ENVIRONMENTAL CONSEQUENCES OF ATMOSPHERIC
KRYPTON-85

Progress Report, for Period

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ABSTRACT

This project examines the thesis that atmospheric background ionization is relevant to the understanding of weather. Projections of future world-wide use of nuclear energy imply that sufficient krypton-85 will be produced and may be released to significantly alter the natural ionization background. The scope of the project includes an assessment of krypton-85 on the electrical aspects of the atmosphere as well as the consequences of an altered electrical state of the atmosphere.

The results of a first approximation model for the effects of krypton-85 on the atmosphere show that the electric field at the surface of the ocean would be reduced by about 25% and at a continental station by about 15%. At about two kilometers altitude, the electric field would be reduced by about 14% over the oceans and 16% over the land. The effects decrease quickly with increasing altitude.

Analytical studies of the equations for fair weather atmospheric electricity yield solutions suitable for the interpretation of time dependent phenomena with periods longer than a few seconds.

A brief analysis shows that a perfect assessment is not necessary to make an error-free decision regarding krypton-85 control measures. From the viewpoint of a decision-maker, those aspects that could swing the decision from one alternative to another are priority areas for analysis.

The initial proposal was submitted to ERDA in July 1975. Funding for the proposal became available during 1977. In the midst of the final negotiations on the contract, the principal investigator learned that he had received a one-year NSF Science Faculty Professional Development Award. It was agreed to begin the contract, then have a one-year suspension of work. This is not inconsistent since some of the principal investigator's activities at the National Center for Atmospheric Research will further the aims of the contract without being charged to D.O.E. The net result is that less work was done on the contract than anticipated, resulting in expenditures much below the support ceiling. Some relevant results from research done at NCAR will be included in this progress report.

The five sections of the report are:

- I. First-Approximation Model to Estimate the Effects of Krypton-85 on the Atmosphere.
- II. An Analysis of the Pathways between Krypton-85 Production and the Atmosphere.
- III. Events of the Past Year Related to Atmospheric Krypton-85.
- IV. An Analytical Model for Fair Weather Atmospheric Electricity.
- V. Compliance

I. First-Approximation Model to Estimate the Effects of Krypton-85 on the Atmosphere

This model focuses attention on the lower atmosphere by assuming that the earth and the ionosphere are concentric spherical surfaces. Current flow between them is essentially radial. The total current passing from the earth to the ionosphere in either direction is taken to be the sum of the currents from various areas on the earth's surface. Each area is assumed to have a horizontally uniform electrical conductivity profile, which will differ from one area to another. This model treats mountainous area as uniform plateaus. The output of the total thunderstorm activity in the atmosphere is assumed to be constant. This has the effect of decoupling the thunderstorm generators from their electrical environment. If, as some authors have suggested, there is a feedback between thunderstorms and ambient atmospheric electric fields, this model underestimates the effects.

The equations that result from the model are as follows:

1. The electric field as a function of height in a horizontally uniform area labeled by index i , $E(i)$ is equal to the air-earth current density in that region $(J)_i$ divided by electrical conductivity at height, $\sigma(h)$, in that area. This is expressed as

$$E_i(h) = \frac{J_i}{\sigma_i(h)} \quad (1)$$

Equation (1) is a restatement of Ohm's Law.

2. The vertical air-earth current density in area i is equal to the ratio of the total resistance between the earth and the ionosphere (R) to the columnar resistance of a one-square-meter column of air extending from the

earth to the ionosphere in area i times the product of the total surface area of the earth (A) and the summation of the air-earth current density in each area J_i times the fractional area covered by area, (f_i).

$$J_i = \frac{R}{R_i} A \sum J_i f_i \quad (2)$$

The current flow will be larger in areas of below average columnar resistance.

3. The ratio of the electric field at height (h) and over an area of i in an atmosphere contaminated by krypton-85 $E_{ik}(h)$ to the same parameter in an identical atmosphere uncontaminated by krypton-85 ($E_i(h)$) is the product of three ratios. The first is the ratio of the total resistance of a contaminated atmosphere R_k to the total resistance of an uncontaminated atmosphere. The second is the ratio of the columnar resistance of area i for uncontaminated air, R_i , to the same parameter for contaminated air. The third term is the ratio of the local conductivity with contamination $\sigma_{ik}(h)$, to the conductivity without contamination.

$$\frac{E_{ik}}{E_i} = \frac{R_k}{R} \frac{R_i}{R_{ik}} \frac{\sigma_{ik}(h)}{\sigma_i(h)}$$

The effect of krypton-85 is to decrease the total resistance and the columnar resistance and increase conductivity. Therefore, we can predict

$$\frac{R_k}{R} \leq 1, \quad \frac{R_i}{R_{ik}} \geq 1, \quad \frac{\sigma_{ik}}{\sigma_i} \leq 1$$

The vertical distribution of krypton-85 and cosmic-ray ionization allows the specification

$$\begin{aligned} \frac{\sigma_{ik}}{\sigma_i} &= 1 & \text{for } h > 10 \text{ km} \\ \frac{\sigma_{ik}}{\sigma_i} &< 1 & \text{for } h = 0 \text{ km.} \end{aligned}$$

The result of the calculation of the ratio of the electric field with and without krypton-85 for a typical land station and a typical ocean station are:

Height	Ocean	Land
0	.7642	.8393
2 km	.8691	.8393
4 km	.9560	.9114
6 km	.9970	.9505
10 km	1.0011	.9544

The columnar resistance over the ocean is reduced by 16% and the columnar resistance over land by 12%.

The five percent reduction in the electric field at 10 km above continents is due to a corresponding decrease in the air-earth current. The tendency is for more current to sink into ocean areas. The net result is that at cloud base (2 to 4 km in altitude) the reduction in the electric field over land and oceans are quite similar. The reduction are projected to be maximum at the ocean surface and minimum at 10 km above the oceans.

II. An Analysis of the Pathways Between Krypton-85 Production and the Atmosphere

Figure I seeks to illustrate the various decisions that affect the atmospheric concentration of krypton-85. The only significant source of this isotope is nuclear fission of uranium, thorium and plutonium. The only significant removal mechanism is the transformation of krypton-85 to rubidium-85 by nuclear beta particle decay. The atmospheric concentration is determined by the rate of release and the rate of decay of this isotope.

The major sources of krypton-85 are on the top line; they include civilian nuclear power, military and research reactors, nuclear weapons production and nuclear explosions. In the past, plutonium production has accounted for most of the atmospheric krypton-85. Projections for the future indicate that civilian nuclear power reactors will become the dominant source of krypton-85 in the future.

Each nation using nuclear reactors will contribute a share to the global inventory of krypton-85. The summation symbol with subscript N indicates that nuclear decision in many individual countries produce the end result.

The steps between the production and release of krypton-85 for different paths can be outlined as:

1. Nuclear explosions. Atmospheric nuclear explosions leave 100% of the krypton-85 that they produce in the atmosphere. Unless underground explosions are accidentally or deliberately vented, the krypton-85 they produce will remain trapped in the explosion-produced cavity and decay there.

2. Plutonium production reactors. The fuel from these reactors will be chemically reprocessed to recover the plutonium. There is no indication in the literature that any country is controlling the krypton-85 produced by this activity. Recent measurements of atmospheric krypton-85 suggest that worldwide plutonium production rates are down from those of a few years ago.
3. Military and research reactors. The spent fuel from these reactors is often reprocessed because the highly enriched uranium they use is too valuable to discard. The scale of this effort is small and krypton-85 controls are not presently used.
4. Civilian nuclear power. Only a small portion of the spent fuel from civilian nuclear power reactors has been removed from the fuel cartridges and reprocessed. Consequently, the krypton-85 contained in these fuel elements constitutes a major reservoir of this isotope. After 75 years of storage, less than one percent of the original krypton-85 will remain. At present, the United States is enforcing a moratorium on civilian nuclear fuel reprocessing. Some nations may decide to store spent fuel for 75 years or more and, as a side effect, prevent the atmospheric release of krypton-85. There will also be a small percentage of failed fuel elements leaking krypton-85 and other isotopes. These materials will be disposed of either by further incapsulation or by reprocessing. At the design stage of a nuclear fuel reprocessing plant there is the opportunity to design and install an effective krypton capture system. Once a plant is in operation, the off-gas system will be contaminated with radioisotopes, notably ruthenium, and changing of the system to accomodate a krypton-85

capture system may not be feasible. A properly operating krypton capture plant should remove 99% of the krypton from the nuclear fuel reprocessing plant. However, to achieve a 99% reduction of the annual output, the krypton capture system must not malfunction in a year of continuous operation. It is more reasonable to expect a system to be down (nonfunctional) less than 10% of the year. Thus an operational system could be expected to remove between 90 and 99% of the krypton-85 in the reprocessed nuclear fuel. This implies that a nation operating a nuclear fuel reprocessing plant without krypton-85 controls will be releasing from 10 to 100 times the amount of krypton-85 released by nations with mandatory controls.

Decision Characteristics

Because the same process that produces krypton-85 also produces plutonium, any decision affecting krypton-85 controls will be made at the national level, on a nation-by-nation basis. These decisions will probably be made semi-independently of one another. Decision-makers in nations with nuclear capabilities will certainly know of other countries' decisions regarding krypton controls. They will not necessarily make the same decisions. Nor is it likely they will have a background in atmospheric science. It is likely that they would want research results in the form of a cost-benefit analysis of the type used in nuclear regulatory proceedings.

The basic premise is that decision-makers wish to know the consequences and/or risks associated with each available course of action. Continuation of the status quo is often one of the available courses of action. The decision-makers attempt to choose a course of action that leads to an acceptable level

of risk at an acceptable economic and social cost. The basis for comparison, in any case, should be the status quo, with reasonable projections for future events. This choice is justified by the observation that indecision or postponement of a decision is equivalent to a deliberate choice of the status quo.

For those decisions involving a choice between two alternatives, there will be a threshold for action. The status quo will be maintained unless there is an unacceptable risk resulting from that course of action and there is an alternative course of action that reduces the risk at an acceptable social and economic cost.

The desired output of the decision-making process is the correct choice between two alternatives. This is called an error-free decision. The projections on which an error-free decision can be based do not have to be perfect, only accurate enough to choose correctly between two alternatives. In particular, those aspects of the prediction that could swing a decision from one alternative to another deserve the most concentrated attention.

III. Events of the Past Year Related to Atmospheric Krypton-85

A number of events will have an impact. They are:

1. The U.S. Environmental Protection Agency has received jurisdiction over environmental releases of radioactivity for U.S. government installations. There is no indication yet as to the Agency's intentions regarding krypton-85 releases.
2. The extended planning inquiry in the United Kingdom about the proposed expansion of the Windscale nuclear fuel reprocessing plant may have implications in other countries as well. The recommendations of the inspector have not been released to date.
3. The untimely deaths of Dr. T. E. Pierce and Dr. Chin-Shan Chiu will slow down progress in the research areas in which they were active.
4. R. Roble and P. Hays have developed a three-dimensional quasi-static numerical model of the earth's atmosphere. A simulation of the addition of krypton-85 to the atmosphere will be modeled within the next few months. The parameterization of quantities in the model is crude, with the result that numerical results should only be taken qualitatively.
5. Interest in solar-terrestrial relationships remains high. R. Markson's review paper on "Solar Modulation of Atmospheric Electrification and Possible Implications for the Sun Weather Problems" has been accepted by Nature.

IV. An Analytical Model for Fair Weather Atmospheric Electricity

The reasons to focus attention on the interpretation of atmospheric electrical measurements include their potential use as a global monitor of certain aspects of meteorological phenomena. The universal time variation is good evidence that the fair weather atmospheric electric field responds rapidly to events around the globe. Fair weather atmospheric electricity shows modulations synchronized with solar phenomena of both periodic and non-periodic types. The existence of these correlations highlights a gap in our present knowledge of the interrelations between cloud physics and atmospheric electricity.

A solution has been obtained for Maxwell's equations for time variations with a range of characteristic periods from a few seconds to many years and for regions of the troposphere and stratosphere that are free of current sources. This corresponds to regions where fair weather atmospheric electricity measurements are made. The results are given in terms of a harmonically analyzed separable solution in spherical coordinates for an exponential conductivity profile with boundaries in the stratosphere and on the surface of the earth. A first-order analytical solution has been found for global-scale phenomena with characteristic lengths of more than 15 degrees of latitude. The temporal and spatial variations of the electric field at the boundaries determine the coefficients of the solution. The solution is sensitive to the ratio of conduction current to displacement current. At low altitudes for short periods, the displacement current dominates. In this region, upward-propagating electric fields are essentially unattenuated below the altitude where conduction currents are dominant. In the conducting region, which lies

above the other region, electric fields are exponentially attenuated. This is consistent with a model of a dielectric atmosphere surrounded by a conducting shell, provided that the thickness of the dielectric layer depends on frequency. The dielectric region is nonexistent for field variations with periods longer than a day.

The magnitude of the fair weather atmospheric electricity field is determined by the balance between the integral of all processes removing charge from the earth and the returning currents. The relationship between cloud processes, lightning and charge transfer from the earth needs further investigation.

The development of charged screening layers on clouds depends on the altitude of the cloud surfaces and the frequency dependence of the fair weather field. Deep convective clouds may have bases in regions of relatively low conductivity and tops in regions of high conductivity.

V. Compliance

Because the principal investigator was supported by an NSF Science Faculty Professional Development Award for much of the time span of the contract, there are significant differences between the proposed budget and the actual expenditures. The principal investigator worked one month on the payroll of Niagara University as the university's contribution to cost sharing. The number of man-months reimbursed by the contract was reduced from three months to one and one-half months. Some aspects of the work were continued at the National Center for Atmospheric Research at no cost to the contract. A summary of the approved budget and the project expenditures projected to 6/30/78 follows:

	<u>Budget</u>	<u>Expended</u>	<u>Carry-over</u>
Salaries and Wages	9968	3855	6113
Equipment	700	695	5
Travel	1500	1300	200
Other Direct Costs	2920	415	2486
Indirect Costs	2786	1060	1726
TOTAL	17874	7325	10530

Figure 1.