Key Solutions

C-14 – A Historical Perspective

Jim Key

Key Solutions, Inc.

www.keysolutionsinc.com

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Early Industry Documents Relating to C-14 at LWRs

- EPA 520 – "Health Impact Assessment of Carbon-14 Emissions From Normal Operations of Uranium Fuel Cycle Facilities," Fowler and Nelson - 1979.
- "Scenarios of ^{14}C Releases to the Atmosphere by the World Nuclear Industry and Estimated Radiological Impacts." Till and Killough – 1978.

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Assumptions – CO_2 Levels

- Anthropomorphic CO_2 Levels
  - Would Continue to Increase as Predicted
  - Seuss Effect
  - Fossil Fuels Would Be Exhausted by 2200

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Seuss Effect

- CO_2 released to the atmosphere from the combustion of fossil fuels is depleted of C-14.
- Increase in airborne CO_2 results in a decrease in the specific activity of C-14 in the carbon cycle.
- Effect is to reduce the long-term environmental dose impact from C-14.
- Projected increases in CO_2 levels were predicted to impact the specific activity of C-14 in the atmosphere.

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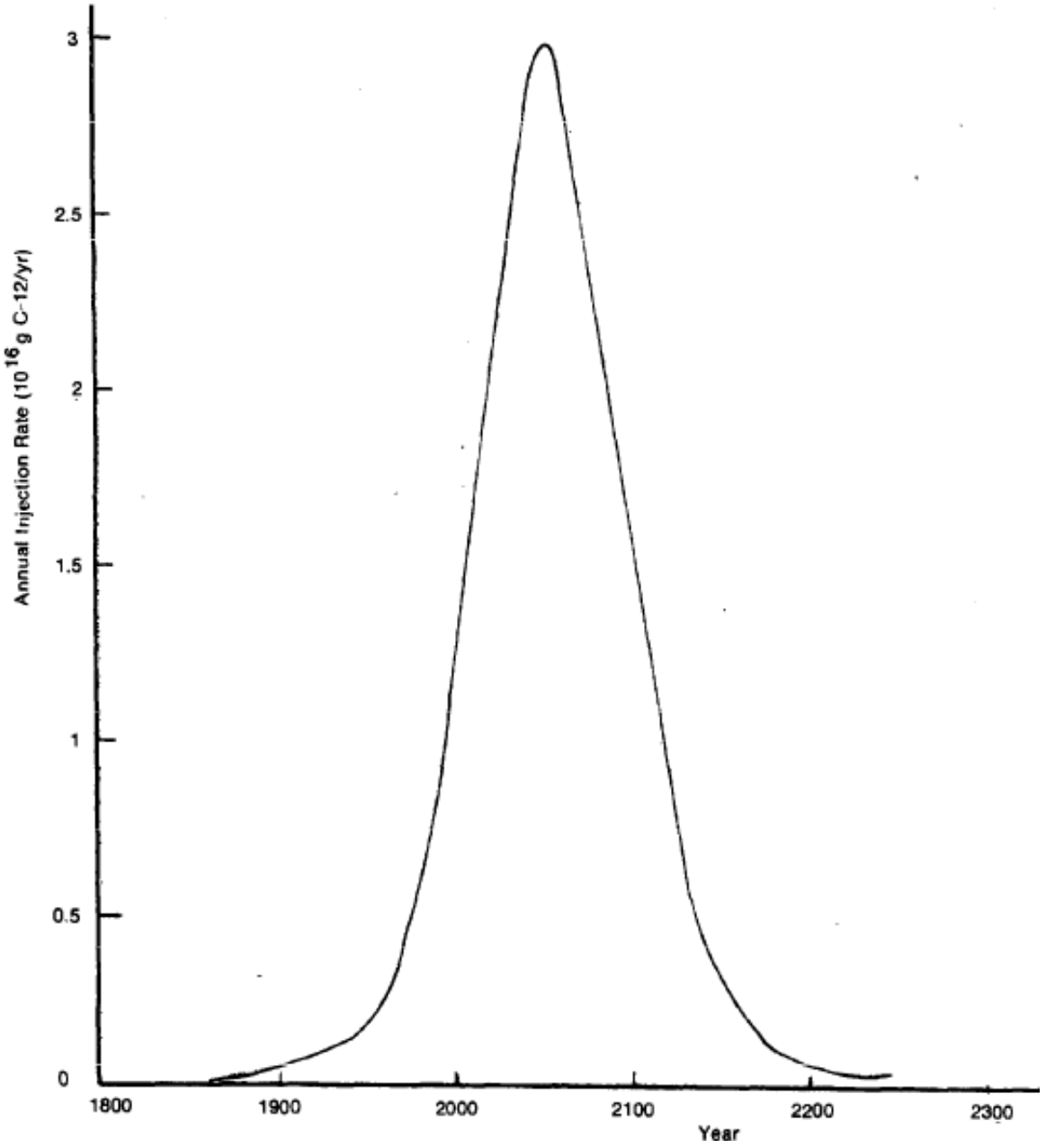
Predicted Annual Atmospheric Injection Rate of CO_2
10^{16} g C^{12}/yr



[Fowler – 1979]

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Global Environmental C-14 Inventory Assumptions

- Natural Global Steady State 2.4×10^8 Ci
- Equilibrium Throughout All Environmental Transport Compartments
- Environmental Distribution
  - Deep Ocean (below 100m) 90%
  - Surface Water, Sediments and Biosphere 8%
  - Atmosphere 2%

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Predicted Contributions to the C-14 Global Inventory - Year 2000

- Natural Steady State 240 MCi
- Weapons Testing 64 MCi (25% Natural)
- Nuclear Power 0.7 MCi (0.3% Natural)

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Assumptions - NPG

- Growth in US and World Nuclear Power Production Would Continue as Predicted
- LWR Would Be Predominate Nuclear Power Source Until Year 2000
  - Capacity Factor – 0.75
  - US
    - 1/3 BWR
    - 2/3 PWR
  - World
    - ½ BWR
    - ½ PWR
- Fuel Reprocessing Would be Taking Place Across the LWR Industry

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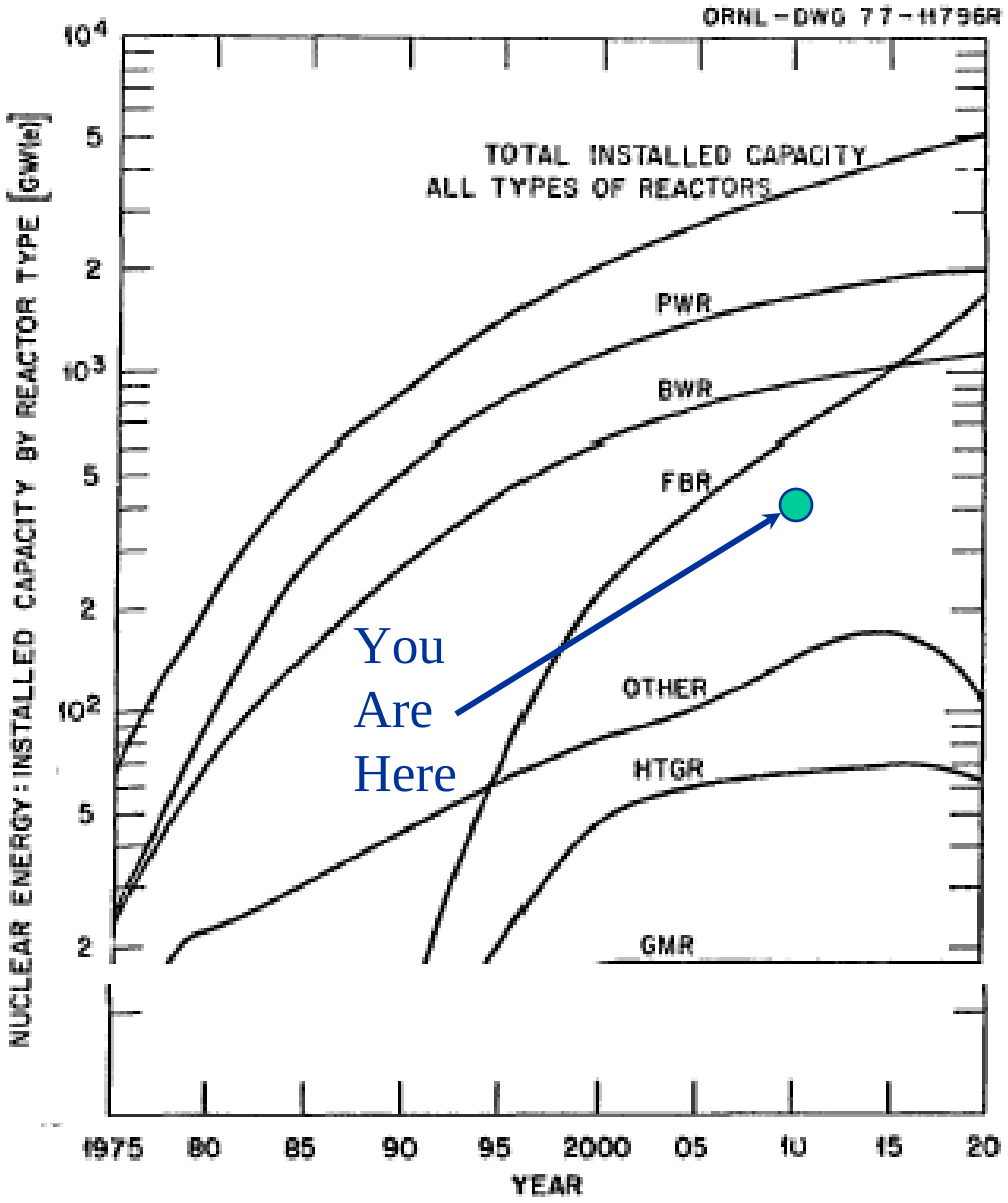
Projected World Wide Installed Nuclear Capacity GW(e)

Current Installed Capacity ~ 400 GW(e)



[Till – 1978]

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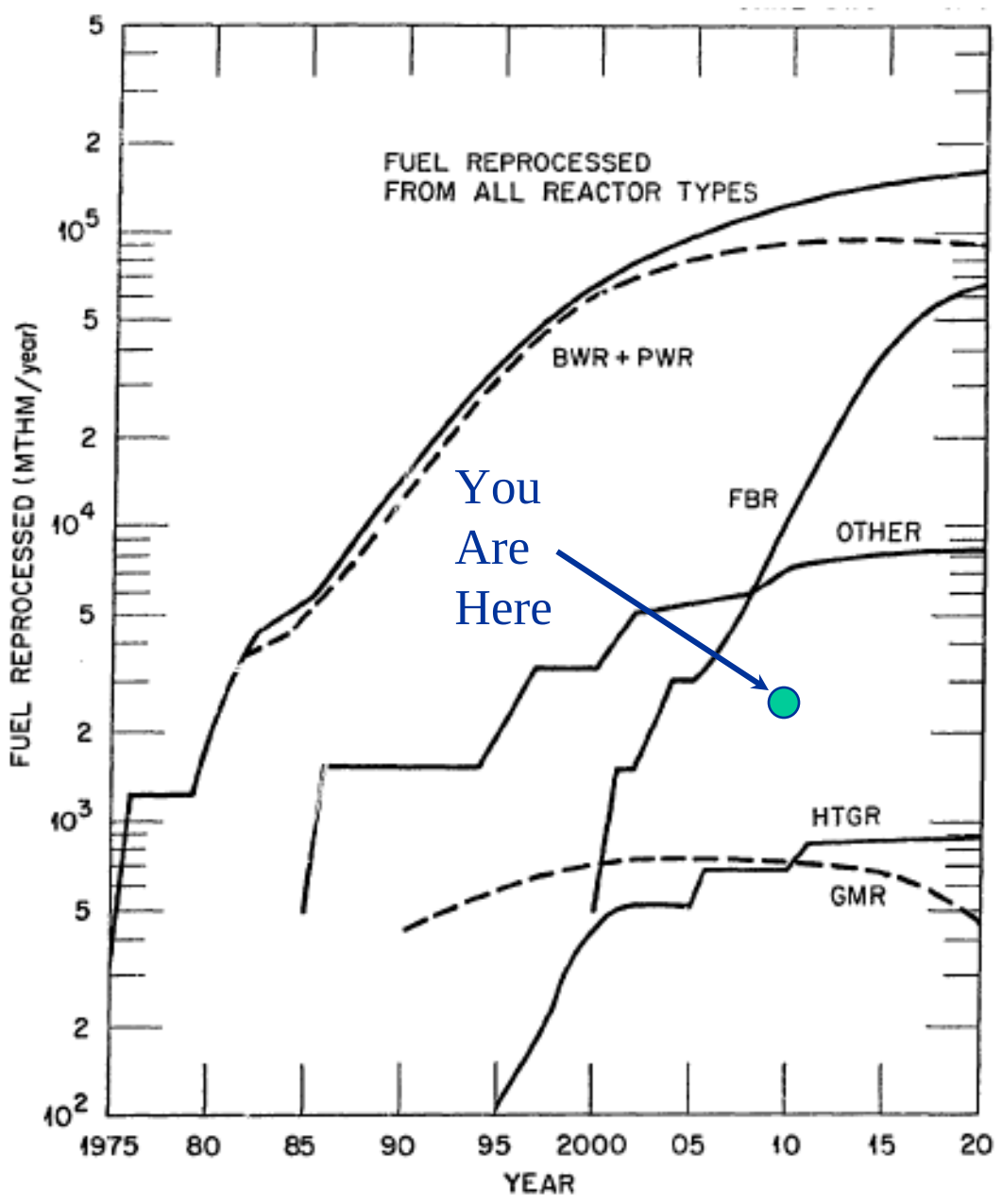
Projected Fuel Reprocessing 1975 – 2020

(Metric Tons Heavy Metal per Year)



[Till – 1978]

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Assumptions – C^{14} Production

- Production in Fuel
- Production in Core Hardware
- Production in Cooling Water

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C-14 Production - Ci/GW(e) -yr

Reactor	In Fuel	Cladding and Core Hardware	In Coolant		Total Calculated
			Calculated	Observed	
BWR		**43.3 – 60.4**	**4.7**	**8**	
Low Value	**9.0**				**57**
Median Value	**17.6**				**74**
High Value	**46.3**				**111**
PWR		**30.5 – 41.6**	**5.0**	**6**	
Low Value	**9.6**				**44**
Median Value	**18.8**				**59**
High Value	**49.5**				**96**

[Davis – 1977]

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Carbon-14 Source Term Assumptions

Source Term Facility	Atmospheric Release of C-14 (Ci/yr)
LWR Fuel Reprocessing	830
PWR	5
BWR	9

[Fowler – 1979]

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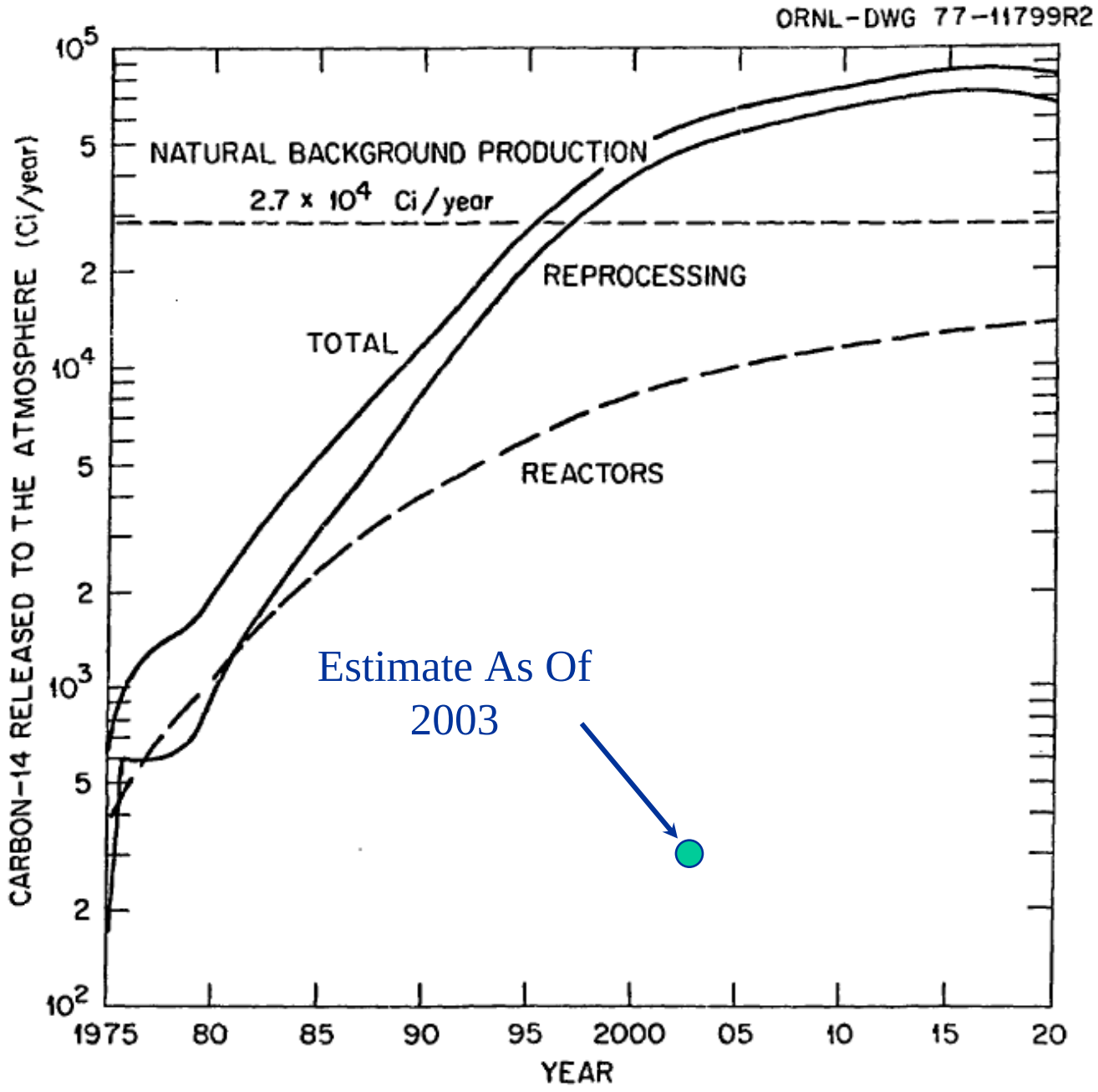
Projected Worst Case C^{14} Release Rate to the Atmosphere (Ci/yr)

Assumes no attempt to mitigate C^{14} atmospheric discharges



[Till – 1978]

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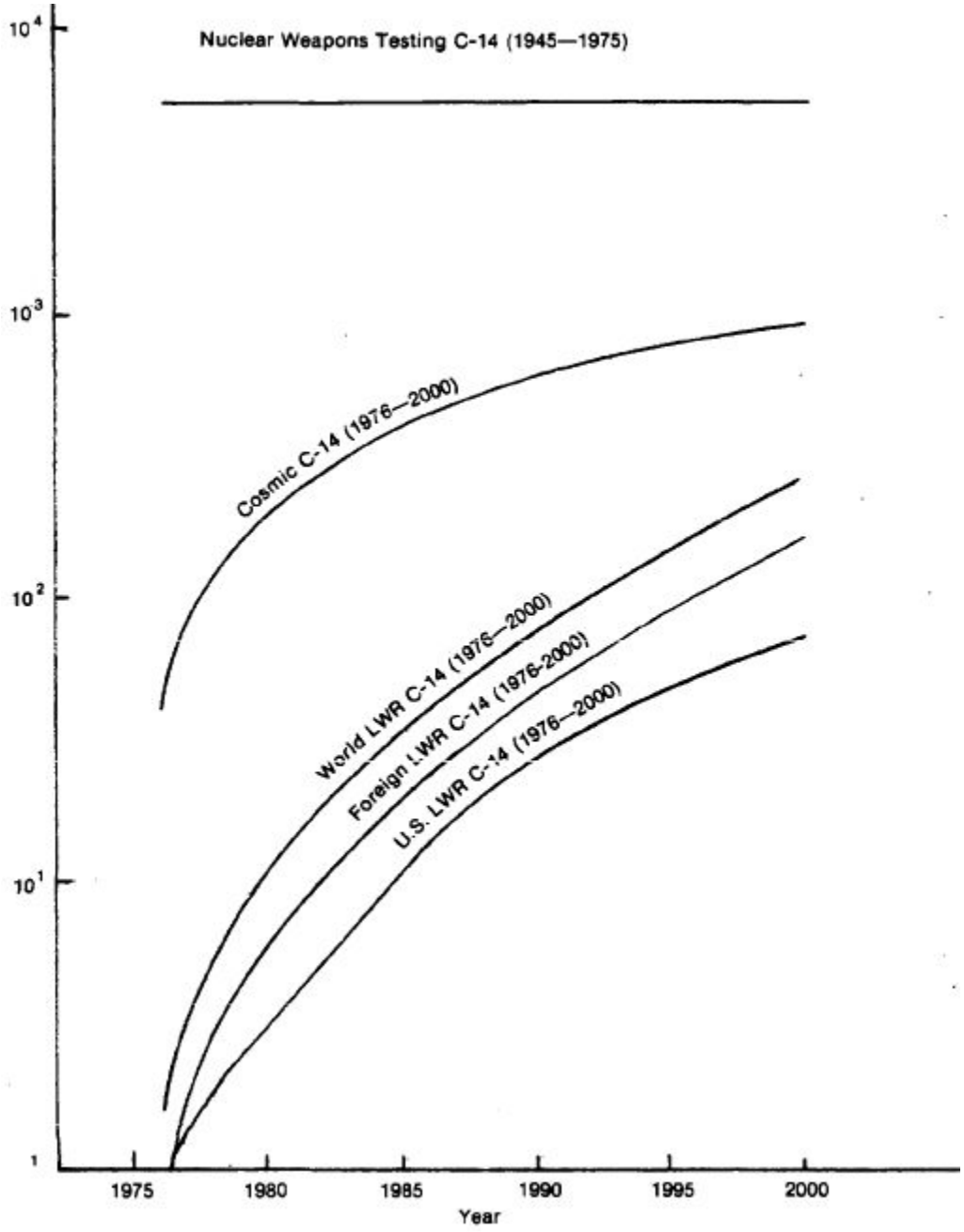
Predicted Cumulative Atmospheric Releases of C-14 (kiloCuries)



[Fowler - 1979]

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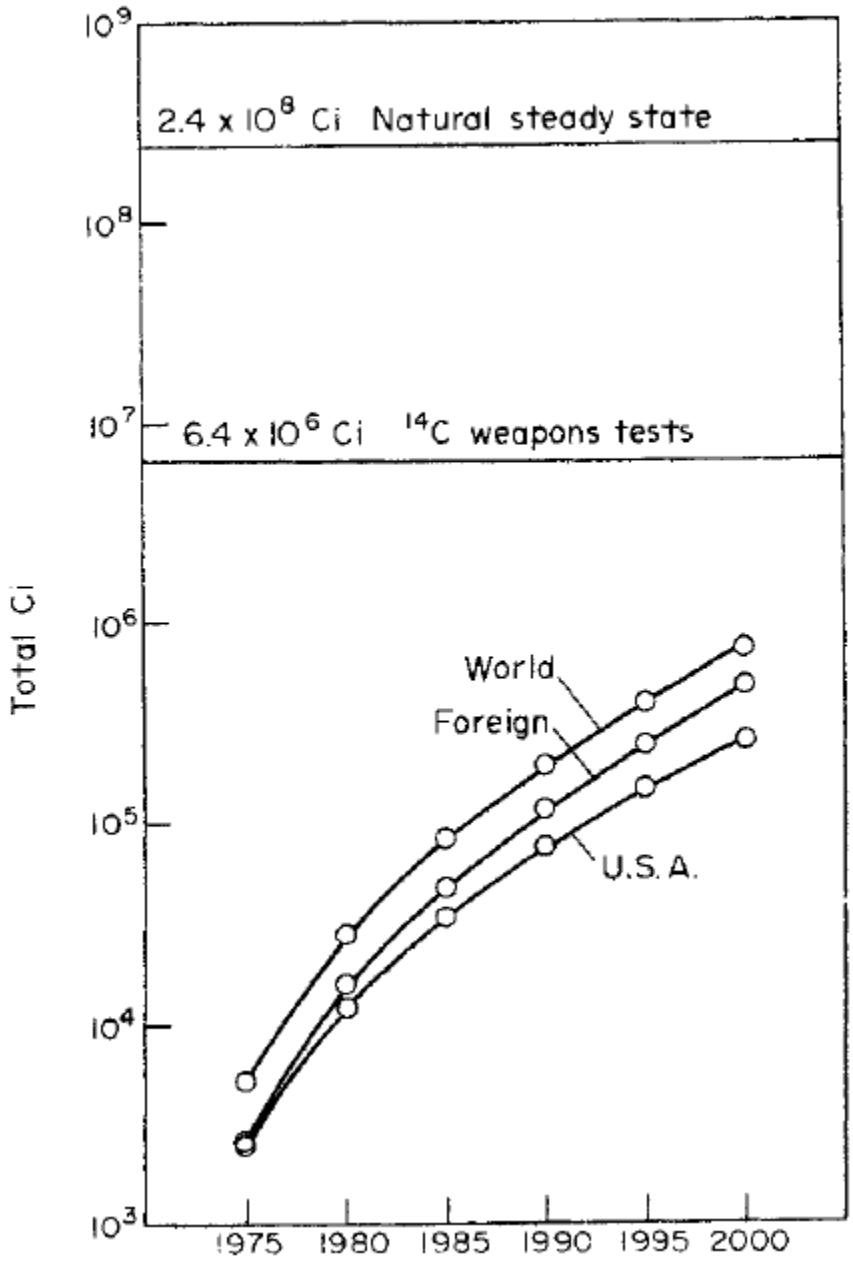
Predicted Cumulative Atmospheric Releases of C-14 (Curies)



[Hayes – 1977]

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From Eisenbud – 1973
Where's the C-14?

TABLE 11–1

COMPOSITION OF TYPICAL BWR AND PWR SPENT FUELS AT 30,000 MW DAYS/METRIC TON URANIUM AFTER 150 DAYS COOLING[a]

Spent fuel	Composition (per ton)
Plutonium	10 to 12 kg
Gross β,γ	5×10^6 Ci
^{90}Sr	98,000 Ci
^{85}Kr	8,400 Ci
^{3}H	375 Ci
^{131}I	2.2 Ci
^{129}I	0.03 Ci

[Eisenbud - 1973]

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From Eisenbud
Where's the C-14?

TABLE 11-2

RADIONUCLIDES DISCHARGED FROM NUCLEAR FUEL SERVICES REPROCESSING PLANT, MAY–OCTOBER, 1969[a]

Nuclide	Curies discharged	Nuclide	Curies discharged
^{3}H	1.7×10^{3}	^{95}Zr	4.6×10^{-3}
^{106}Ru	5.2×10^{1}	^{60}Co	2.0×10^{-1}
^{137}Cs	8.0	^{125}Sb	5.9×10^{-1}
^{134}Cs	2.0	^{54}Mn	2.7×10^{-3}
^{90}Sr	8.3	Pu (α)	1.8×10^{-3}
^{144}Ce	1.6×10^{-1}	U (α)	3.2×10^{-2}
^{147}Pm	9.2×10^{-2}	Gross α	4.8×10^{-2}
		Gross β	8.2×10^{1}

[Eisenbud - 1973]

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From Eisenbud - Where's the C-14?

TABLE 11–4

DOSE COMMITMENT ACCRUED IN 1968 FROM ALL MAN-MADE SOURCES IN THE VICINITY OF THE NUCLEAR FUEL SERVICES PROCESSING PLANT[a]

Radio-nuclide	Critical organ	Media	Dose commitment[b] (mrem) Typical individual	Dose commitment[b] (mrem) Maximum individual
^{90}Sr[c]	Bone	Diet[d]	77	90
		Deer	1.9	227
		Fish	16	215[e]
^{137}Cs	Whole body	Diet	1.7	4.5
		Deer	1.6	200[f]
		Fish	0.2	8.6
^{134}Cs	Whole body	Deer	0.4	48
^{60}Co	G.I. tract	Deer	<0.01	0.2
		Fish	0.05	0.5
^{106}Ru-Rh	G.I. tract	Fish	0.9	16.4
^{3}H	Whole body	Diet	<0.1	0.3
		Deer	0.1	0.3
		Fish	<0.01	0.3
		Drinking water	<0.17	1.0
		Air (Inhalation and skin absorption)	<0.05	0.1
^{85}Kr	Whole body	Submersion in air	0.05	0.3

[Eisenbud - 1973]

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Anticipated Dose Impact

- Studies examined impact of releases from the entire LWR fuel cycle.
- Highest releases were expected from fuel reprocessing ~ 66% of C-14 source term.
  - Majority of releasable reactor produced C-14 stays in the fuel.
  - Cutting open fuel bundles during the reprocessing was expected to release 100% of the fuel bound C-14 resulting in the release of substantial amounts of $^{14}CO_2$.

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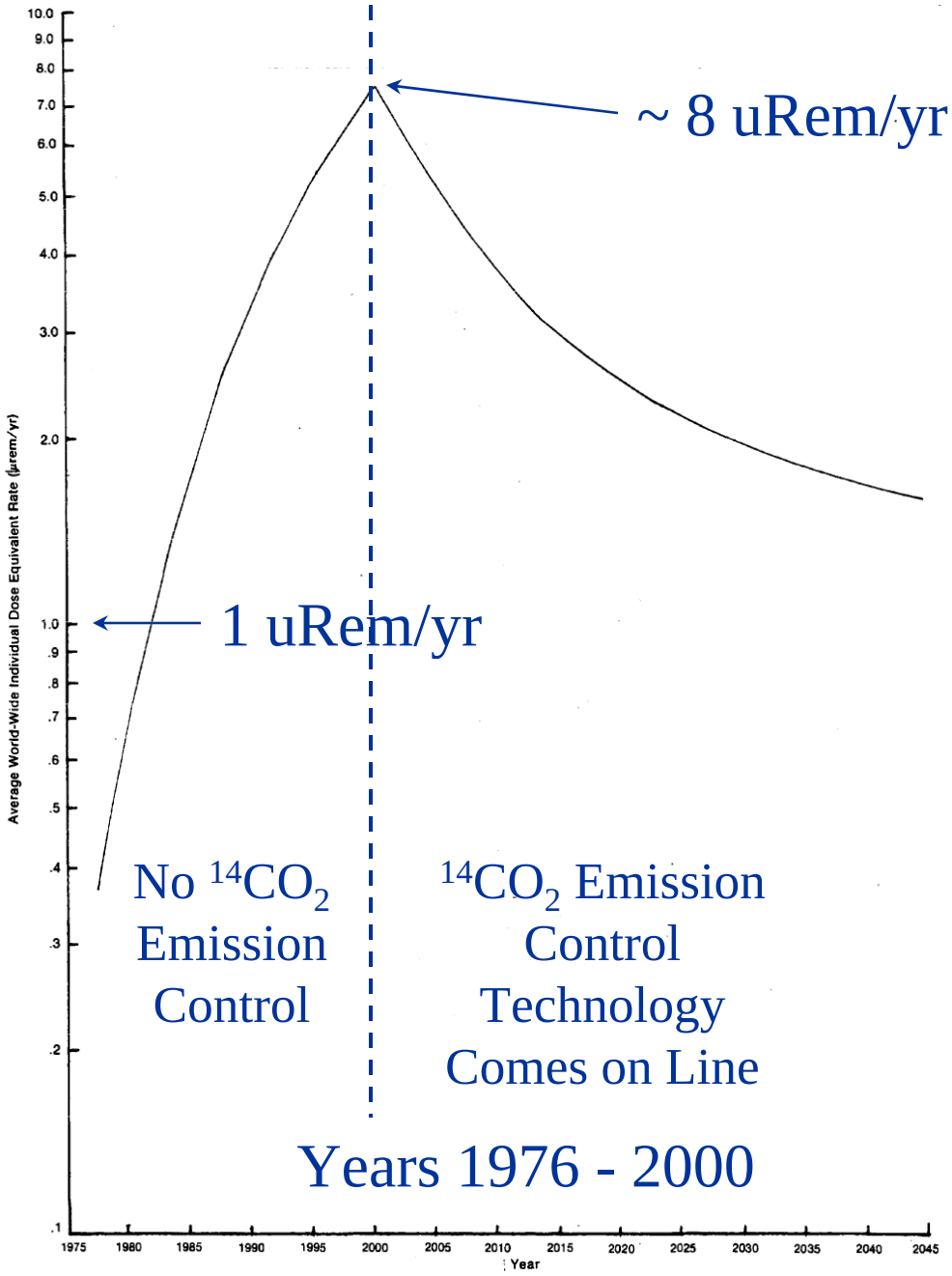
Average Individual Total Body Dose Equivalent Due to C-14 Releases from U.S. LWR Cycle Including Fuel Reprocessing (μRem/yr)



[Fowler – 1979]

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Average World-Wide Individual Total Body 70-Year Lifetime Dose Equivalent Due to Carbon-14 Releases

Carbon-14 Source Term	Average Individual Total Body Lifetime Dose Equivalent (mrem)
US LWR Nuclear Industry Releases 1976-2000	0.13
World LWR Nuclear Industry Releases 1976-2000	0.67
Cosmic C-14 Produced During 1976-2000	2.8
Cosmic C-14 Steady State	91
Nuclear Weapons Testing 1945-1974	11

[Fowler – 1979]

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Total Body Dose Equivalent Rates for Airborne Emission From BWR and PWR Facilities

Facility	Maximum Individual (mrem/yr)	Average Individual (mrem/yr)	Regional Population (man-rem/yr)
BWR			
All radionuclides	1.8	3.5E-03	8.6
C-14 only	0.41	5.6E-04	1.4
PWR			
All radionuclides	0.78	2.3E-03	5.7
C-14 only	0.23	3.1E-04	0.78

[Fowler – 1979]

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UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C.

November 20, 1981

Dr. Sudhakar Pandey
Franklin Research Center
Benjamin Franklin Parkway
at Twentieth
Philadelphia, Pennsylvania 19103

Dear Dr. Pandey,

As a result of our recent meeting with the Atomic Industrial Forum working group, it has been decided that the following changes could be made in the RETS requirements.

First, the requirement of 3.11.2.3 to account for doses from C-14 may be dropped. Our data show that C-14 will not make a significant contribution to the doses.

[Willis – 1981. Correspondence excerpt.]

Key Solutions

References

Davis, D. (1977). Carbon-14 Production in Nuclear Reactors, Oak Ridge National Laboratory. ORNL/NUREG/TM-12.

Eisenbud, M. (1973). “Environmental Radioactivity” Academic Press, New York.

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Till, J. E. & Killough, G. G. (1978). “Scenarios of 14C Releases to the Atmosphere by the World Nuclear Industry and Estimated Radiological Impacts.” In: *Tagungsbericht Radioaktivität und Umwelt, 12.* Jahrestagung, Norderney, 2.–6. Oktober 1978, Fachverband für Strahlenschutz e.V.: 680–695. Norderney, Federal Republic of Germany.

Willis, C.A. (1981). Letter to Pandey, S. Franklin Research Center, Philadelphia, PA, November 20, 1981. US NRC, NRR.