Conf-701205--2

NUCLEAR POWER AS A SOURCE OF CONTAMINATION
ON A GLOBAL SCALE

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December 1970

Paper to be presented to the State of Washington Ecological Commission on December 15, 1970, Richland, Washington.

This paper is based on work performed under United States Atomic Energy Commission Contract AT(45-1)-1830.

RECEIVED BY DTIC FEB 4 1971

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Introduction

There is not a single doubt that our world depends on electrical power to maintain and advance the standard of living of the population. How will we meet the growing demands for electrical power? Increased use of fossil fuel and the development and use of nuclear fuels seem the only practical way to meet our power needs for the next 30 to 50 years. Both fossil and nuclear fuels will see increasing use by the year 2000. The control and treatment of waste from both fossil and nuclear fuels are required to establish a quality environment in which to live.

Power Needs

The U.S. electrical power requirements through the year 2000 are summarized in Table I.

Table I

U.S. Electrical Power Requirements

<u>Year</u>	<u>Total Electrical Power - MWe</u> ⁽¹⁾	<u>Nuclear Generated Electrical Power - MWe</u> ⁽²⁾
1965	250,000	1,900
1970	300,000	9,600
1980	570,000	120,000
1990	1,100,000	430,000
2000	1,600,000	1,030,000

The resources used to generate this electricity are summarized in Table II.

Table II

Electricity Generation Resources⁽³⁾

<u>Resource</u>	<u>% of Total</u>		<u>Quantities Used</u>	
	<u>1968</u>	<u>2000</u>	<u>1968</u>	<u>2000</u>
Coal	51.9	30.2	297	1,000 (million of tons)
Oil	7.0	5.5	187	800 (million of barrels)
Gas	23.2	4.8	3.1	4 (trillion of cubic feet)
Hydropower	17.3	7.0	--	--
Nuclear Power	0.8	52.5	--	--

The U.S. electrical power requirements are predicted to increase by a factor of about 5 between 1970 and 2000. The increase will be met by increases in the number of all types of generating plants. Coal consumption is predicted to increase by about a factor of 3, and oil by about a factor of 4. During this period there is not only this increase in the use of fossil fuels but also a dramatic increase in the use of nuclear fuels for the generation of electricity. Particularly, the nuclear power portion of the total U.S. electrical power generated increases from less than one percent in 1968 to nearly 53 percent in the year 2000.

Global Contaminants

The operation of a nuclear reactor for the generation of electricity, or any other purpose, results in the generation of radioactive activation products and fission products. Some of the more common of these radioactive materials are listed in Table III.

Table III

Nuclear Power Waste Products

- 1) Activation Products - ^3H , ^{24}Na , ^{41}A , ^{51}Cr , ^{55}Fe , ^{60}Co , ^{65}Zn
plus many others.
- 2) Fission Products - ^3H , ^{85}Kr , ^{90}Sr , $^{95}\text{Zr-Nb}$, ^{131}I , ^{137}Cs , ^{144}Ce
plus many others.

Waste treatment and containment practices for man-made radionuclides have kept our environment essentially free of radioactive waste. Most radioactive waste can be separated from nonradioactive materials and stored for long periods of time with safety and dependability. Table IV summarizes the waste control practices.

Table IV

Waste Control Practices

- 1) High-Level Waste. - Long-Term Storage
- 2) Medium-Level Waste - Long-Term Storage
- 3) Low-Level Waste - Concentrate and Store or Release

The ability to provide both safe and controlled long-term storage of nuclear reactor waste has been repeatedly demonstrated at various AEC installations throughout the country. High-level waste are stored in fixed configurations that assure containment and long-term isolation from the environment. Medium-level waste received similar treatment although the

degree of confinement may be relaxed under certain favorable conditions. Medium-level waste are commonly processed to result in a high-level waste concentrate and a low-level waste residue. Low-level waste may be concentrated and then stored as high-level waste or if conditions are suitable, they may be released to the environment. Monitoring and confinement surveillance is a part of each waste control practice and can provide an early signal for corrective action if any abnormality is found.

In view of the effective nuclear waste control programs, what is the resultant global contamination that may arise from nuclear power? There are two radionuclides that result in world-wide or global contamination--tritium and krypton-85. The factors contributing to this situation are summarized in Table V.

Table V

Why Tritium and Krypton-85?

- 1) Generation Rate
- 2) Half-Lives
- 3) Ease of Dispersion
- 4) Release Practices

The generation rate (fission yield) of both tritium and krypton-85 in nuclear fission is high enough to lead to appreciable quantities of these radionuclides. Of course, tritium generation as an activation product also adds to the total quantity available for global distribution.

The half-lives of tritium (12.26 years) and krypton-85 (10.76 years) are long enough to result in their global distribution and buildup. Other radionuclides that may be present in larger initial quantities and are released rather than retained for long-term storage generally decay too rapidly to become distributed on a global scale. Also, both tritium and krypton-85 are present in forms readily amenable to global dispersion. Tritium as tritium water vapor or water can mix throughout the world water supplies--in oceans, rivers, lakes, rain and living matter. Krypton-85 as a noble gas is dispersed throughout the atmosphere without reaction. The entire quantity released is essentially available for dilution with the global atmosphere.

The final factor that results in tritium and krypton-85 global contamination is their release from nuclear reactor stations and fuel reprocessing facilities. Current technology is not able to contain these radionuclides for economically practical expenditures. Research now in progress is showing promise for economically acceptable control equipment to prevent the release of tritium and krypton-85 to the environment. The insignificant global impact of current release practices does not bargain on technical grounds for needs to change current release practices with regard to these two radionuclides.

For current reactor technology, every 1000 megawatts of electrical power from a nuclear power plant will result in the generation of tritium and krypton-85 quantities as shown in Table VI.

Table VI

Tritium and Krypton-85 Per Day Per 1000 MWe

<u>Radionuclide</u>	<u>Generated - Ci Per Day</u>
Tritium	50-90 ⁽⁴⁾
Krypton	1,300 ⁽⁵⁾

Tritium

A) Nuclear Power - Tritium may be produced in nuclear reactors by two principle mechanisms;

- a) neutron addition to deuterium, coolant additives or control rods containing boron or lithium;
- b) generation as a fission product.

The largest source of tritium is usually in the fission of nuclear fuel. Tritium produced as a fission product is contained within the fuel elements and is released only at the time of fuel processing. Tritium may be released at a reactor site from a leakage of ordinary or heavy water or from leakage of water coolant if a boron "Chemical Shim" is used. It is estimated that about 1000 parts per million boron in the coolant water leads to tritium production at a rate about equal to the fission production of tritium.⁽⁶⁾ The use of boron and lithium in control rods also leads to tritium production.

The 12.26 year half life of tritium results in very little decay in the nuclear fuel or water while it is in the reactor system. The ability of tritium to mix rapidly with the hydrogen compounds of the environment, particularly water, leads to its rapid dispersion in the environment.

Tritium production rates and inventories at various times through the year 2000 are given in Table VII (based on current nuclear power reactor contributions to the Free World power needs).

Table VII

Free World Fission Product Tritium⁽⁷⁾

<u>Year</u>	<u>Tritium Production Rate, 10^6 Ci/Yr</u>	<u>Accumulated Tritium, 10^6 Ci</u>
1965	0.03	0.03
1970	0.1	0.3
1980	2	6
1990	6	32
2000	15	96
Steady State	15	260

If one assumes that the "Non-Free World" power production matches that of the "Free World", these quantities may all be doubled to estimate "Total World" nuclear power tritium production.

B) Natural Production

Tritium is produced naturally in the environment by the high altitude cosmic ray interactions with the atmosphere. The annual natural production rate of tritium by this process is estimated to be 4 to 8×10^6 Ci; the equilibrium inventory of naturally produced tritium in the environment is 70 to 140×10^6 Ci.⁽⁸⁾

C) Nuclear Explosives

Nuclear testing above and below ground also adds to the environmental inventory of tritium. It is roughly estimated that 1×10^7 Ci of tritium are released per megaton of fusion energy released during such testing.⁽⁵⁾ It is further estimated that nuclear testing through the mid-1960's contributed a total of 1.7×10^9 Ci of tritium to the environment.⁽⁹⁾ The limited Plowshare program has resulted in only limited quantities of tritium release compared to the weapon testing activities. The tritium release rate per megaton of Plowshare explosive should be the same as stated above for weapons testing.

D) Summary

The tritium in the environment arises from three sources; a) nuclear reactors, b) natural production and c) nuclear explosives. Table VIII summarizes the relative contributions. Note that the units are not normalized.

Table VIII

<u>Tritium Production</u>		
<u>Nuclear Power</u>	<u>Natural Production</u>	<u>Nuclear Explosives</u>
2 to 3×10^4 Ci/Yr 1000 MWe	4 to 8×10^6 Ci/Yr	1.7×10^9 Ci Total

Note that the tritium contribution from the nuclear power industry will approximate the formation rate from natural cosmic ray production when 200,000 MW of electrical power are generated annually. The nuclear power program is predicted to reach this power output about the mid-1980's.

In the year 2000, nuclear power generated tritium contributions will be about 5 times the natural production rate. Nuclear weapons testing programs of the mid-1960's have all ready put into the atmosphere about 100 times the annual production rate predicted for the year 2000 based on projected nuclear power growth. If the year 2000 nuclear power generation rate is then sustained without growth until tritium equilibrium is attained, about 80 years, the global contribution from the nuclear power industry will be about twice that currently in the environment due to past nuclear weapons testing programs.

Krypton

A) Nuclear Power

Krypton-85 is produced as a fission product and is principally released at the fuel reprocessing plants. Its half-life of 10.76 years results in little decay during the life of the reactor fuel. The noble gas properties of krypton-85 make its separation during fuel reprocessing difficult and expensive using today's technology. Krypton-85 collection technology is now being developed and appear that practical equipment for its containment will become available within the next 10 years.

Krypton-85 production rates and inventories at various times through the year 2000 are given in Table IX (based on current nuclear reactor contributions to the Free World power needs). If one assumes that the "Non-Free World" power production matches that of the "Free-World", then these quantities may all be doubled to estimate the "Total World" nuclear power krypton-85 production.

Table IX

Free World ^{85}Kr Production⁽¹⁰⁾

<u>Year</u>	<u>^{85}Kr Production Rate, 10^6 Ci/Yr</u>	<u>Accumulated ^{85}Kr, 10^6 Ci</u>
1965	0.96	0.96
1970	4.8	13
1980	62	210
1990	210	1100
2000	520	3150
Steady State	520	8100

Once released, the krypton is distributed throughout the atmosphere. Its decay scheme shows that its largest human dose contribution is one of skin exposure. Only 0.4% of its decays are by gamma-ray emission. The whole body dose rate is about 1% of the skin dose rate. One should use care in discussing krypton-85 dose rates to assure that the non-penetrating properties of most of its radiations are emphasized. It is unfortunate that unqualified statements relating to krypton-85 dose rates have been made and quite often one cannot then be sure whether the dose rate being discussed is applicable to the population genetic dose or to the skin dose.

B) Natural Production

Krypton-85 production by natural causes is so very low that one does not normally consider the presence of a "naturally" produced krypton-85 background.

C) Nuclear Explosives

Nuclear testing above and below ground also adds to the environmental inventory of krypton-85. It is roughly estimated that 3×10^2 Ci of krypton-85 are released per megaton of fusion energy released.⁽⁵⁾ Similarly, 3×10^2 Ci of krypton-85 are released per 10 kiloton of fission energy released in a nuclear explosion.⁽⁵⁾ It is estimated that nuclear testing through the mid-1960's contributed a total of 5×10^4 Ci of krypton-85 to the environment.

The limited Plowshare program has resulted in only limited quantities of krypton-85 released compared to the weapons testing activities. The krypton-85 release rate per unit of Plowshare explosive power should be the same as stated above for weapons testing.

D) Summary

The krypton-85 in the environment arises from two sources; 1) nuclear reactors, and 2) nuclear explosives. Table X summarizes the relative contributions. Note that the units are not normalized.

Table X

Krypton-85 Production

<u>Nuclear Power</u>	<u>Natural Production</u>	<u>Nuclear Explosives</u>
$\frac{1300 \text{ Ci/day}}{1000 \text{ MWe}}$	-0-	$5 \times 10^4 \text{ Ci Total}$

For krypton-85, the nuclear power industry is a major contributor to the environmental inventory. A nuclear power industry of 40,000 MWe will generate krypton-85 at an annual rate equal to the total nuclear testing

program. This level may be reached in the early 1970's. In the year 2000, nuclear power generated krypton-85 contributions will be about 10^4 times the krypton-85 quantities already in the atmosphere due to nuclear testing. If the year 2000 nuclear power generation rate is then sustained without growth until krypton-85 equilibrium is attained, about 70 years, the global contribution from the nuclear power industry will be about 10^5 times that currently in the environment due to past nuclear testing programs.

Dose Considerations

Calculations of quantities of release and inventories of the global contamination levels are meaningless until translated into some measure of effect on the world ecological system with emphasis on man. The resultant radiation dose from these global contaminants may be used to assess the consequences of present and past release practices.

Three groups are recognized as authoritative sources for radiation dose control recommendations. Internationally, the ICRP (International Commission on Radiological Protection) sets the guidance to be used. For the United States the NCRP (National Council on Radiation Protection and Measurements) establishes the guidance to be used. For installations operated by the federal government or government contractors, the FRC (Federal Radiation Council) provided radiation protection guidance until it was recently dissolved.

The guidance provided by these groups may differ slightly but for the most part their recommendations are similar. In some cases one may anticipate a time lag between changes proposed and accepted between the ICRP, the NCRP, and the FRC. Relative to the hazards in the environment, these groups have recommended the control levels as summarized in Table XI.

Table XI

Annual Dose Rate Guidance for the Public

<u>Organ or Tissue</u>	<u>Dose, rem/yr</u>				
	<u>ICRP⁽¹¹⁾</u>	<u>FRC⁽¹²⁾</u>		<u>IAEA⁽¹³⁾</u>	<u>NCRP⁽¹⁴⁾</u>
		<u>Indiv.</u>	<u>Pop. Ave.</u>		
Whole Body	0.5	0.5	0.17	0.5	0.5 ^(C)
Gonads	0.5	--	0.17	0.5 ^(B)	0.5
Red Bone Marrow	0.5	0.5	0.17	0.5	0.5
Bone	3.0	1.5	0.5	3.0	3.0
Thyroid	3.0 ^(A)	1.5	0.5	3.0	3.0
Other Single Organs	1.5	--	--	1.5	1.5

(A) If under age 16, limit is 1.5 rem/yr.

(B) Values for individuals. For whole population, gonadal dose limited to 5 rems in 30 years, or 0.17 rem/yr. ave.

(C) Dose to individual from external sources.

Table XII is a summary of the doses resultant in man due to tritium and krypton-85 release practices. Note the units in Table XII are mrem and hence are a factor of 1000 smaller than the units of rem used in Table XI. A comparison between Table XI and Table XII shows that a very small contribution to the dose guidance recommended by the various authoritative groups will arise from current and anticipated tritium and krypton-85 releases. Even if the values in Table XII are doubled to allow for "Non-Free World" contributions equal to the "Free World" contributions, the whole body dose due to tritium only reaches 0.08 mrem/yr compared to a guidance limit of 170 mrem/yr. The total contribution to human exposure is about 0.2 mrem/yr.

Table XII
Radiation Dose
Units of mrem per year

	<u>Nuclear Power</u>		<u>Natural Production</u>		<u>Nuclear Explosives*</u>		<u>Total Dose</u>	
	<u>T</u>	<u>Kr-85</u>	<u>T</u>	<u>Kr-85</u>	<u>T</u>	<u>Kr-85</u>	<u>T</u>	<u>Kr-85</u>
1970	5×10^{-5}	5×10^{-4}	2×10^{-3}	0	3×10^{-2}	2×10^{-6}	3×10^{-2}	5×10^{-4}
2000	2×10^{-3}	5×10^{-2}	2×10^{-3}	0	3×10^{-2}	2×10^{-6}	3×10^{-2}	5×10^{-2}
Equilibrium	5×10^{-3}	1×10^{-1}	2×10^{-3}	0	3×10^{-2}	2×10^{-6}	4×10^{-2}	1×10^{-1}

* Assumes nuclear explosives just maintain current atmospheric inventories.

The population, as a whole, experiences much greater dose variations due to the type of houses they choose to live in--frame vs stone or brick and due to elevation such as Denver vs Seattle (a difference of perhaps 30 mrem/yr). Even living over a granite rock formation as opposed to a sedimentary rock formation will result in an annual dose increase of about 50 mrem/yr.

Conclusions

The generation of electric power by either fossil or fissile fuels has led to the contamination of man's environment. The data examined indicates that dose contributions are expected to be about 0.2 mrem/yr for the world-wide distribution of tritium and krypton through the year 2000. The people of the world routinely subject themselves, although largely unknowingly, to annual dose variations tens and hundreds of times greater than that resulting from the nuclear power and all other sources of tritium and krypton-85 exposure.

Prudent management in the nuclear power industry would nevertheless indicate that separation and storage of these radionuclides to prevent their uncontrolled release to the environment should be a serious objective to be realized as soon as practical. Radiation exposure conditions in local areas near where tritium and krypton are released--while not discussed in this presentation--needs careful study and very likely will dictate the degree of containment required.

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