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Castle-Bravo Air Concentration and Deposition Patterns from a 3-D Particle-in-Cell Code*

by

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ABSTRACT

The MATHEW-ADPIC code suite has been extensively modified to give the total external dose from the detonation of the Castle-Bravo nuclear test at Bikini Atoll until evacuation of the inhabitants of nearby atolls. The advantages of this code suite is that it uses all the observed winds (in a mass-conservation sense) at and after the detonation to provide dose rates and doses due to passage of the debris cloud and to the time-integrated deposition up to evacuation time. Previous assessments have given the fallout pattern (deposition only) at time H+1 hours.

The present code formulation gives excellent agreement with the estimated total external dose (based on measurements) to people on Rongelap and Ailinginae atolls.

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Acknowledgments

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INTRODUCTION

Operation Castle was an atmospheric nuclear test series conducted in the Marshall Islands from March to May of 1954. The most notorious test of the series was Bravo, a 15 megaton[1] thermonuclear explosive. The top of the resultant debris cloud reached to nearly 35 km at stabilization time.[1]

Because of an unexpected shift in mid-tropospheric wind directions following detonation of Bravo, the fallout pattern, instead of heading in the predicted northeast direction, had an easterly alignment. As a result, persons on the atolls of Rongelap and Rongerik were exposed to relatively high levels of fallout from the nuclear explosion. Prompt action was taken by U. S. Task Force personnel to evacuate the natives of these islands. Some of the natives on Rongelap, the closest to the detonation point, suffered temporary nausea and minor skin burns. None exhibited any medium or long term effects from their exposure.

However, after about 10 years, those Rongelap natives, who were young children in 1954 developed non-maligment nodules on their thyroid glands. Since then the occurrence of similar nodules among the Utirik natives has been reported. The rate of occurrence has been higher than would be expected statistically. The purpose of this report is to calculate deposition and surface air concentration plots, using a three-dimensional particle-in-cell suite of codes to estimate the doses at the islands from which the natives were evacuated. We will also consider the dose from rainout as part of the debris cloud crossed the atolls. Finally, the calculated time history of air concentrations on the downwind islands will be presented for several nuclides.

Several fallout patterns for Castle Bravo were prepared in the late 1950's. Some of the better known patterns appear in Ref. 1 and were prepared by (a) the Air Force Special Weapons Project, (b) the Naval Radiological Defense Laboratory, and (c) the Rand Corporation. A comparison of these three patterns shows significant differences in the maximum dose rates, as well as the shapes of the contours. This is due in large part to the subjectivity involved in the calculations. Portions of the AFSWP and NRDL contours were based on dose rate measurements at Rongelap, Rongerik, and Utirik, as well as a crude estimate of the dose rate received by the Japanese fishing ship, the Lucky Dragon. The remainder of these patterns were obtained using the observed winds in a subjective manner to bend the pattern and achieve an approximate mass balance.

The Rand contours used estimated winds between Bikini and Rongelap. These winds were obtained from interpolation of streamline analyses at several levels at different times.

By contrast, the altered versions of the MATHEW-ADPIC codes used in this report allow us to use the observed winds at different locations and different times after detonation. No artificial bending of the pattern is required. The only subjectivity lies in the selection of code input parameters. At all times, the codes automatically assure conservation of mass.

COMPUTER CODES

The suite of codes developed for the Atmospheric Release Advisory Capability (ARAC) were extensively modified in order to incorporate a larger number of upper air wind levels. All prior uses of the codes have been to handle calculations for releases that did not rise higher than a few kilometers. Also, the standard ARAC codes do not involve sophisticated gravitational fall velocity calculations, nor do they include time-integrated deposition.

One of the major codes that was modified is MATHEW[2]; its purpose is to adjust observed winds, using variational analysis methods, so as to conserve mass from cell to cell. After modification, all observed upper air wind data from 10 m to 35 km were entered as input. This was done for four time periods, using winds for one to three observing stations for each time. The obvious advantages of this code (over most other fallout codes) is that mass is not permitted to accumulate in any of the cells and winds are available for each 3-D cell intersection for four times.

The MATHEW winds are used then by the modified ADPIC[3] particle-in-cell code to calculate the transport, diffusion, and deposition of an instantaneous source. Modifications required of ADPIC, to handle the Bravo test, consisted of allowing more upper air input than is used in typical ARAC assessments. Furthermore, since particles falling from the stratosphere undergo a large increase in air density, it was necessary to add a turbulent wake correction to the larger particles; this correction follows the method set forth by McDonald.[4] Other modifications were to incorporate a tropical atmosphere into the fall velocity calcuations and to make the particle activity increase as the cube of particle radius. Finally, time-integrated deposition was added; this allows calculation of the total dose from detonation time to evacuation.

INPUT DATA

Surface meteorological observations were available from some atolls and from the U.S.S. Curtiss which cruised south of Bikini; however, since the larger particles fall rapidly from the debris cloud to the surface and spend little time near the surface, not many surface reports were used. Of far greater importance are the upper air wind observations taken at four sites near Bikini atoll. Other significant input data consisted of a flat topography, cell sizes of 34 km (east-west) by 17 km (north-south), and 1 km in the vertical, stem and cap debris cloud geometries at stabilization time, source rates for both gross fission products and selected individual nuclides, and particle size spectrum parameters.

CALCULATIONS

Gross Fission Products

The time-integrated external dose pattern (in rads) due to gross fission products from detonation time to evacuation time of Rogelap atoll (51 hours) are shown in Fig. 1. The numbers next to Ailinginae, Rongerik, and Utirik atolls are integrated values up to the time people were evacuated from those atolls.

For comparison, the value of total dose, estimated by Dunning[5] and Strauss[6] are given in Table 1. Note that the agreement is very good for Rongelap and Ailinginae atolls. However, calculations for Rongerik and Utirik are at odds with earlier estimates. The code calculations for Rongerik are higher, while those for Utirik are lower. This variation appears to be in part a problem of "tuning"; also a possible variation in wind directions and speeds at late times when the only wind observations were from the U.S.S. Curtis, south of Bikini (some distance from the atolls of concern) may be an explanation.

Table I. Comparison of gross fission product total external doses for computer calculations vs. estimates by Dunning[5] and Strauss[6]

Atoll	Evacuation Time (hours)	Present Calculations (rads)	Previous Estimates (roentgens)	Ref.
Rongelap (northern part)	51	1300	2000	[6]
Rongelap (southeastern part)	51	110	175	[5]
Ailinginae (Sifo Island)	58	24	<100	[5]
Rongerik (southeastern part)	30	340	78	[5]
Utirik	78	0.33	~10	[5]

With the modified MATHEW-ADPIC code suite, it is possible to calculate the instantaneous immersion dose rate from gross fission products as a function of time. This can be done for any time inteval. Figures 2a to 2f show surface immersion dose rate contours for every three hours from one hour after Bravo cloud stabilization time to H+16 hours. Note that after an easterly traverse, most of the debris reaches the trade wind level; the contour pattern moves south and finally toward the southwest.

Individual Nuclides

Calculations were made of instantaneous and time-integrated concentrations at 2 m above the surface for the several atolls affected by Castle-Bravo. The nuclides considered were Te-129, I-131, I-133, Cs-137, and Eu-155. These calculations agree well with observations at Rongelap and Ailinginae atolls, but are too high at Rongerik and too low at Utirik atoll. The surface concentrations for Rongelap, both the northern and southeastern parts of the atoll, and for Ailiginae Atoll are presented in Figures 3a to 5e. The time of arrival of the first Bravo debris is in agreement with reports made by the inhabitants.

REPORTS OF RAIN DURING BRAVO FALLOUT

Transcripts of post-detonation briefings suggest that self-induced rainout occurred for a short time after Bravo was detonated. The crew of the Japanese fishing ship, No. 5 Fukura Maru (Lucky Dragon), while fishing downwind just outside the exclusion zone, noted that the initial fallout on their ship was accompanied by "a light rain or drizzle."[7] It is unlikely that this was a continuation of the self-induced rainout, some two or more hours after Bravo's detonation; it was probably a natural rain system superimposed on the debris cloud.

Another report of rain during Bravo fallout was made by a group of Rongelap natives after evacuation.[8] They lived in Rongelap Village, on the southern part of Rongelap Atoll, and stated that it "rained a little" during the afternoon of March 1st.

Another interview with an American Air Force radio operator[8] who had been on Rongerik Atoll prior to evacuation disclosed that "rain commenced about 2100 [LST] and continued for 30 minutes."

Finally, the S. S. Roque, owned by Micronesian Lines, left Kwajalein at 0845 LST and arrived at Utirik at about noon on March 2, 1954. The ship left Utirik (apparently a few days later) and arrive at Majuro Atoll on March 7. A radiological survey at Majuro disclosed radiation readings of 10 to 30 mr/h on March 7. The ship's captain mentioned that he had encountered rain squalls during his voyage, but was not specific about where or when. It appears certain that the S. S. Roque encountered Bravo fallout, possibly accompanied by rain showers, either while approaching or while in harbor at Utirik. If 10 mr/h are "grown back" to five or six days earlier (when the Bravo debris cloud passed near Utirik), the dose rate is estimated at about 100 mr/h.

SUMMARY AND CONCLUSIONS

Extensive modification of the MATHEW-ADPIC code suite has produced contours of Castle Bravo accumulated and time-integrated deposition for gross fission products. Through the use of dose conversion factors, these contours have been converted to dose rates and total doses up to the time of evacuation from the atolls affected by the debris cloud. In addition, both instantaneous and time-integrated surface concentrations have been calculated. For the nearest atolls, the calculations agree well with the measurements and total dose estimates based on these measurements. At the more distant atolls the agreement is not as good, indicating the need for more "tuning" of the code input parameters.

The internal dose to the inhabitants of the affected atolls have not been made in this report. Interviews with natives of Rongelap Village and Ailinginae[8] indicate that many people ate fresh seafood and drank water from cisterns following contamination of their islands. Although there is no direct evidence that those at Utirik ate and drank contaminated food and water, it seems likely that they did since the dry deposition from Bravo was considerably less than at atolls to the west. However, the previous section indicated that rain probably occurred during the time of fallout. This would result in wet deposition, producing local doses 10 to 50 times greater than in those areas where rain did not occur. This effect could have resulted in development of thyroid nodules in those Utirik residents who consumed contaminated food and water.

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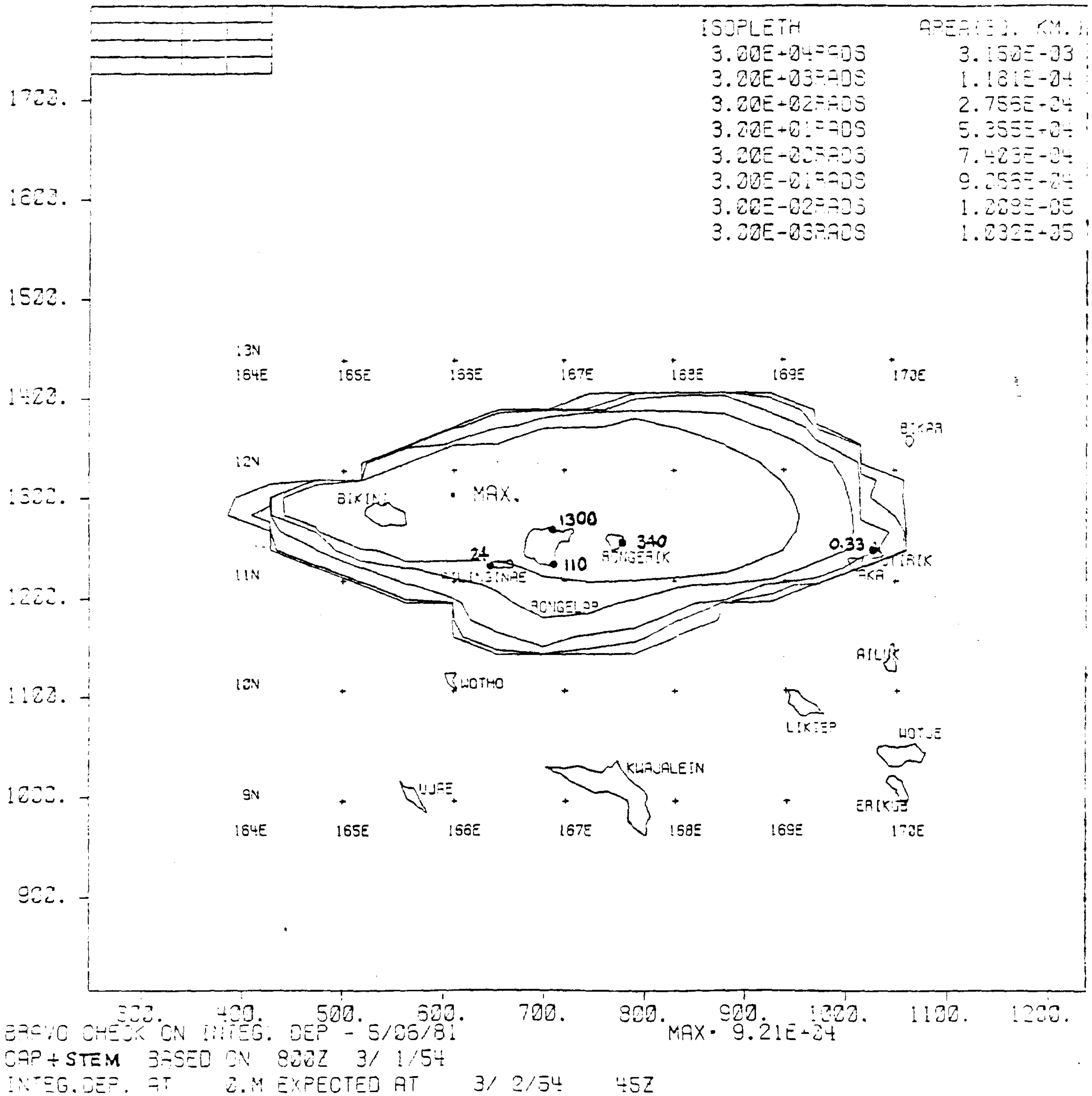


Figure 1. Castle Bravo time-integrated external gamma dose from gross fission products. Contours are for an H+51 hour evacuation time from Rongelap. Numbers added for other atolls are integrated to the appropriate evacuation time for those atolls.

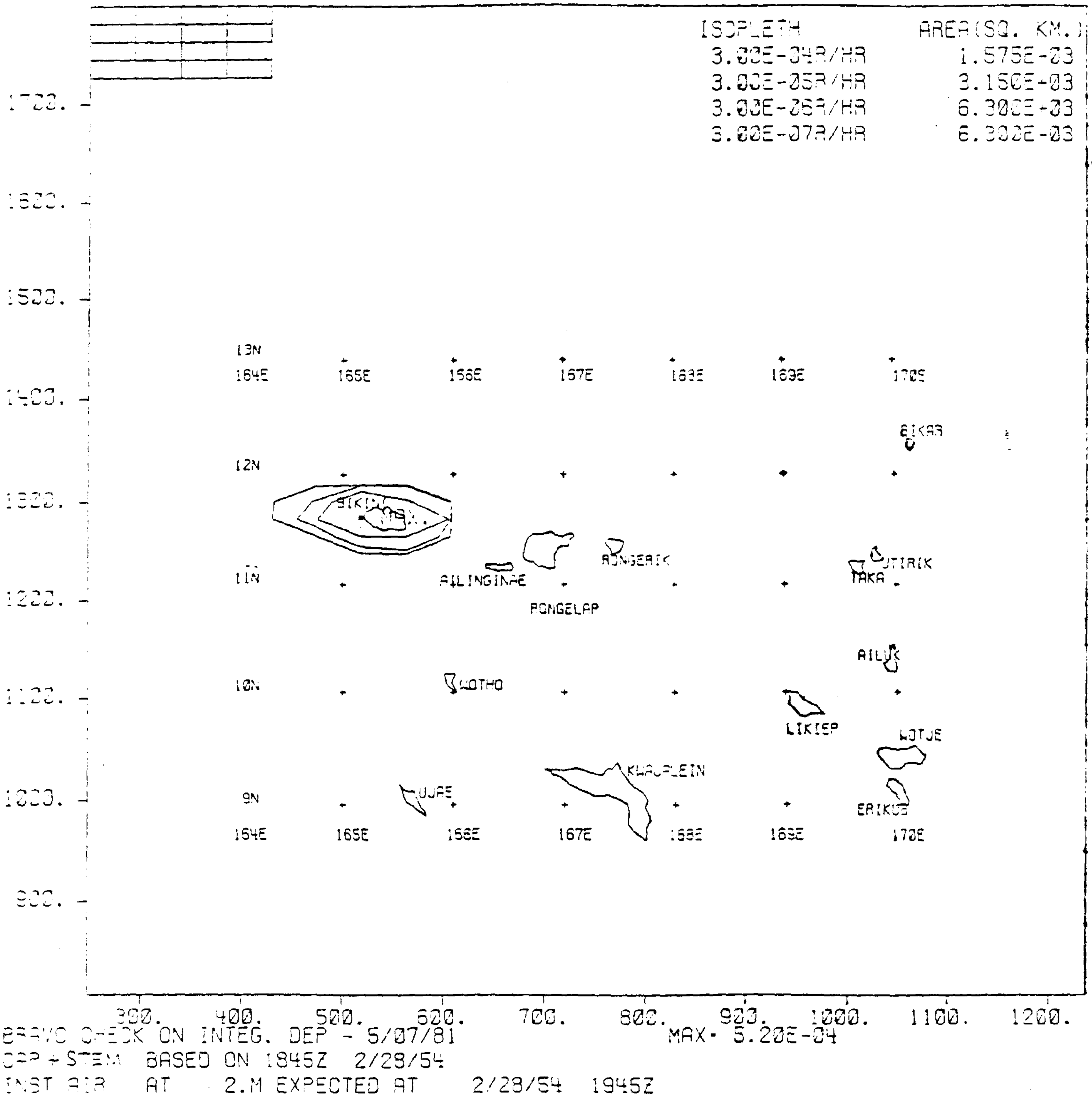


Figure 2a. Castle Bravo instantaneous external gamma dose rate contours from gross fission products. Time is H+1 hour.

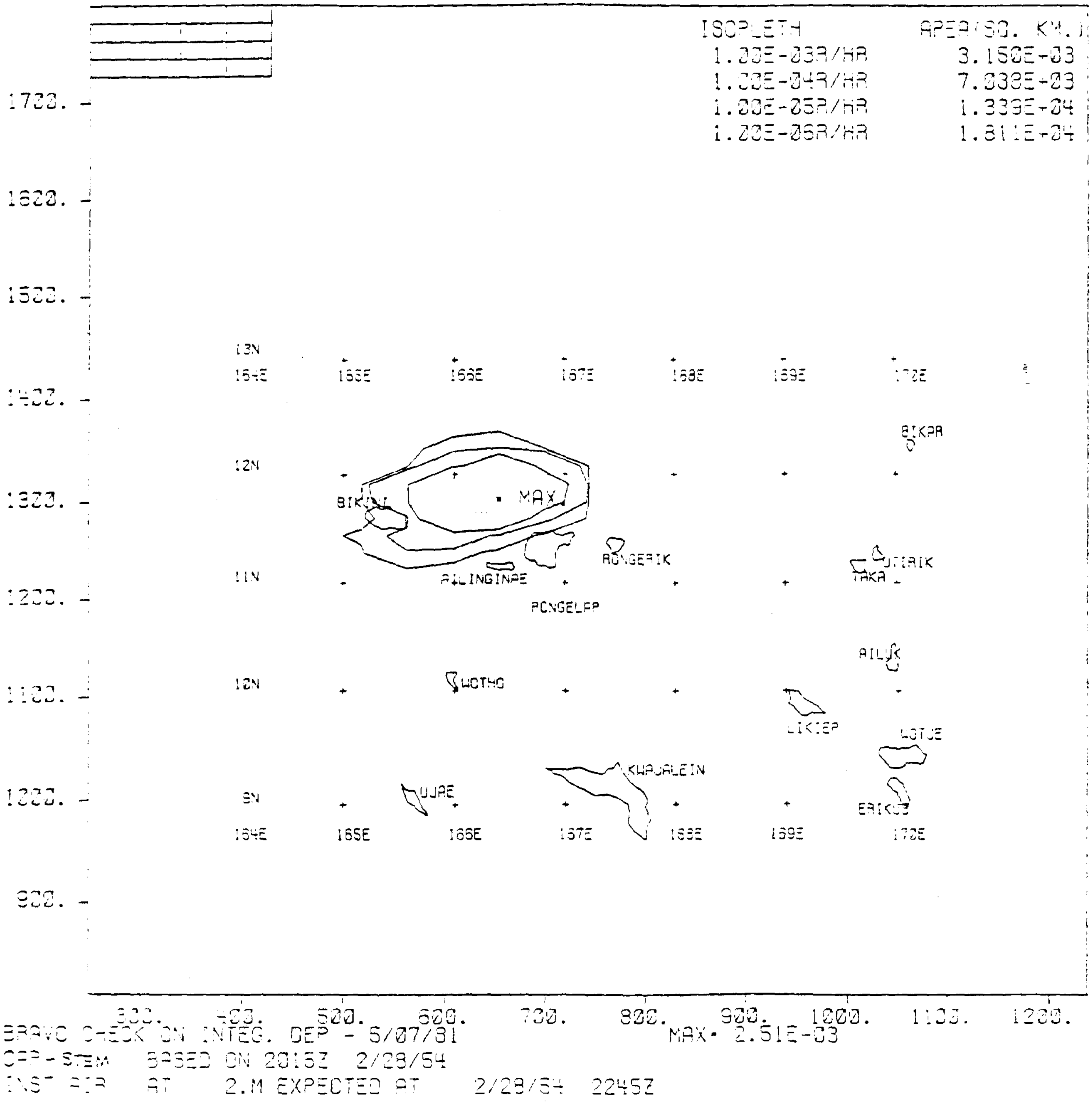


Figure 2b. Same as Fig. 2a, except time is H+4 hours.

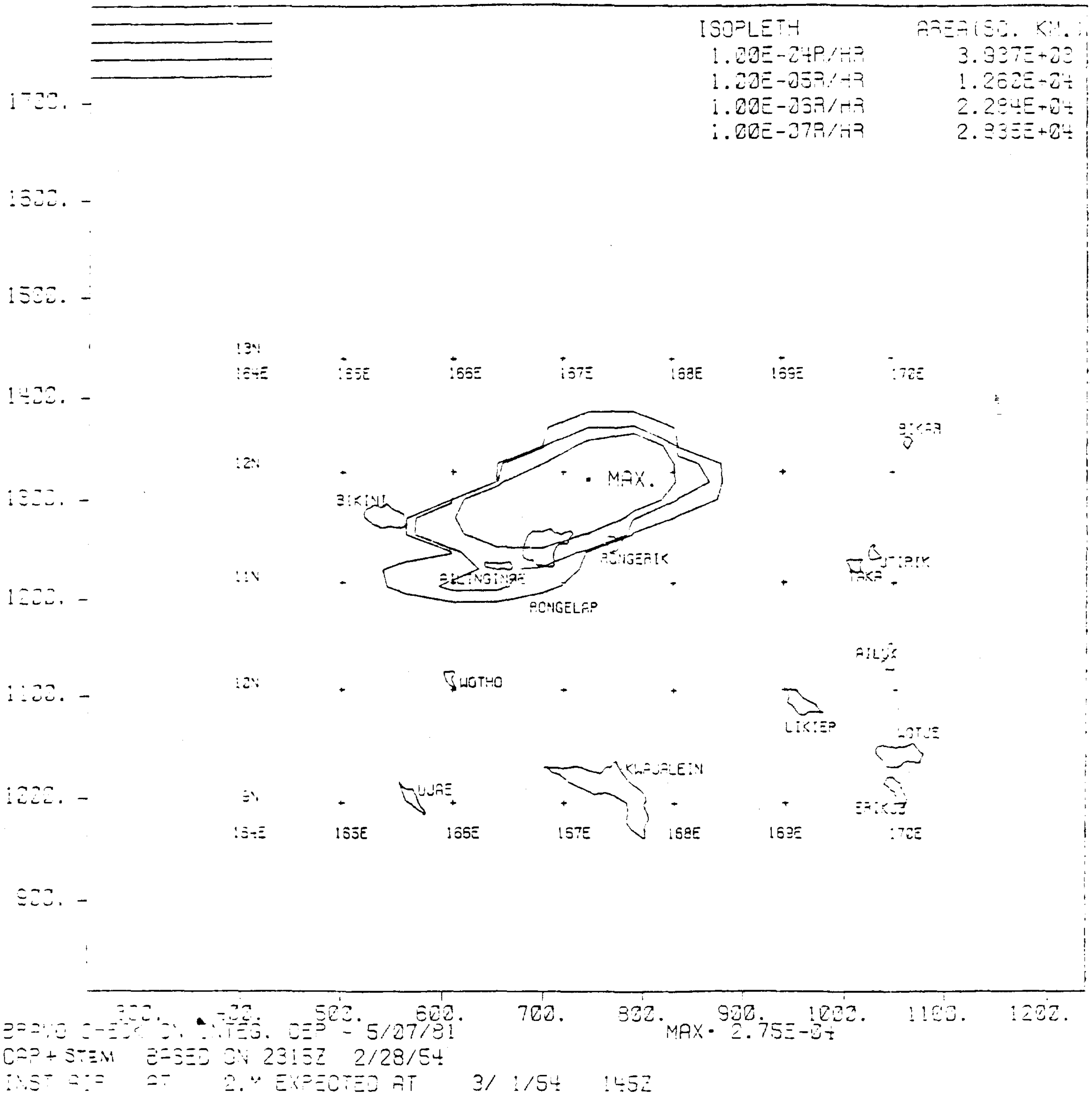


Figure 2c. Same as Fig. 2a, except time is H+7 hours.

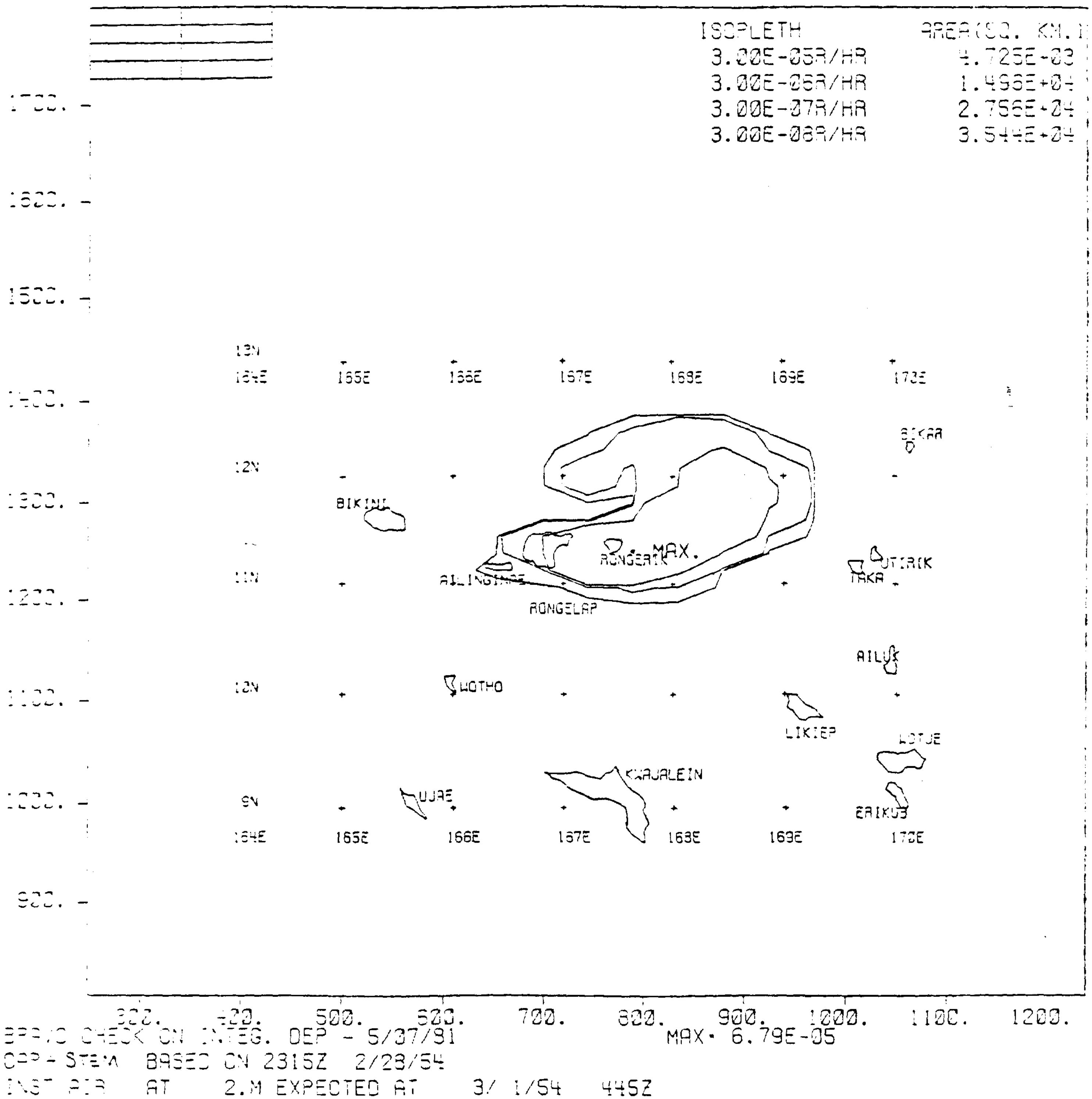


Figure 2d. Same as Fig. 2a, except time is H+10 hours.

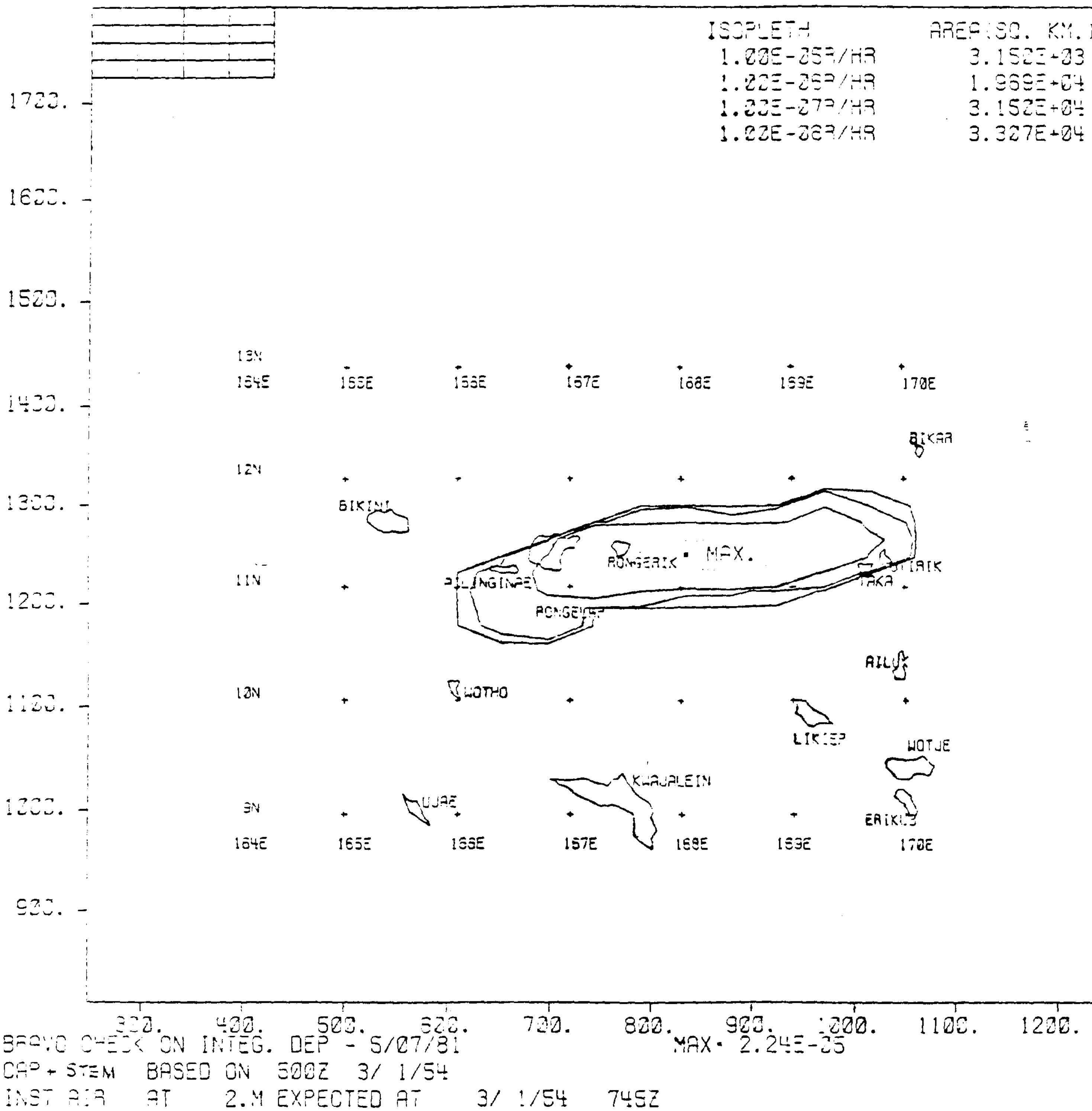


Figure 2e. Same as Fig. 2a, except time is H+13 hours.

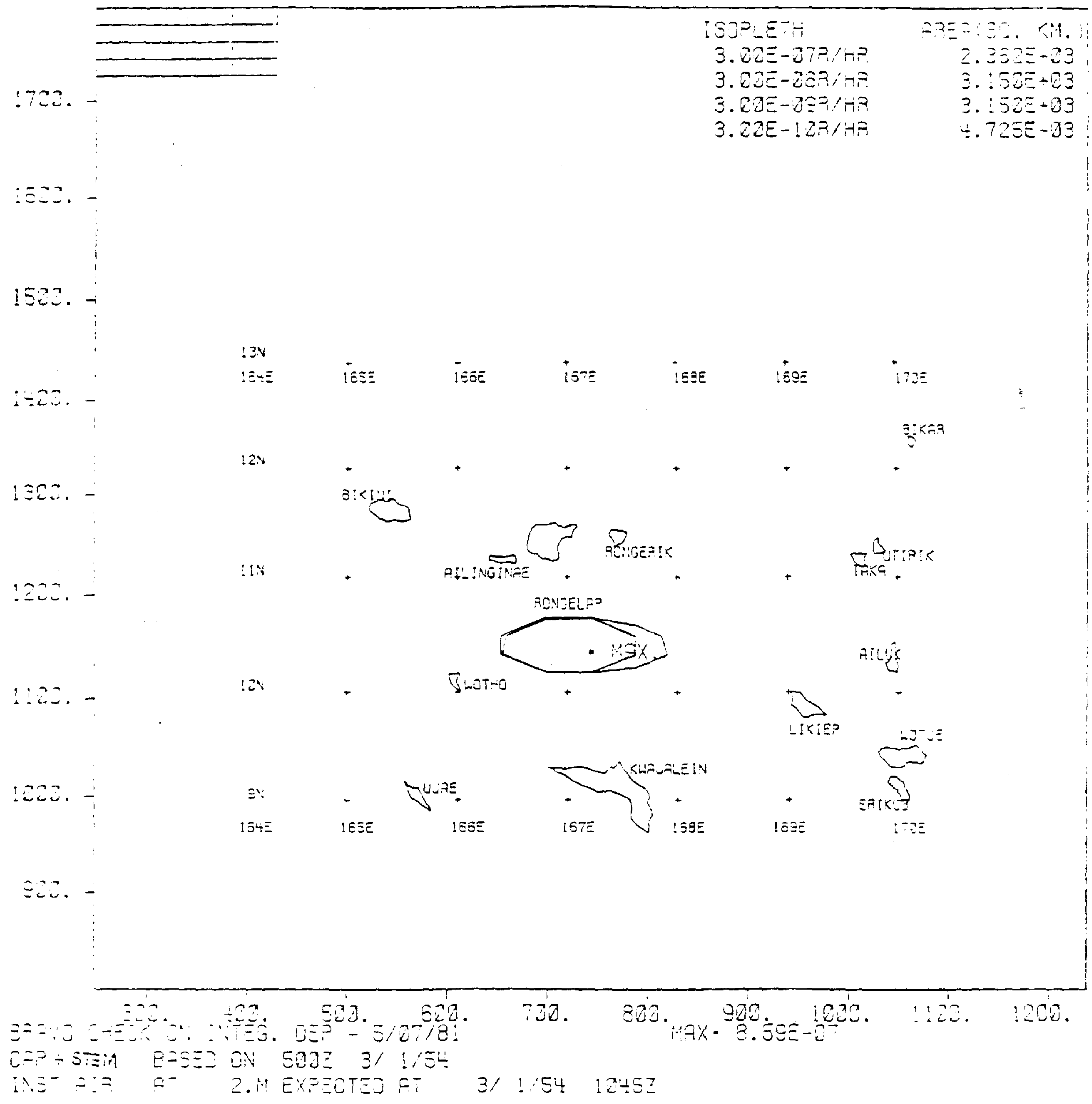


Figure 2f. Same as Fig. 2a, except time is H+16 hours.

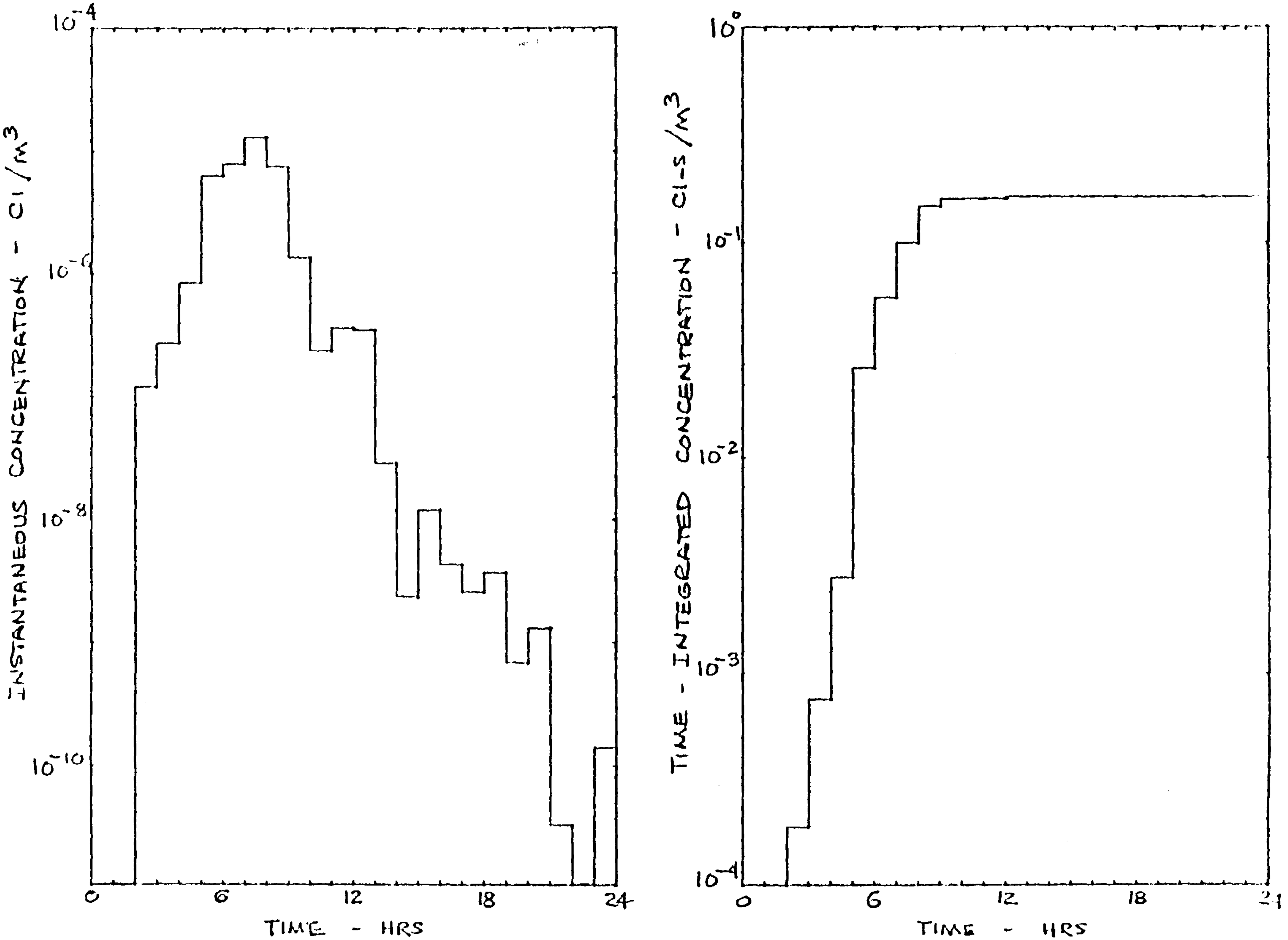


Figure 3a. Castle Bravo instantaneous and time-integrated surface air concentrations for northern part of Ronelap. The nuclide is tellurium-129.

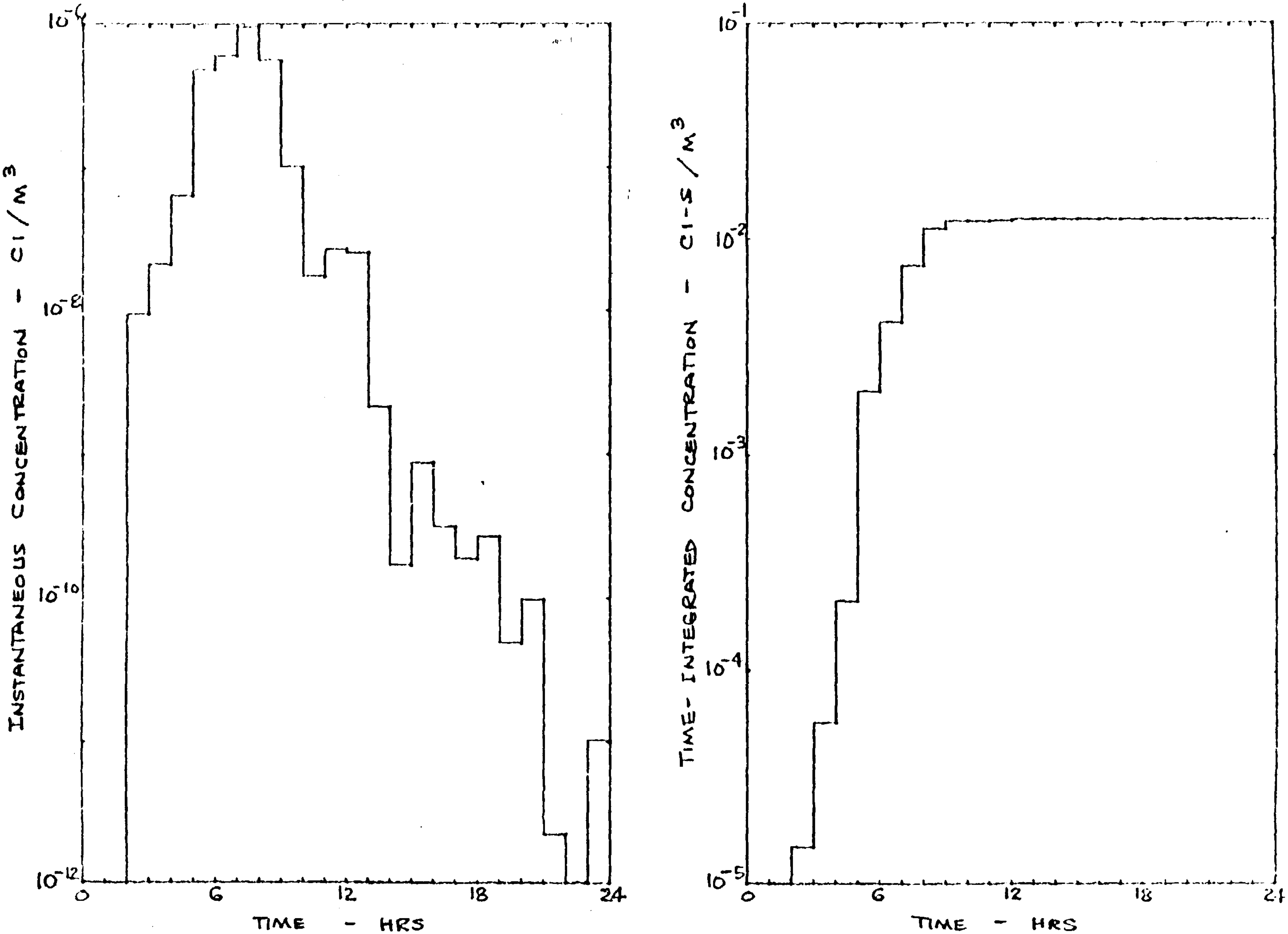


Figure 3b. Same as Fig. 3a, except nuclide is iodine-131.

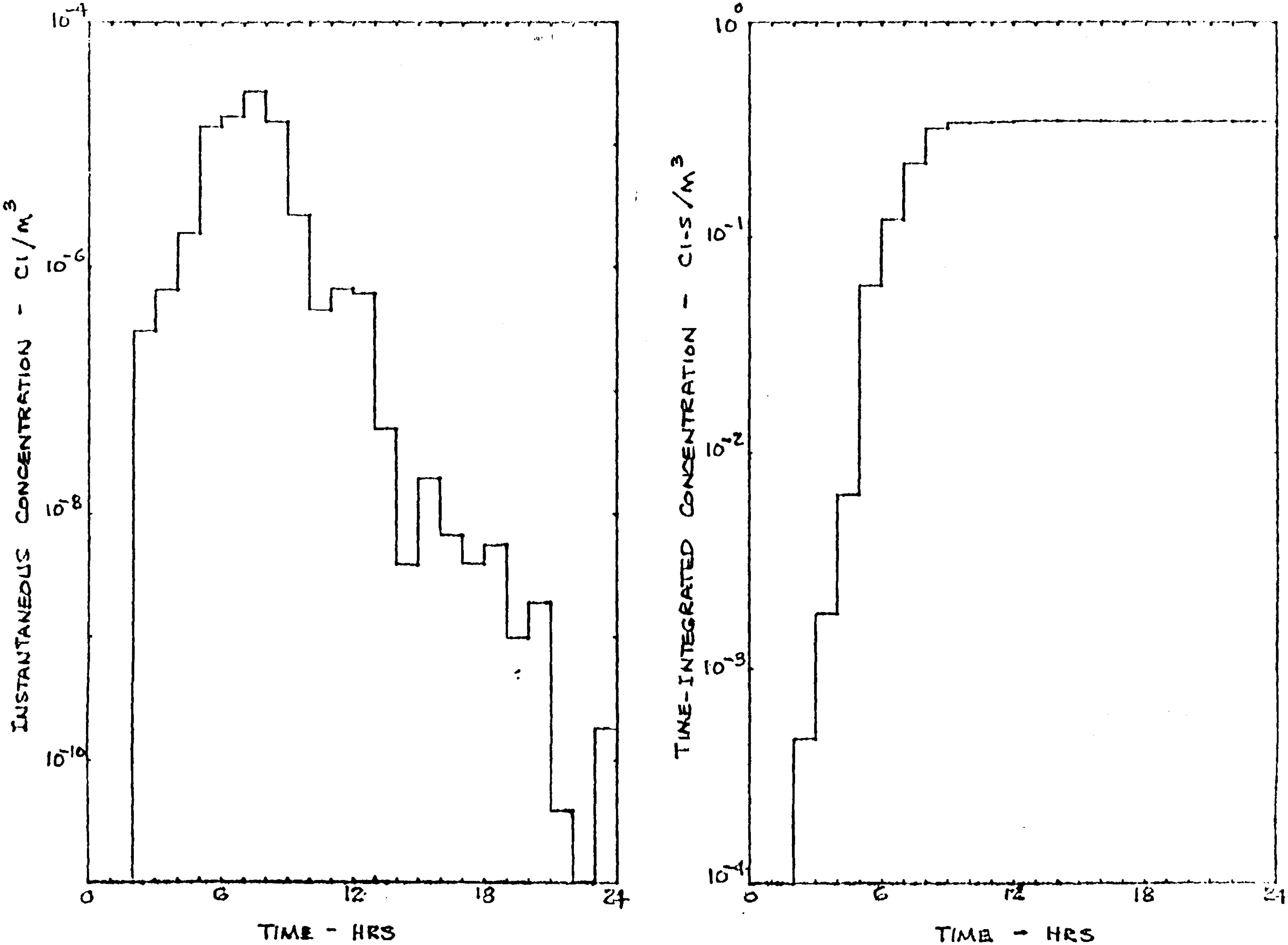
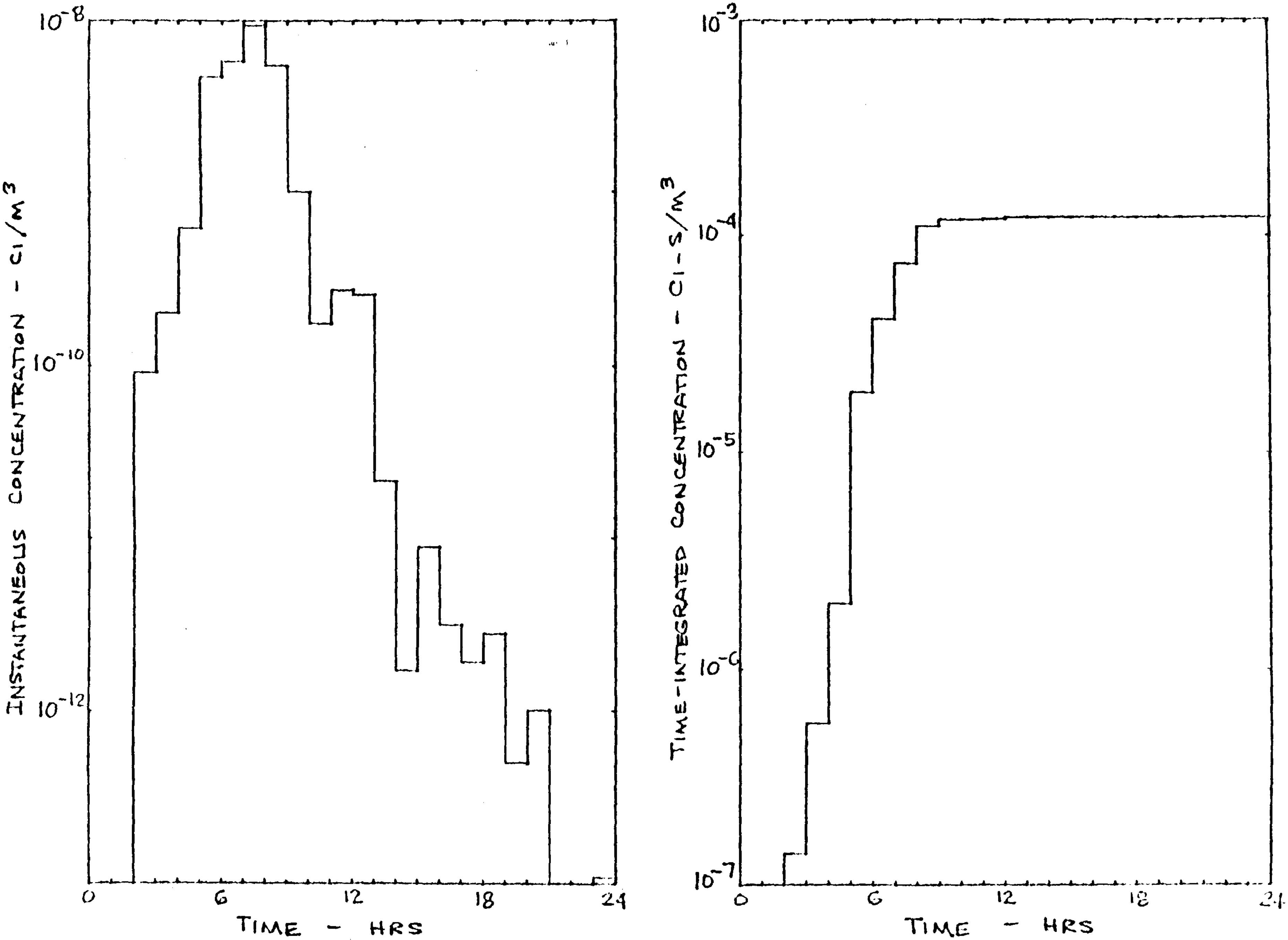


Figure 3c. Same as Fig. 3a, except nuclide is iodine-133.



Figures 3d. Same as Fig. 3a, except nuclide cesium-137.

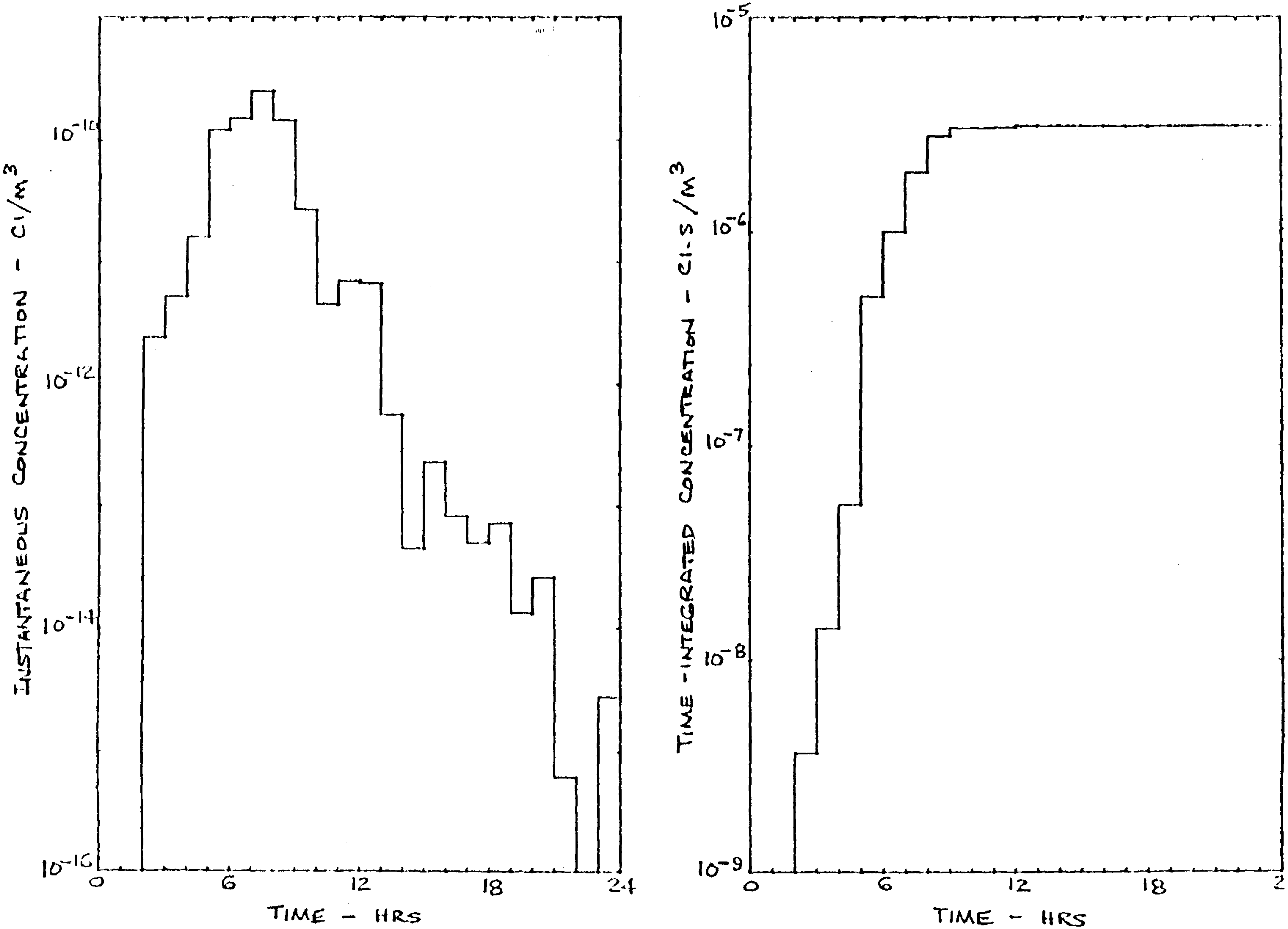
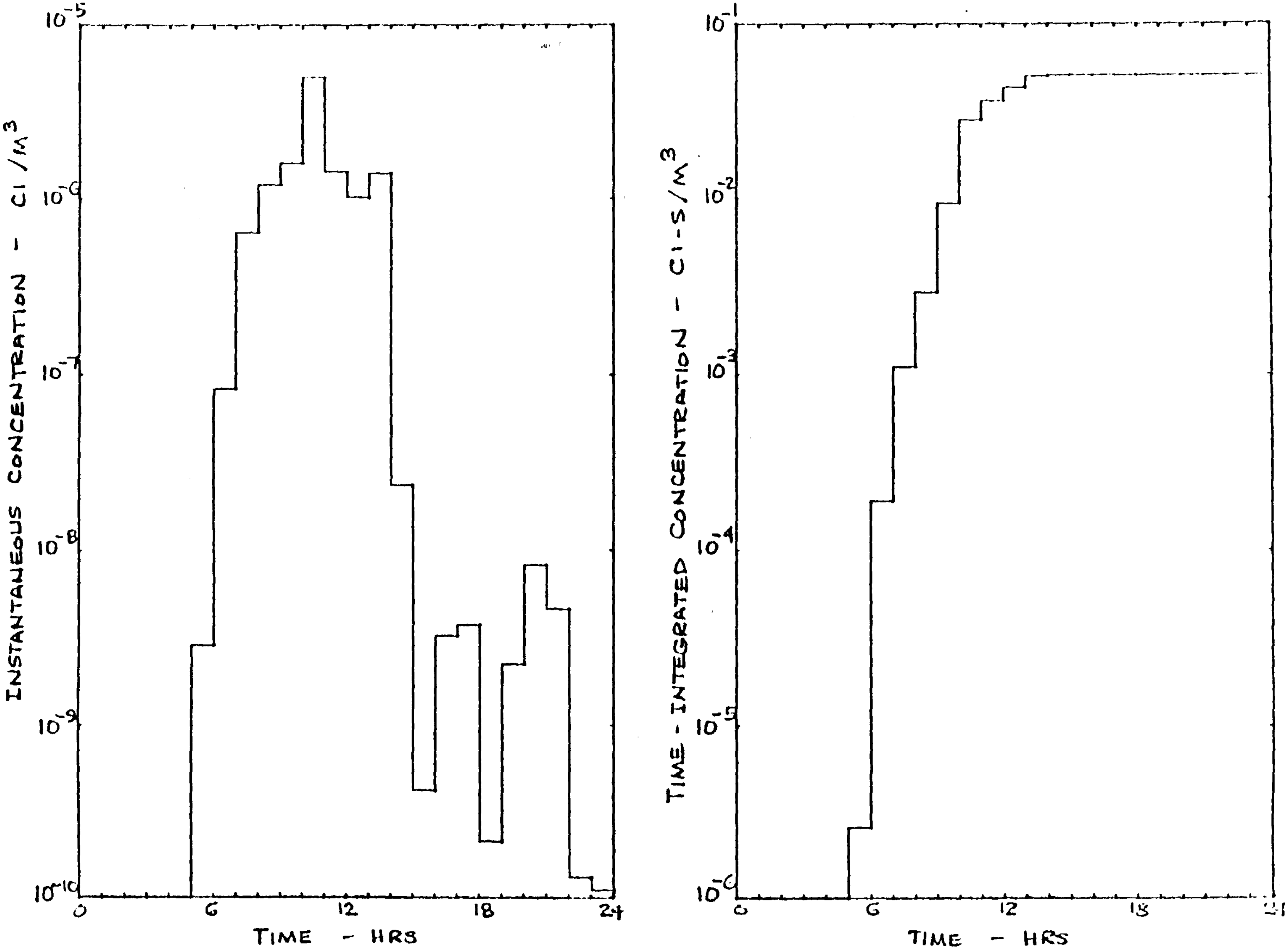


Figure 3e. Same as Fig. 3a, except nuclide europium-155.



Figures 4a. Castle Bravo instantaneous and time-integrated surface air concentrations for southeastern part of Rongelap. The nuclide is tellurium-129.

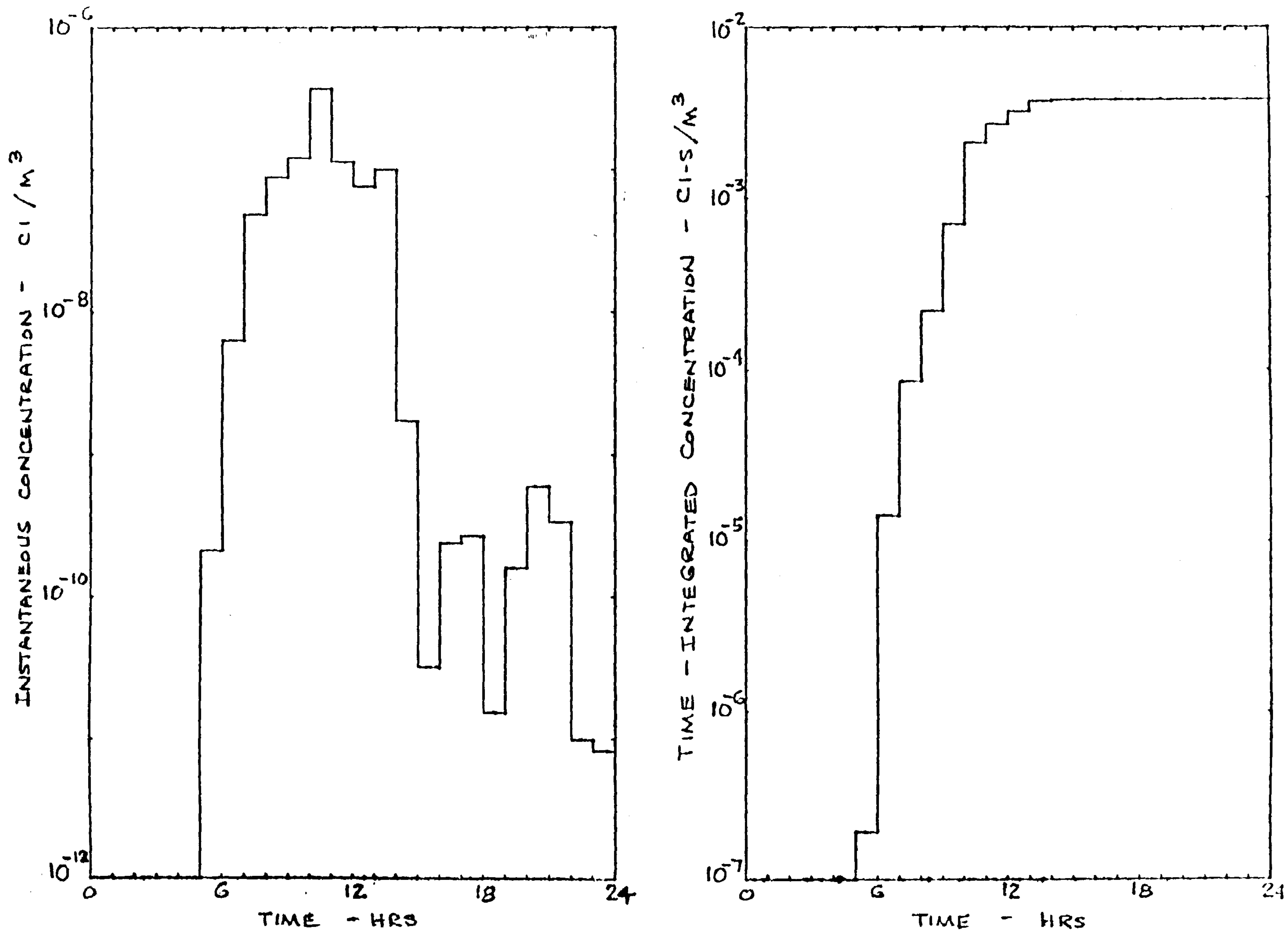


Figure 4b. Same as Fig. 4a, except nuclide is iodine-131.

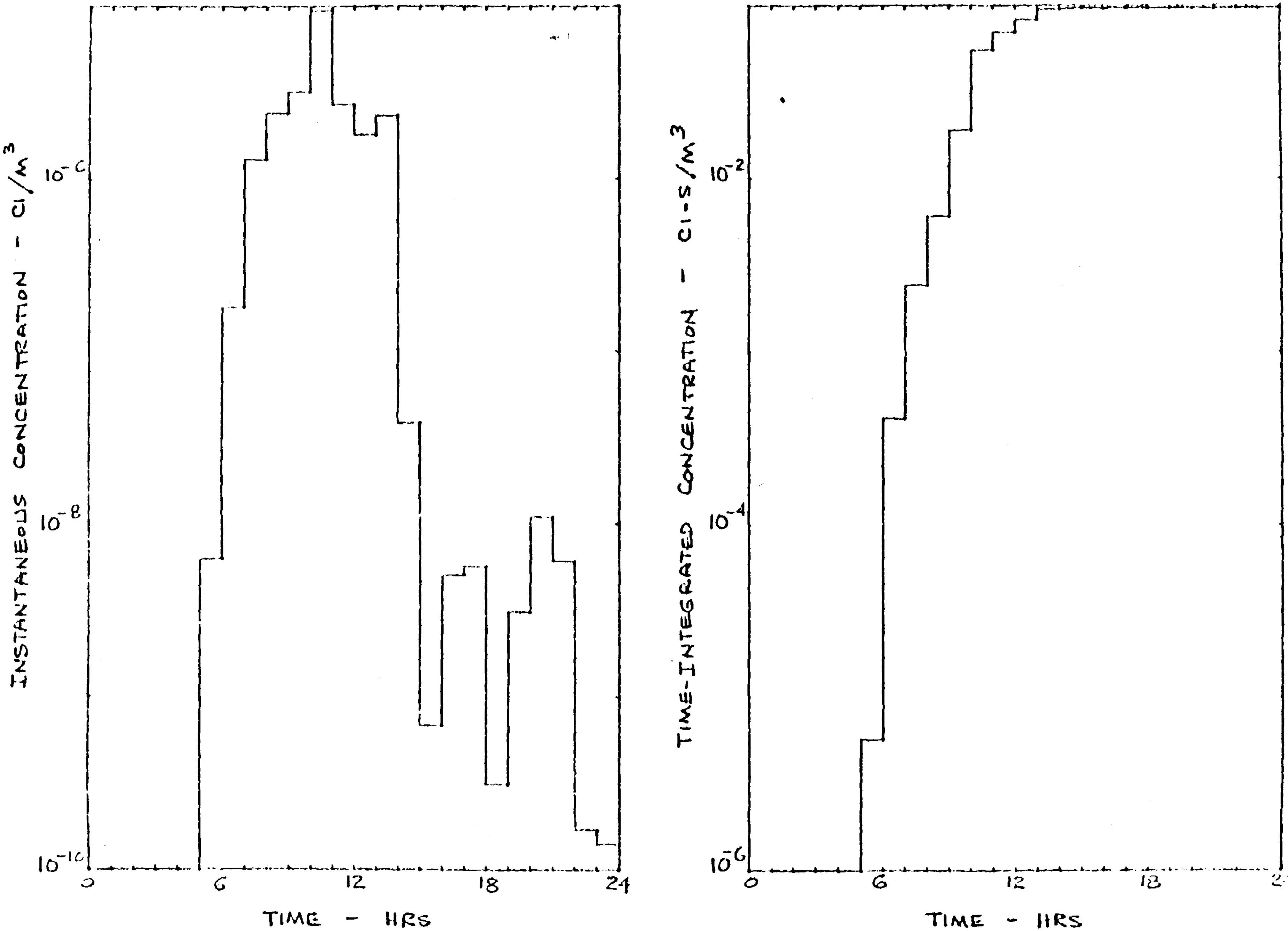


Figure 4c. Same as Fig. 4a, except nuclide is iodine-133.

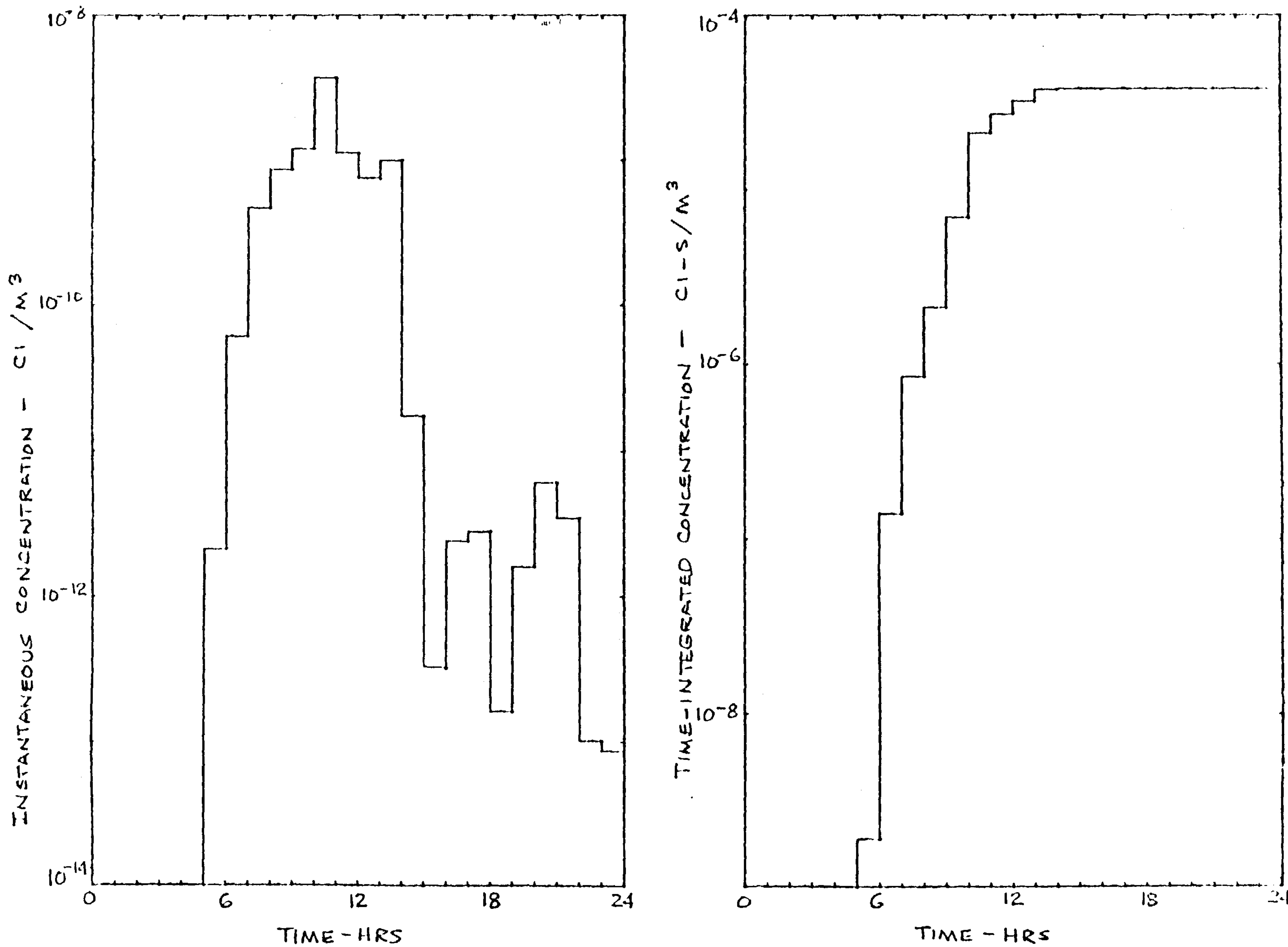


Figure 4d. Same as Fig. 4a, except nuclide is cesium-137.

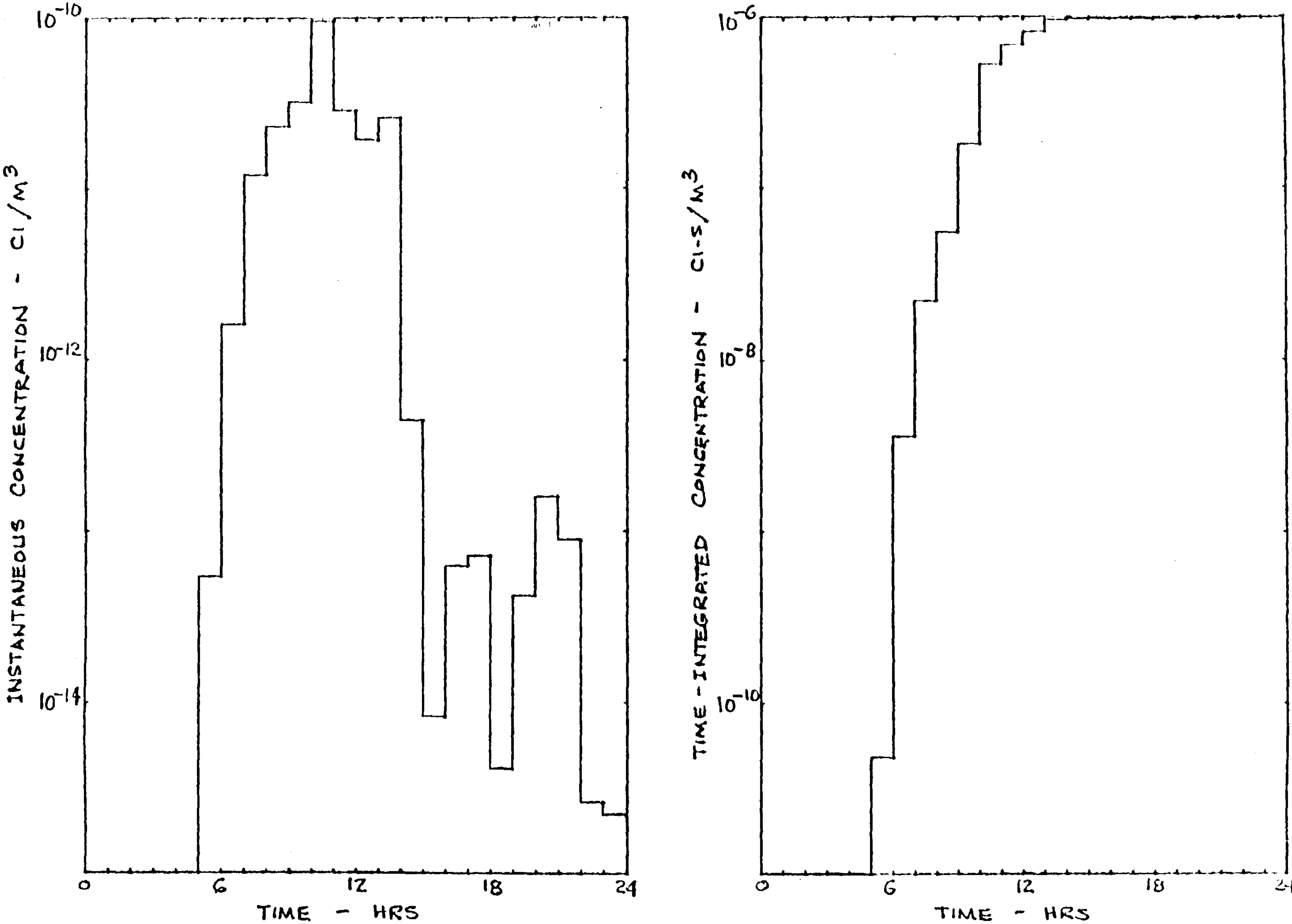


Figure 4e. Same as Fig. 4a, except nuclide is europium-155.

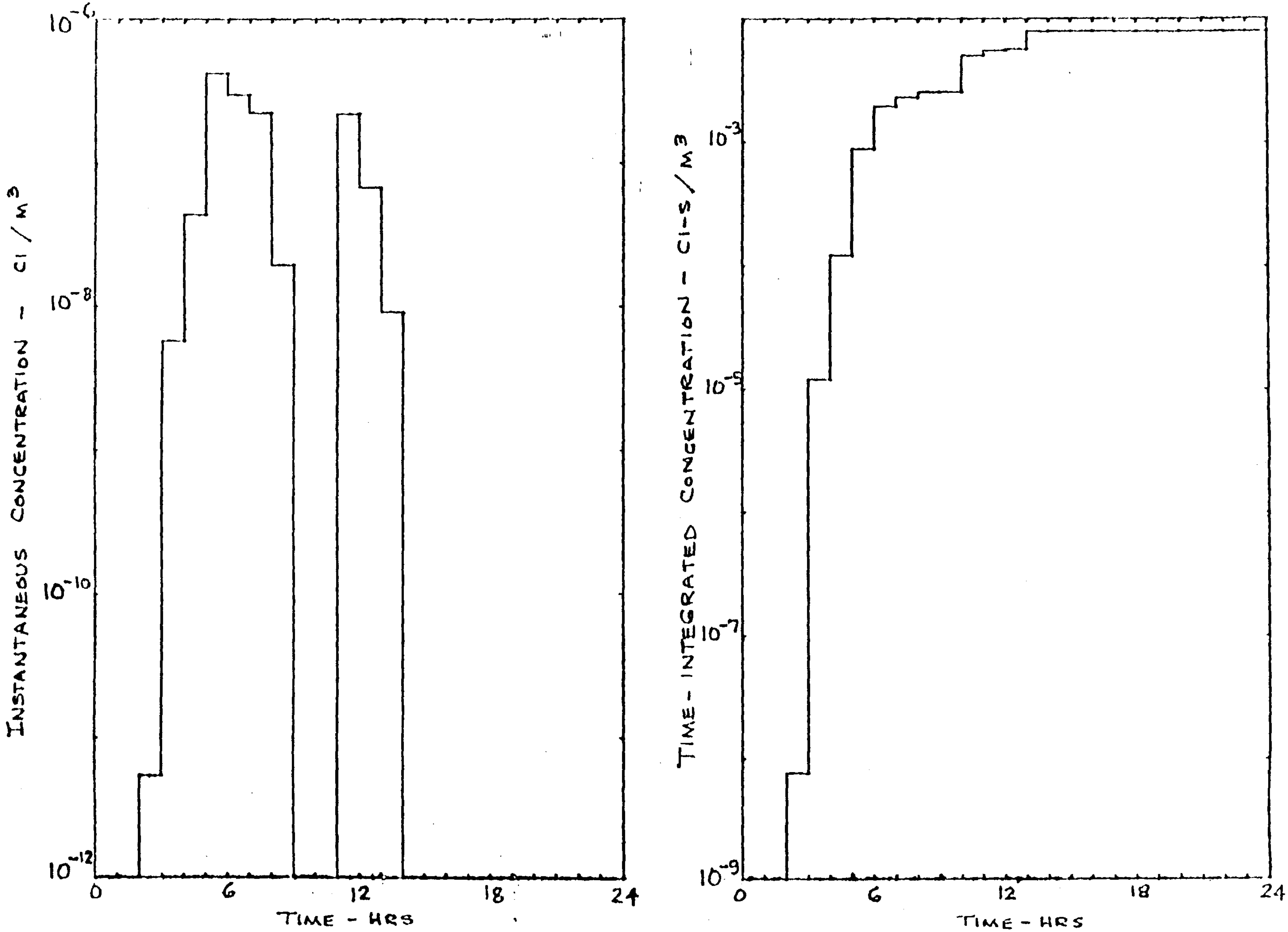


Figure 5a. Castle Bravo instantaneous and time-integrated surface air concentrations for Sifo Island, Ailinginae Atoll. The nuclide is tellurium-129.

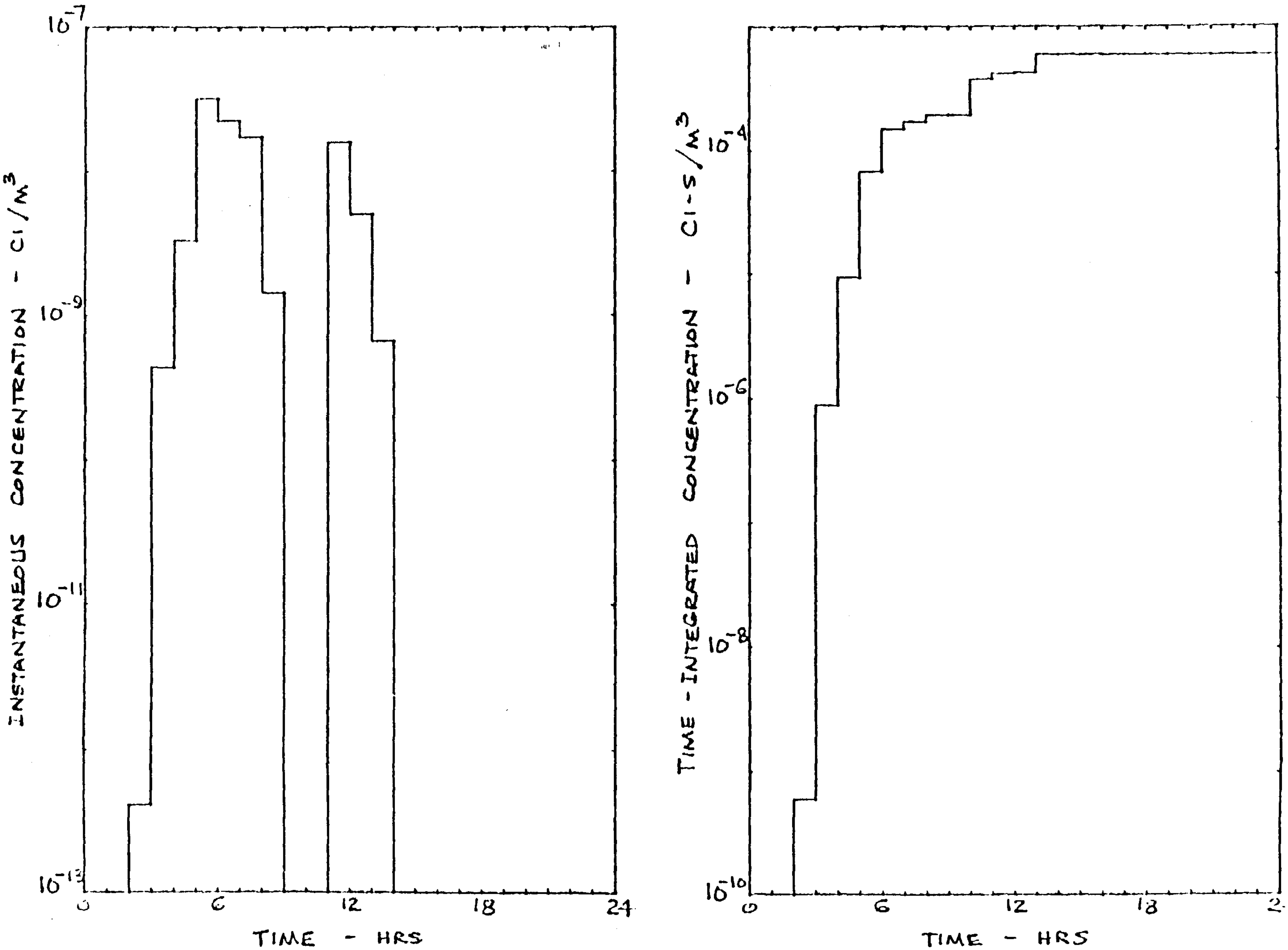


Figure 5b. Same as Fig. 5a, except nuclide is iodine-131.

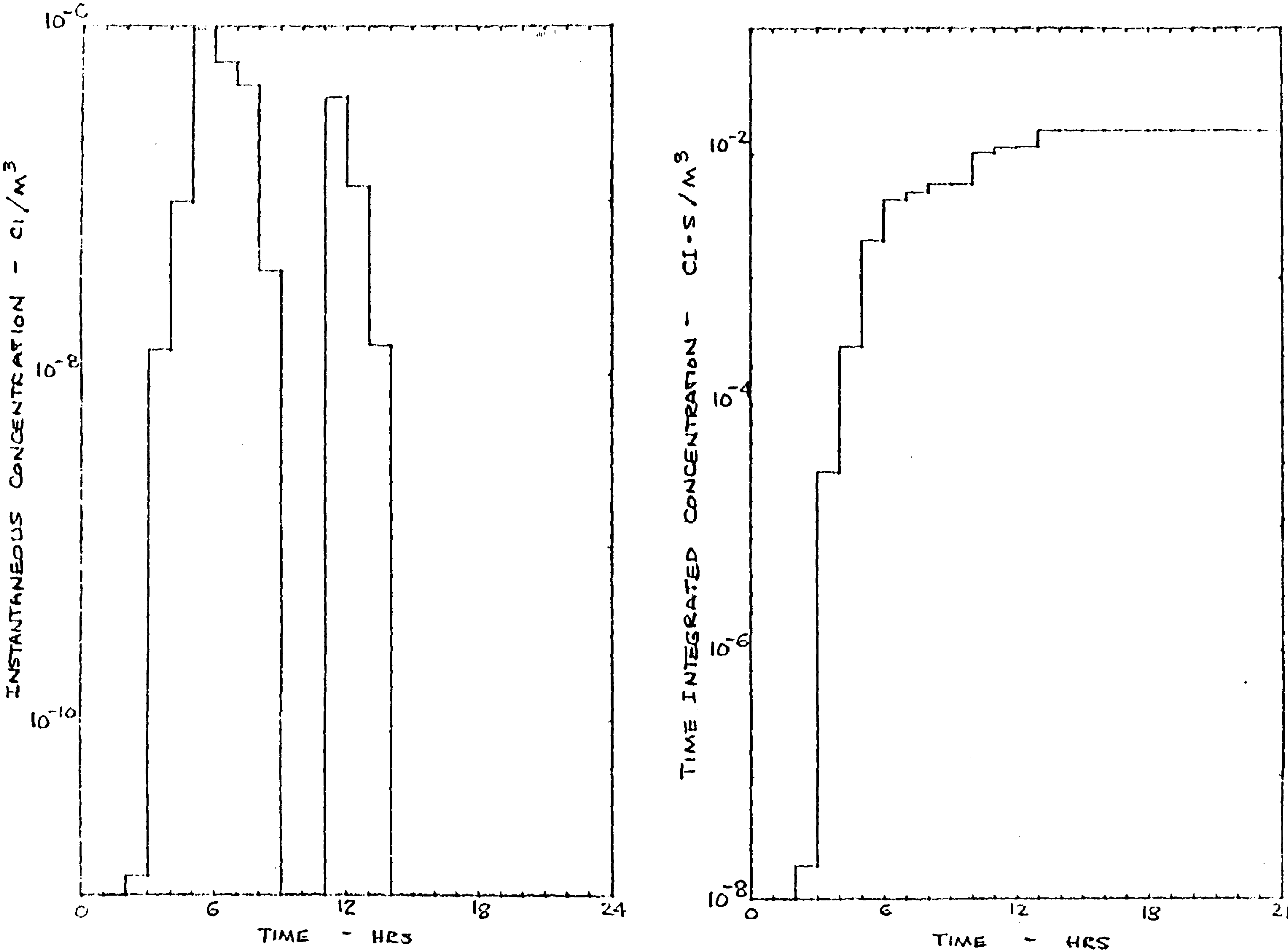


Figure 5c. Same as Fig. 5a, except nuclide is iodine-133.

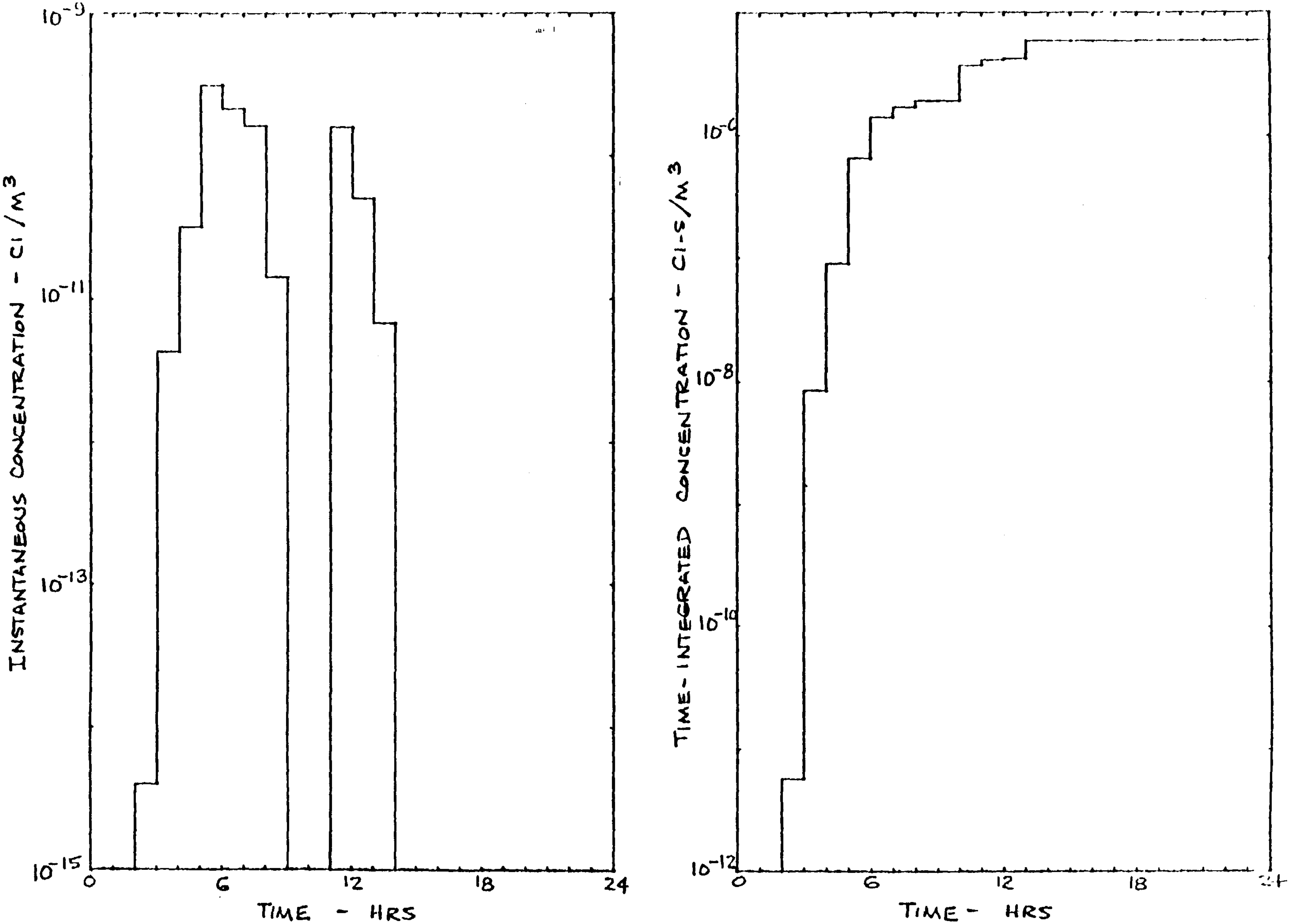


Figure 5d. Same as Fig. 5a, except nuclide is cesium-137.

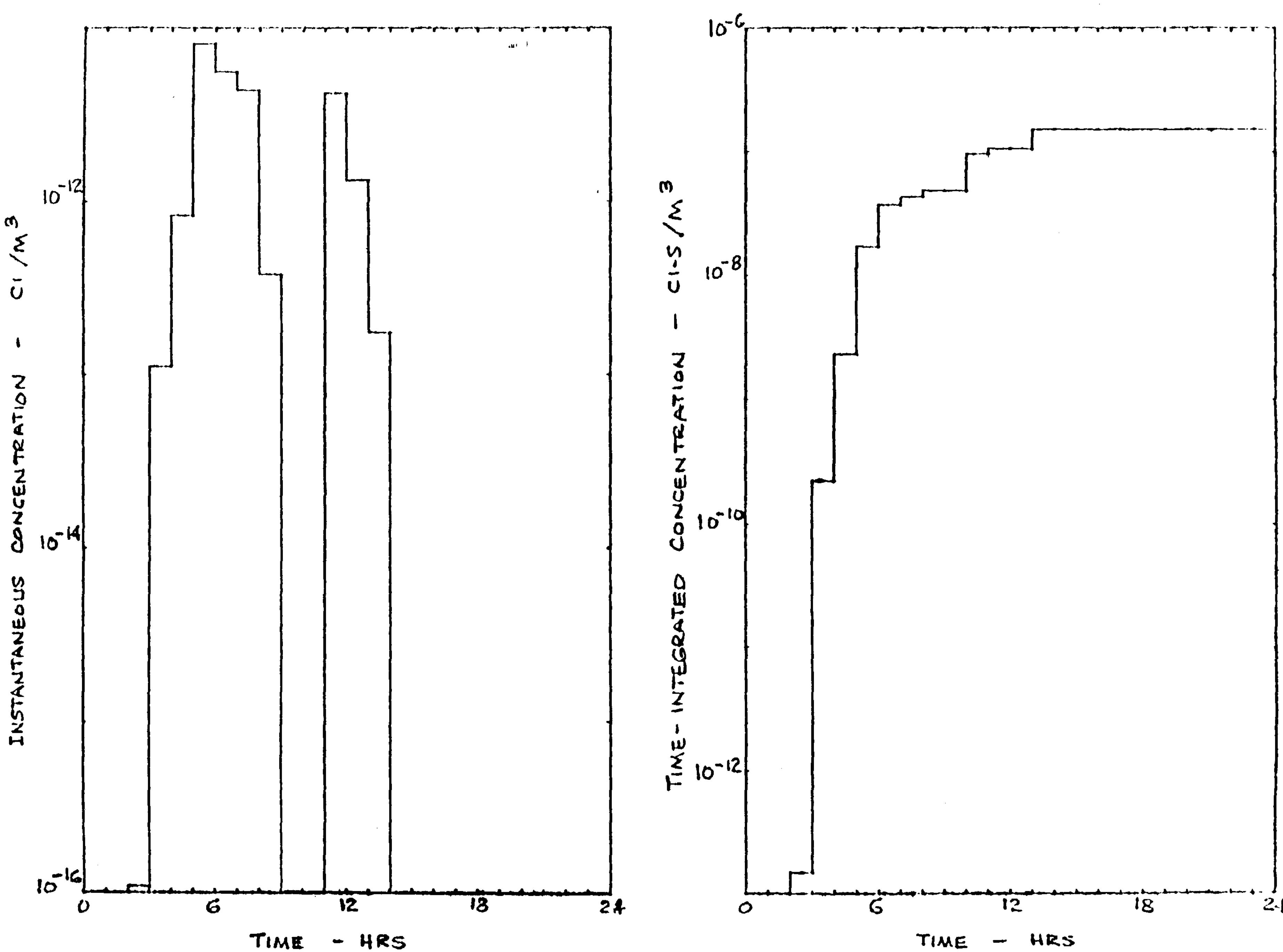


Figure 5e. Same as Fig. 5a, except nuclide is europium-155.