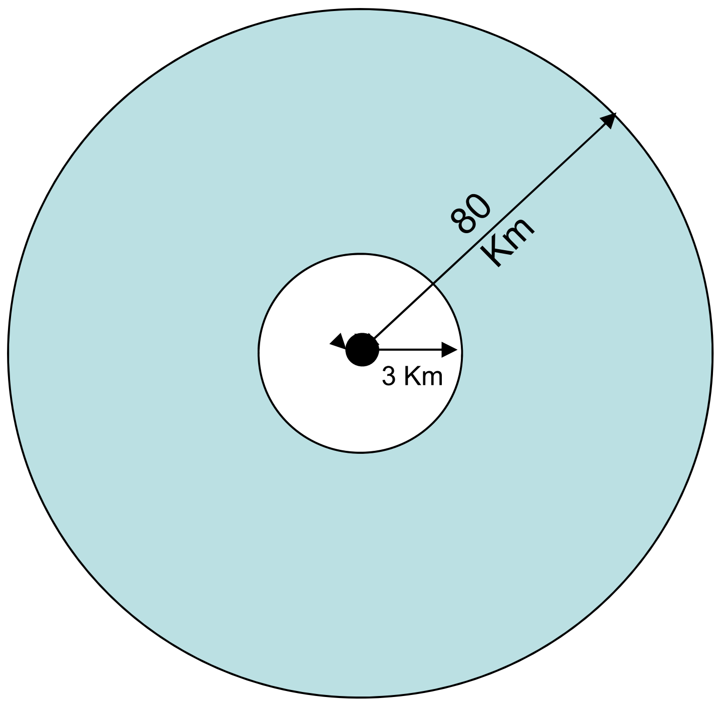


Radionuclide Pathways



Fission Product Transport in Region Surrounding Reprocessing Plant

- Annual-average dilution factors (X/Q) used to determine
  - Dose at 3 km (2 mi) from plant (nearest population)
  - Average dose within 80 km (50 mi) from plant
- Assumptions
  - Continuous release from 1500 tonne/yr plant
  - Population doubles over plant lifetime of 40 years
  - Lifetime doses are constructed by integrating over 40 years
  - Health effects are proportional to dose (HE = RF • D)



Initially (1980) 1.5 million people in surrounding region

Health Effects for U.S. Population from Kr-85

Assumes Kr "cloud" makes one pass over Eastern U.S.

- **Effects are uniform**
- **Exposure pathway is immersion**

Accounts for population growth in U.S.

Health Effects for World from Kr-85

Kr uniformly dispersed in entire atmosphere.

World population is exposed by immersion

Health effects calculated using "Collective Dose"- 2 μRem to 4 billion people

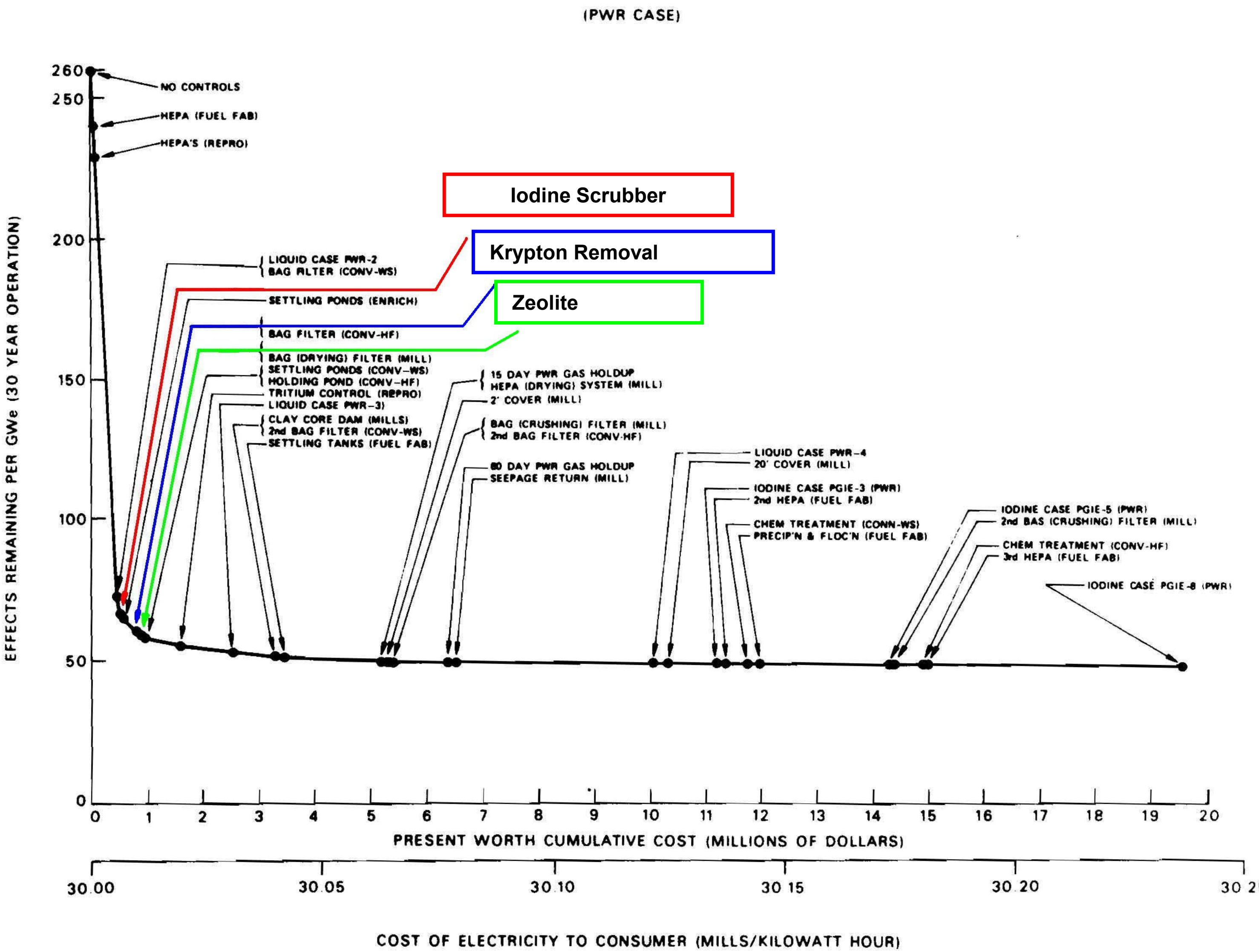
Individual and Collective Doses

Collective and Individual Annual Doses from 1500 MT/yr Plant								
		3 km	Regional	Regional	US	US	World	World
Radionuclide	Organ	mrem/yr	Person-rem/yr	µrem/yr	Person-rem/yr	µrem/yr	Person-rem/yr	µrem/yr
Kr-85	Effective	0.37	24	10	560	2	7900	2
H-3	Effective	3.2	200	89	3900	16	1000	0.2
I-129	Thyroid Infant	1400	28000	12000				
	Thyroid Adult	400	12000	5000				

Calculated Health Effects for 1500 MT/yr Plant

		Estimated Health Effects Based on LNT from 40 Years of Operation of 1500 MT/yr Plant				
Radionuclide	Organ	3 km	Regional	US	World	Total
Kr-85	Effective	6.0 E-6	0.38	6.4	130	140
H-3	Effective	5.2 E-5	3.2	62	24	90
I-129	Thyroid Adult	7.4 E-2	2	12		

Cost Effectiveness of Decontamination Technologies



DFs Implied by EPA Standard

- **Based on this analysis EPA concluded that the following would be appropriate**
  - DF=1000 for I-129
  - DF=10 for Kr-85
  - DF=1 for T-3 and C-14 because of insufficient control measures at that time
- **It appears that actual limits added margin**
  - DF needed for I ~200
  - DF needed for Kr ~5

Envisioned Benefit of “New” Standard

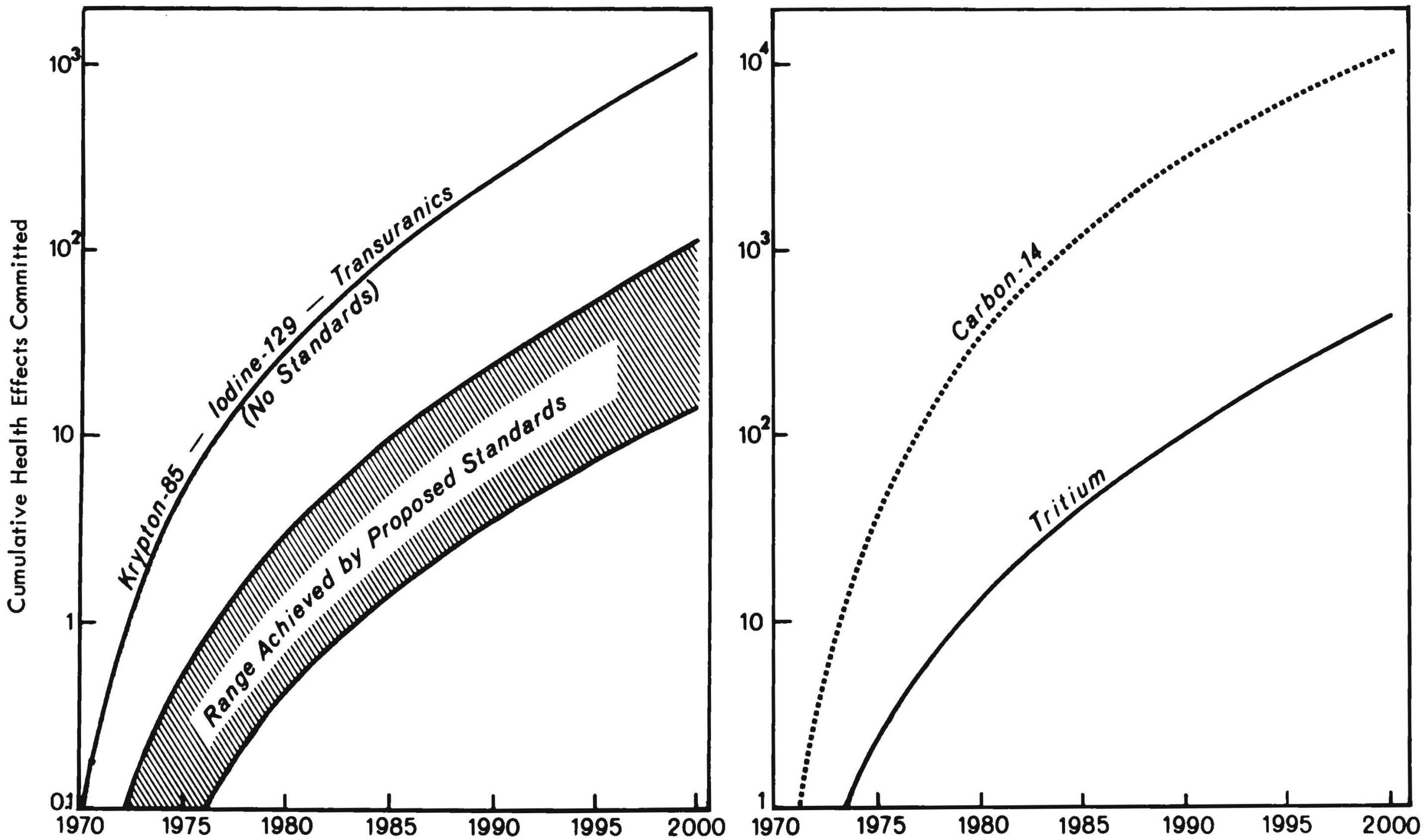


Figure 11. Projected health effects attributable to releases of long-lived radionuclides. Health effects are projected for 100 years following release only, and the exclusive use of uranium fuel is assumed.

What's Changed Since 1976?
(Besides Nuclear Gwe)

- Inventory of Radionuclides
- Dose Conversion Factors / Health Effects Modeling
- Cooling Time Assumptions
- Decontamination System Costs

Global Build-up of Kr-85

“Actual” environmental burden uses historic global growth, no controls

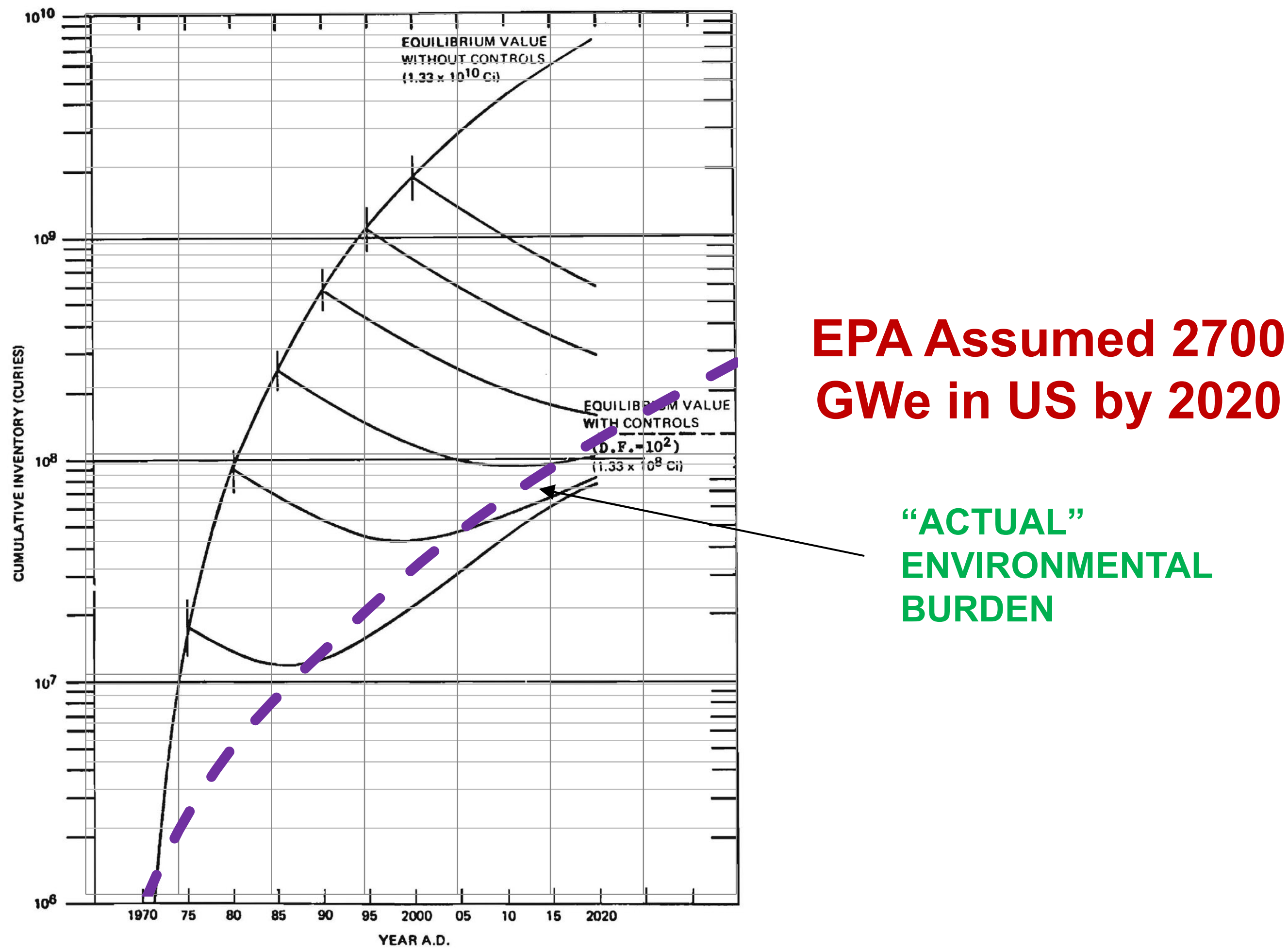


FIGURE 8. PROJECTED ENVIRONMENTAL BURDENS OF KRYPTON-85 FROM THE UNITED STATES NUCLEAR POWER INDUSTRY FOR CONTROL INITIATED IN VARIOUS YEARS. THE EQUILIBRIUM VALUES ARE THOSE FOR MAXIMUM POWER PRODUCTION EQUAL TO THAT PROJECTED FOR THE YEAR 2020.

Actual global capacity growth From www.eia.doe.gov, Table 27

Evolution of Dose Conversion Factors

Dose Conversion Factors

(rem•cm^3/yr/μCi)

	ICRP- 8 (1970)	*ICRP-72 (2008)*	*Ratio*
Kr	**15,000**	**28,000**	**2**
H-3 (ingestion)	**100**	**55**	**1/2**

Effect of Fuel Cooling Time

Longer Cooling Time is Beneficial for Kr

Isotope	*Fuel Cooling Time (yrs)*	*mCi per GWY(e) in Fuel*	*40CFR190 Quantity Limit (mCi)*	*Required DF to meet Standard*
Kr-85	**4**	**2.21E+08**	**5.00E+07**	**4.5**
Kr-85	**10**	**1.50E+08**	**5.00E+07**	**3**
Kr-85	**27**	**5.00E+07**	**5.00E+07**	**1**
I-129	**27**	**9.32E+02**	**5.00E+00**	**190**

Table assumes 50 GWd fuel burn-up

Financial cost of compliance (2008 dollars)

		EPA 1500 MTHM/yr		INRA 800 MTHM/yr
Isotope	Technology	Annual Operating Cost Estimate	Capital Cost Estimate	Capital Cost Estimate
I-129	Silver zeolite beds & voloxidation	$ 1.8 M	$ 16 M	$ 300 M
Kr-85	Cryogenic Distillation	$ 6.1 M	$ 120 M	$ 1.0 B

Industry cost estimate is greater than 10 times that of EPA's

Observations on EPA Methodology

- **Obviously, the growth in nuclear power projected in 1970 has not been met (10x lower)**
- **EPA dose and health effects model is conservative, but is not significantly different from current methods**
- **There has been no major change in assessing biological effects of radiation**
- **Need realistic cooling time assumptions (Kr-85)**
- **Cost basis for decontamination technologies seems overly optimistic (10X lower)**
- **EPA results are dominated by collective dose model**

Collective Dose Model

- **Collective dose calculated with linear no-threshold dose response is frequently used in studies comparing technology options (e.g., PEIS)**

- **However, its use in an absolute sense leads to unrealistically high number of cancers and has been a subject of debate for decades.**

- **For dose standards, it is preferable to use Maximum Exposed Individual as the metric**

What would be acceptable effluent management approaches?

- **25 mrem/yr at site boundary would still seem to be relevant**

- **Some degree of sequestration of I-129, H-3, C-14 might be advisable**
  - Ocean disposal probably not an option
  - Public concern about H-3 releases might be raised
  - Capture, store, and geologically store majority and release some fraction might be an option
  - Worker doses may become a problem without radiological controls

- **Recycling of older fuel helps mitigate expected doses**
  - Kr-85 no longer is an issue (probably is not a real issue in any case)
  - Tritium decay would also be significant
  - Unlikely that industry could build enough recycling plants to even deal with backlog

- **Issues with recycling older fuel**
  - Utilities might desire hotter fuel removed first
  - Fissile quality of recycle product degrades with build up of Am-241

Summary

- **Collective dose method drives the regulation**
  - This is especially true for world-wide projections
  - Need to develop an alternate approach

- **Cost estimates for decontamination systems should be re-evaluated**

- **Realistic growth curves for nuclear power should be incorporated into analysis**

- **Need to develop a holistic approach for effluent control**

Questions?

Extra Slides

General Form of Dose and Risk Calculations

$$D \sim Q \cdot 1/DF \cdot TF \cdot DCF \cdot P$$

$$HE = RF \cdot D$$

Symbol	Description	Units
D	Dose	rem or person-rem
Q	Isotopic Source (Material at Risk)	Ci
DF	Decontamination Factor	dimensionless
TF	Environmental Transport Factor	dimensionless
DCF	Dose Conversion Factor	Rem/Ci
P	Population	Persons
HE	Health Effects	Cancers, fatalities, etc.
RF	Risk Factors	Health Effects/rem

Evolution of Health Effects Modeling

DOCUMENT	DATE	"NATURAL" U.S. BACKGROUND	Kr-85 EXPOSURE ESTIMATES (MREM)	DOSE RESPONSE MODEL –EXPOSURE
Second Life Style Symposium	1941			0.1 µg Ra body burden 1E-11 Ci/liter in surrounding air
Chalk River Meeting	1953			15 mrem/year uniformly distributed throughout the body
ICRP 8	1965	80 to 100 mrem/year		
BEIR I	1972	180 mrem/year natural+medical +fallout+nuclear power	4E-4/person in 1970 4E-2/person in 2000	5.68E-4 LCFper rem-year per LCF in general population; 1.15E-4LCF per rem-year
Fuel Cycle EIS	1973	200 mrem/year natural+medical +fallout+nuclear power	0.38 mrem/y whole body; 13 mrem/y skin; PROJECTED	1.5E-3/rem/year to U.S. population
UNSCEAR	1977			4.03-4/ rem/year: relative; 1.58E-4 absolute
BEIR III	1980	210 mrem/year natural+medical +fallout+nuclear power	2.1E-2/person in 1970 1.7/person in 2000	1.69E-4/ rem/year: relative; O.67E-4 absolute
BEIR V	1990	360 mrem/year natural+medical +fallout+nuclear power		5.6E-4/ rem/year relative
ISCORS Technical Report 1	2002			6E-4/ rem/year relative
BEIR VII	2006	365 mrem/year natural+medical +fallout+nuclear power		**6.1E-4/ rem/year relative**