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Atmospheric Tritium Sampling

April 1982—March 1983

Los Alamos
Los Alamos National Laboratory
Los Alamos, New Mexico 87545

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Allen S. Mason

Los Alamos
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Los Alamos, New Mexico 87545

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by

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ABSTRACT

As part of Project Airstream (sponsored by the USDOE), tritium gas and tritiated water vapor are sampled in the stratosphere. Airstream data show that three perturbations of the stratospheric tritiated water burden have occurred since 1980. An atmospheric nuclear detonation in 1980 injected about 2.1 MCi. The massive eruptions of the Mexican volcano El Chichon appeared to double the removal rate in 1982. An unusually large winter-time exchange with the upper stratosphere occurred between 1982 and 1983.

I. INTRODUCTION

The data upon which this report is based were collected by Project Airstream, the aircraft component of the US Department of Energy's High Altitude Sampling Program. The project, aircraft, and equipment used have been described in previous publications.[1,2]

Before 1975, analyses for tritiated water vapor and tritium gas were performed on whole-air samples collected by Airstream in high-pressure spheres, but these data were not published. In 1973, the former US Atomic Energy Commission sponsored the University of Miami's development of a catalytic-adsorptive tritium sampler. The sampler design was based on technology developed for ground-level and transport-aircraft-borne samplers.[3] Since 1975, this sampler has been used on all Airstream deployments to collect separately the two dominant tritium-containing chemical species: water vapor (HTO) and hydrogen gas (HT). Previous data have indicated that atmospheric detonations deposit HTO almost exclusively,[4,5] and although HT data are tabulated, this report is concerned primarily with the HTO species. A recent publication[6] used the Airstream HTO data to compare the stratospheric residence times of ^{95}Zr and HTO and to estimate injections of the two species from large Chinese atmospheric tests of June 27, 1973 and November 17, 1976. This publication is the first to estimate the injection from the October 16, 1980 Chinese test and is an expansion of an earlier, unpublished report.[7] Measurements of the stratospheric sulfate aerosol burden are also a regular part of the project and have been used to quantify the injections from recent volcanic eruptions, including those from El Chichon in 1982 (Refs. 1 and 8).

II. EXPERIMENT RESULTS

Tritium data from Airstream deployments between April 1975 and November 1981 were reported in earlier publications: Airstream missions 4 through 16 (April 1975--August 1979),[5] missions 17 through 19 (October 1979--August 1980),[9] and missions 20 through 23 (October 1980--November 1981).[10] The Airstream missions discussed in this report were flown on the following dates:

Mission 24	April 14 to May 8, 1982
Mission 25	July 14 to August 4, 1982
Mission 26	October 13 to 30, 1982
Mission 27	March 8 to 28, 1983

This report contains data through March 1983 in Tables I-IV. Figures 1 through 4 present HTO isopleths calculated from these data. To assess the movement of the El Chichon aerosol across the intertropical convergence zone, the latitude spans of the October 1982 and March 1983 deployments were extended to 10°S.

TABLE I

TRITIUM GAS AND TRITIATED WATER VAPOR

SAMPLED BY AIRSTREAM MISSION 24

Flight	Sample No.	North Lat.	West Long.	Alt. (km)	Pressure (mbar)	Temp. (°C)	θ (K)	Tritium (pCi/scm) HTO	σ	HT	σ
1	1	28.8	95.2	9.1	301	-38.2	331	1.30	0.07	1.43	0.06
1	2	29.0	94.8	12.2	188	-59.1	345	0.57	0.03	1.54	0.08
1	3	28.9	94.8	13.7	148	-61.3	366	0.49	0.04	1.34	0.06
1	4	29.2	94.3	15.2	116	-69.0	377	2.78	0.13		
1	5	28.9	94.7	16.8	92	-62.2	417	3.48	0.18	1.16	0.07
1	6	28.8	95.1	19.2	63	-57.3	477	16.82	0.67		
1	1	23.4	95.1	16.8	92	-72.9	396	1.42	0.08		
2	2	23.5	95.0	19.2	63	-60.5	469	5.79	0.26		
2	3	28.4	95.2	18.3	72	-64.7	442	7.24	0.36		
3	1	23.4	87.5	13.7	148	-64.9	360	0.37	0.02		
3	2	17.4	83.9	13.7	148	-65.6	358	0.25	0.02		
3	3	11.5	81.3	13.7	148	-66.8	356	0.18	0.02		
4	1	11.5	79.4	16.8	92	-79.0	384	0.36	0.03		
4	2	17.5	79.2	16.8	92	-75.1	392	0.59	0.04	1.86	0.09
4	3	17.5	79.4	19.0	64	-63.5	460	0.49	0.03		
4	4	11.5	79.5	19.2	63	-58.2	475	0.65	0.04		
5	1	1.5	79.7	15.2	116	-77.7	361	0.85	0.05	1.58	0.09
5	2	1.6	79.6	18.3	72	-72.4	425	0.22	0.03		
5	3	5.6	79.6	18.3	72	-70.9	429	0.32	0.06	2.07	0.14
5	4	4.4	79.5	19.2	63	-59.1	473	0.35	0.03	1.32	0.09
5	5	1.5	79.6	16.8	92	-78.8	385	0.40	0.04		
6	1	11.0	78.8	12.2	188	-57.6	348	1.52	0.07	1.31	0.07
6	2	13.2	78.8	13.7	148	-67.0	356	0.19	0.03		
6	3	10.8	79.0	15.2	116	-76.9	363	0.24	0.02	1.69	0.08
6	4	10.7	79.1	16.8	92	-82.5	377	0.21	0.03		
6	5	10.4	79.5	19.2	63	-67.1	455	1.64	0.08		
7	1	11.5	81.4	15.2	116	-76.4	364	0.20	0.02		
7	2	17.5	84.0	15.2	116	-73.3	369	0.46	0.03	1.30	0.07
7	3	23.5	87.9	15.2	116	-68.0	379	0.27	0.02		

TABLE I (cont)

Flight	Sample No.	North Lat.	West Long.	Alt. (km)	Pressure (mbar)	Temp. (°C)	θ (K)	Tritium (pCi/scm) HTO	σ	HT	σ
8	1	34.5	100.6	16.8	92	-56.2	429	2.78	0.14	1.23	0.06
8	2	44.0	108.3	16.8	92	-49.1	444	3.94	0.18		
8	3	43.2	108.6	18.3	72	-48.1	477	8.21	0.37		
8	4	39.5	108.5	19.2	63	-48.5	496	10.83	0.51		
8	5	36.4	107.6	19.2	63	-53.4	485	9.97	0.46		
9	1	34.5	102.3	15.2	116	-60.1	394	6.43	0.29		
9	2	40.5	110.3	15.2	116	-58.0	398	4.01	0.19		
9	3	46.0	145.3	15.2	116	-56.6	400	5.46	0.27		
10	1	46.5	123.9	13.7	148	-55.1	377	7.66	0.35		
10	2	52.5	132.3	13.7	148	-50.4	385	4.14	0.21	1.51	0.06
10	3	58.7	142.9	13.7	148	-46.0	392	5.09	0.24		
11	1	66.5	148.3	12.2	188	-47.4	364	5.01	0.26	1.39	0.07
11	2	73.0	148.4	12.2	188	-46.9	365	5.34	0.25	1.21	0.05
11	3	73.0	148.4	16.8	92	-38.6	464	11.70	0.52	1.56	0.08
11	4	66.5	148.1	16.8	92	-39.6	462	9.87	0.47	1.61	0.09
12	1	60.0	149.6	15.2	116	-42.7	426	3.35	0.17		
12	2	66.5	148.6	15.2	116	-42.1	427	4.45	0.23		
12	3	72.8	148.2	15.2	116	-42.7	426	5.92	0.32		
12	4	72.8	147.9	18.9	65	-36.0	518	12.01	0.59		
12	5	66.5	148.6	19.1	64	-36.7	520	13.12	0.63		
13	1	61.5	149.8	9.1	301	-54.6	308	1.18	0.06	1.46	0.07
13	2	61.9	149.1	10.7	238	-49.6	337	2.86	0.15	1.52	0.07
13	3	62.6	150.3	12.2	188	-46.2	366	8.39	0.42	1.47	0.07
13	4	62.6	150.4	13.7	148	-43.4	397	17.88	0.77	0.99	0.05
14	1	58.5	144.2	16.8	92	-44.9	452	3.87	0.19		
14	2	52.5	138.0	16.8	92	-49.9	442	3.67	0.20	1.49	0.07
14	3	46.5	133.8	16.8	92	-53.5	435	5.32	0.26		
15	1	40.5	109.7	13.7	148	-53.8	379	4.45	0.21	1.22	0.05
15	2	34.5	101.6	13.7	148	-55.5	376	0.11	0.02		

TABLE II

TRITIUM GAS AND TRITIATED WATER VAPOR
SAMPLED BY AIRSTREAM MISSION 25

Flight	Sample No.	North Lat.	West Long.	Alt. (km)	Pressure (mbar)	Temp. (°C)	θ (K)	Tritium (pCi/scm) HTO	σ	HT	σ
1	1	28.5	95.4	9.1	301	-35.9	334	3.01	0.17	1.73	0.08
1	2	28.5	95.2	12.2	188	-60.7	343	1.59	0.09	1.72	0.10
1	3	28.5	95.6	13.7	148	-67.8	354	1.54	0.08	1.74	0.09
1	4	28.5	95.4	15.2	116	-70.3	375	2.00	0.10		
1	5	28.4	95.4	16.8	92	-65.4	411	3.96	0.17	1.62	0.09
1	6	28.2	95.5	19.2	63	-57.9	475	11.40	0.46		
2	1	23.5	93.8	16.8	92	-64.4	413	5.37	0.22		
2	2	23.5	93.8	19.2	63	-55.9	480	11.26	0.47		
2	3	28.5	94.3	18.3	72	-58.5	455	11.96	0.51		
3	1	23.5	88.7	15.2	116	-66.1	383	3.58	0.16		
3	2	17.5	84.2	15.2	116	-68.0	379	3.04	0.14		
3	3	11.5	81.3	15.2	116	-71.6	373	2.51	0.12		
4	1	11.5	54.4	16.8	92	-67.1	408	1.44	0.08		
4	2	17.5	79.1	16.8	92	-69.1	404	2.08	0.09	1.41	0.09
4	3	17.5	79.1	19.2	63	-57.9	475	3.70	0.17		
4	4	11.5	79.4	19.1	63	-62.2	464	4.85	0.24		
5	1	1.5	79.6	15.2	116	-74.2	368	0.83	0.05	1.52	0.07
5	2	1.5	79.8	16.8	92	-72.7	397	0.40	0.04		
5	3	7.5	80.0	18.3	72	-63.7	444	2.12	0.11	1.47	0.05
5	4	1.5	79.7	18.3	72	-63.3	445	2.91	0.14	1.37	0.06
5	5	1.5	79.8	19.2	63	-61.6	467	3.05	0.15		
7	1	8.9	80.2	13.7	148	-69.7	351	1.52	0.06	1.07	0.04
7	2	11.5	81.1	13.7	148	-69.5	352	0.22	0.02		
7	3	17.5	84.0	13.7	148	-65.7	358	0.54	0.03	1.37	0.07
7	4	20.5	85.4	13.7	148	-66.8	356	2.48	0.10		
7	5	23.5	87.7	13.7	148	-68.5	353	0.66	0.03		
8	1	36.0	92.7	16.8	92	-62.0	418	4.35	0.21		

TABLE II (cont)

Flight	Sample No.	North Lat.	West Long.	Alt. (km)	Pressure (mbar)	Temp. (°C)	Θ (K)	Tritium (pCi/scm) HTO	σ	HT	σ
8	2	40.0	93.2	16.8	92	-60.0	422	5.31	0.25	1.47	0.08
8	3	46.0	93.0	19.1	63	-51.5	488	12.45	0.59		
8	4	39.0	92.9	19.2	63	-54.7	482	12.58	0.58		
8	5	35.0	92.9	19.2	63	-56.7	478	13.14	0.61		
9	1	34.5	102.0	15.2	116	-66.7	382	1.15	0.06		
9	2	40.5	109.5	15.2	116	-65.6	384	1.47	0.07		
9	3	46.0	119.3	15.2	116	-61.1	392	3.59	0.17		
10	1	46.5	124.7	13.7	148	-55.3	376	0.64	0.04		
10	2	52.5	132.8	13.7	148	-52.5	381	0.96	0.05	1.32	0.05
10	3	58.5	142.6	13.7	148	-51.5	383	2.10	0.10		
11	1	66.5	149.6	12.2	188	-47.7	364	2.26	0.11	1.48	0.07
11	2	73.0	148.3	12.2	188	-45.0	368	1.40	0.07	1.87	0.10
11	3	73.0	149.6	16.8	92	-41.3	459	2.18	0.11	1.19	0.07
11	4	66.5	149.8	16.8	92	-43.3	455	1.99	0.10	1.22	0.07
12	1	60.0	150.2	15.2	116	-43.3	425	1.03	0.05		
12	2	66.5	149.8	15.2	116	-42.0	427	1.61	0.08		
12	3	73.0	149.0	15.2	116	-43.2	425	2.61	0.11		
12	4	73.0	148.1	18.6	69	-37.0	507	6.44	0.30		
12	5	66.5	149.3	19.2	63	-37.4	521	6.33	0.30		
13	1	59.2	154.7	9.1	301	-49.3	316	1.85	0.07	1.39	0.07
13	2	59.6	154.1	10.7	238	-54.9	329	1.68	0.08	1.44	0.09
13	3	59.6	154.2	12.2	188	-46.0	366	5.10	0.22	1.40	0.07
13	4	59.8	153.7	13.7	148	-44.0	396	8.80	0.36		
13	5	59.7	154.3	16.8	92	-40.8	460	8.98	0.35	0.95	0.06
13	6	59.8	153.8	19.0	64	-38.4	515	14.86	0.59		
14	1	58.5	144.5	16.8	92	-42.6	456	1.57	0.08		
14	2	52.5	133.1	16.8	92	-44.6	452	2.40	0.12	1.34	0.07
14	3	46.5	133.8	16.8	92	-48.9	444	2.95	0.15		
15	1	40.5	109.4	13.7	148	-62.0	365	1.81	0.09	1.24	0.06
15	2	34.5	101.3	13.7	148	-66.5	357	0.07	0.02		

TABLE III

TRITIUM GAS AND TRITIATED WATER VAPOR
SAMPLED BY AIRSTREAM MISSION 26

Flight	Sample No.	North Lat.	West Long.	Alt. (km)	Pressure (mbar)	Temp. (°C)	θ (K)	Tritium (pCi/scm) HTO	σ	HT	σ
1	1	28.3	95.7	13.7	148	-66.9	356	1.03	0.06	1.38	0.08
1	2	28.5	95.0	15.2	116	-70.9	374	0.48	0.04	1.34	0.07
1	3	28.6	95.1	16.8	92	-70.1	402	0.62	0.04	1.64	0.10
1	4	28.5	96.2	19.2	63	-58.8	473	1.75	0.09		
2	1	23.5	93.8	16.8	92	-67.8	407	0.57	0.03		
2	2	23.5	93.7	19.2	63	-61.5	467	1.35	0.07		
2	3	28.5	94.6	18.3	72	-60.1	451	2.55	0.12		
3	1	23.5	87.7	15.2	116	-70.4	375	0.56	0.03		
3	2	17.5	84.1	15.2	116	-78.0	361	0.48	0.03		
3	3	11.5	81.4	15.2	116	-80.2	357	0.34	0.02		
4	1	11.5	79.4	16.8	92	-77.7	387	0.31	0.03		
4	2	17.5	79.1	16.8	92	-78.4	386	0.81	0.05	1.24	0.08
4	3	17.6	79.1	19.2	63	-59.7	471	5.48	0.25		
4	4	11.5	79.5	19.2	63	-60.5	470	6.02	0.27		
5	1	5.7	79.3	15.2	116	-75.3	366	1.31	0.07	1.34	0.06
5	2	-2.0	79.7	15.2	116	-76.6	363	0.33	0.03		
5	3	-8.3	78.1	15.2	116	-75.4	366	0.59	0.05	1.45	0.11
5	4	-8.5	78.2	18.3	72	-69.7	431	1.10	0.06	1.58	0.09
5	5	-2.0	79.7	18.3	72	-71.8	427	1.52	0.08		
5	6	5.0	79.5	18.3	72	-72.2	426	1.39	0.08	1.46	0.07
6	1	5.0	79.6	16.8	92	-76.2	390	0.32	0.02		
6	2	-2.0	79.7	16.8	92	-73.1	396	0.67	0.04	1.31	0.07
6	3	-8.5	78.1	16.8	92	-74.6	393	0.66	0.04		
6	4	-8.5	78.2	19.3	62	-55.9	481	3.06	0.15		
6	5	-2.0	79.7	19.8	57	-55.1	494	2.20	0.11	1.42	0.08
6	6	5.0	79.6	20.1	54	-53.8	505	2.58	0.13		
7	1	11.5	81.5	13.7	148	-68.8	353	0.29	0.02		
7	2	17.5	83.9	13.7	148	-69.1	352	0.32	0.03	1.25	0.07

TABLE III (cont)

Flight	Sample No.	North Lat.	West Long.	Alt. (km)	Pressure (mbar)	Temp. (°C)	θ (K)	Tritium (pCi/scm) HTO	σ	HT	σ
7	3	23.5	87.6	13.7	148	-65.8	358	0.17	0.02		
8	1	36.0	93.0	16.8	92	-64.9	412	0.60	0.04		
8	2	40.0	93.0	16.8	92	-64.1	414	1.26	0.06	1.25	0.08
8	3	46.0	93.5	19.2	63	-56.5	478	3.04	0.15		
8	4	39.0	93.5	19.2	63	-57.7	476	3.92	0.19		
8	5	35.0	93.7	19.2	63	-58.0	475	5.83	0.27		
9	1	34.5	102.4	15.2	116	-63.8	387	1.26	0.06		
9	2	40.5	110.3	15.2	116	-62.4	390	1.35	0.07		
9	3	46.0	119.4	15.2	116	-60.2	394	1.73	0.08		
10	1	46.5	124.2	13.7	148	-54.6	377	0.93	0.05		
10	2	52.5	130.6	13.7	148	-52.5	381	4.19	0.19	1.30	0.06
10	3	58.5	142.2	13.7	148	-56.4	374	2.32	0.11		
11	1	66.5	148.4	12.2	188	-51.2	358	0.93	0.05	1.29	0.06
11	2	73.0	147.8	12.2	188	-51.1	358	1.65	0.08	1.17	0.05
11	3	73.0	147.1	16.8	92	-50.4	441	2.83	0.13	1.56	0.08
11	4	66.5	148.8	16.8	92	-49.5	443	3.89	0.19	1.61	0.08
12	1	60.0	150.2	15.2	116	-57.0	400	0.95	0.05		
12	2	66.5	148.8	15.2	116	-54.9	403	2.03	0.09		
12	3	73.0	148.5	15.2	116	-53.3	406	2.99	0.14		
12	4	73.0	149.0	18.9	66	-49.5	487	7.66	0.35		
12	5	66.5	148.9	19.2	63	-51.3	490	9.19	0.42		
13	1	61.9	153.4	9.1	302	-51.8	312	2.55	0.12	1.17	0.05
13	2	61.3	154.5	10.7	239	-45.8	342	1.63	0.10	1.06	0.05
13	3	61.5	154.8	12.2	188	-47.7	364	1.16	0.06	1.05	0.07
13	4	61.3	154.6	13.7	148	-49.2	387	2.15	0.10		
13	5	60.9	154.6	16.8	92	-50.2	441	2.24	0.11	1.26	0.07
13	6	60.9	152.1	19.0	64	-47.0	496	4.46	0.21		
14	1	58.5	143.8	16.8	92	-49.0	444	1.86	0.09		
14	2	52.5	138.0	16.8	92	-50.0	442	2.95	0.14	1.36	0.06
14	3	46.5	133.6	16.8	92	-52.5	437	4.43	0.21		
15	1	40.5	110.1	13.7	148	-64.0	361	3.95	0.18	1.30	0.06
15	2	34.5	102.2	13.7	148	-60.7	367	1.33	0.07		

TABLE IV

TRITIUM GAS AND TRITIATED WATER VAPOR

SAMPLED BY AIRSTREAM MISSION 27

Flight	Sample No.	North Lat.	West Long.	Alt. (km)	Pressure (mbar)	Temp. (°C)	θ (K)	Tritium (pCi/scm) HTO	σ	HT	σ
1	1	28.7	95.1	13.7	148	-49.8	386	2.61	0.12	1.46	0.07
1	2	28.6	95.0	15.2	116	-53.3	407	3.87	0.17		
1	3	28.6	95.6	16.8	92	-54.8	432	3.78	0.18	1.54	0.09
1	4	29.1	93.5	19.2	63	-56.5	478	11.88	0.52		
2	1	23.5	93.7	16.8	92	-70.2	402	0.15	0.02		
2	2	23.5	93.8	19.2	63	-68.6	452	0.28	0.03		
2	3	28.5	93.8	18.3	72	-63.9	443	0.94	0.05		
3	1	23.5	87.6	15.2	116	-75.6	365	0.74	0.04		
3	2	17.5	84.0	15.2	116	-75.6	365	0.69	0.05		
3	3	11.5	81.4	15.2	116	-77.1	362	0.72	0.04		
4	1	11.5	79.4	16.8	92	-80.0	382	0.19	0.02		
4	2	17.5	79.1	16.8	92	-80.8	381	0.31	0.02		
4	3	17.5	79.1	19.2	63	-69.5	450	0.77	0.05		
4	4	11.5	79.5	19.2	63	-67.3	455	1.07	0.06		
5	1	5.0	79.6	15.2	116	-78.3	360	0.96	0.05	1.38	0.08
5	2	-2.0	79.7	15.2	116	-79.2	359	0.08	0.01		
5	3	-8.5	78.2	15.2	116	-78.0	361	0.26	0.03	1.16	0.07
5	4	-8.5	78.3	18.3	72	-67.6	436	0.67	0.05	1.29	0.07
5	5	-2.0	79.7	18.3	72	-66.8	437	0.97	0.05		
5	6	5.0	79.7	18.3	72	-72.3	426	1.26	0.07	1.31	0.08
6	1	5.0	79.6	16.8	92	-74.6	393	0.23	0.02		
6	2	-2.0	79.7	16.8	92	-78.3	386	0.57	0.04	1.39	0.11
6	3	-8.5	78.2	16.8	92	-82.1	378	0.17	0.02		
6	4	-8.5	78.1	19.6	59	-63.2	471	1.96	0.10		
6	5	-2.0	79.7	20.0	55	-62.9	481	3.33	0.16	1.32	0.09
6	6	5.0	79.6	20.2	53	-61.7	489	3.17	0.15		
7	1	11.5	81.0	13.7	148	-68.5	353	0.32	0.03		
7	2	17.5	85.0	13.7	148	-66.8	356	0.42	0.03	1.16	0.05
7	3	23.5	87.6	13.7	148	-64.8	360	0.13	0.01		

TABLE IV (cont)

Flight	Sample No.	North Lat.	West Long.	Alt. (km)	Pressure (mbar)	Temp. (°C)	θ (K)	Tritium (pCi/scm) HTO	σ	HT	σ
8	1	36.0	92.9	16.8	92	-55.2	431	0.59	0.04		
8	2	40.0	92.7	16.8	92	-52.9	436	1.51	0.08	1.45	0.07
8	3	46.0	92.9	19.1	63	-48.6	495	2.47	0.14		
8	4	39.0	92.9	19.2	63	-52.3	488	2.58	0.13		
8	5	35.0	93.0	19.2	63	-55.2	481	3.78	0.17		
9	1	34.0	101.3	15.2	116	-56.8	400	1.99	0.10		
9	2	40.0	108.9	15.2	116	-59.7	395	2.96	0.14		
9	3	46.0	119.1	15.2	116	-56.1	401	2.90	0.14		
10	1	46.0	123.9	13.7	148	-48.9	387	4.69	0.21		
10	2	52.0	131.8	13.7	148	-44.8	394	3.67	0.18	1.34	0.07
11	1	60.0	150.2	15.2	116	-45.6	421	2.04	0.10	1.38	0.08
11	2	66.5	148.7	15.2	116	-44.9	422	1.89	0.10	1.28	0.07
11	3	73.0	148.1	15.2	116	-47.0	418	3.06	0.15		
11	4	73.0	148.6	12.2	188	-51.6	357	5.26	0.25	1.38	0.06
11	5	66.5	148.3	12.2	188	-48.8	362	0.95	0.05		
12	1	66.5	148.2	16.8	92	-44.2	453	3.35	0.16	1.39	0.07
12	2	73.0	147.8	16.8	92	-43.1	455	4.17	0.20	1.45	0.07
12	3	73.0	148.2	18.5	70	-40.6	498	8.52	0.41		
12	4	66.5	148.5	19.0	65	-40.9	508	10.86	0.51		
12	5	59.5	150.9	19.2	63	-42.2	510	11.18	0.52		
13	2	68.9	157.2	13.7	148	-47.2	390	5.74	0.28		
13	1	73.0	162.8	2.4	753	-19.1	275	25.97	1.12	1.28	0.08
13	3	73.0	159.6	2.4	753	-19.1	275	8.22	0.36		
13	5	73.0	156.4	2.4	753	-19.1	275	7.29	0.32	1.38	0.08
13	4	70.0	151.4	10.7	239	-52.4	332	7.24	0.33		
14	1	58.5	144.4	16.8	92	-46.7	448	1.98	0.10		
14	2	52.6	137.0	16.8	92	-46.7	448	2.40	0.12	1.46	0.08
14	3	46.5	133.9	16.8	92	-48.3	445	2.92	0.15		
15	1	40.0	108.4	13.7	148	-54.4	378	3.94	0.19	1.11	0.07
15	2	34.0	100.3	13.7	148	-54.1	378	5.10	0.24		

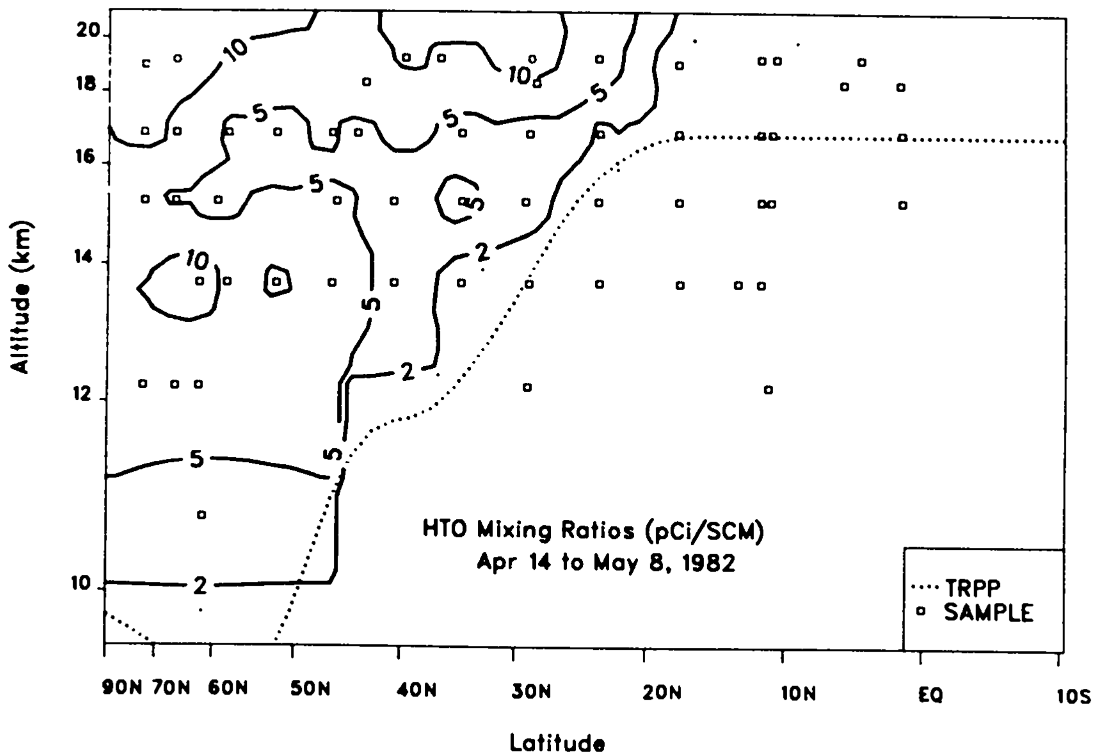

Fig. 1. Airstream mission 24 HTO contours.

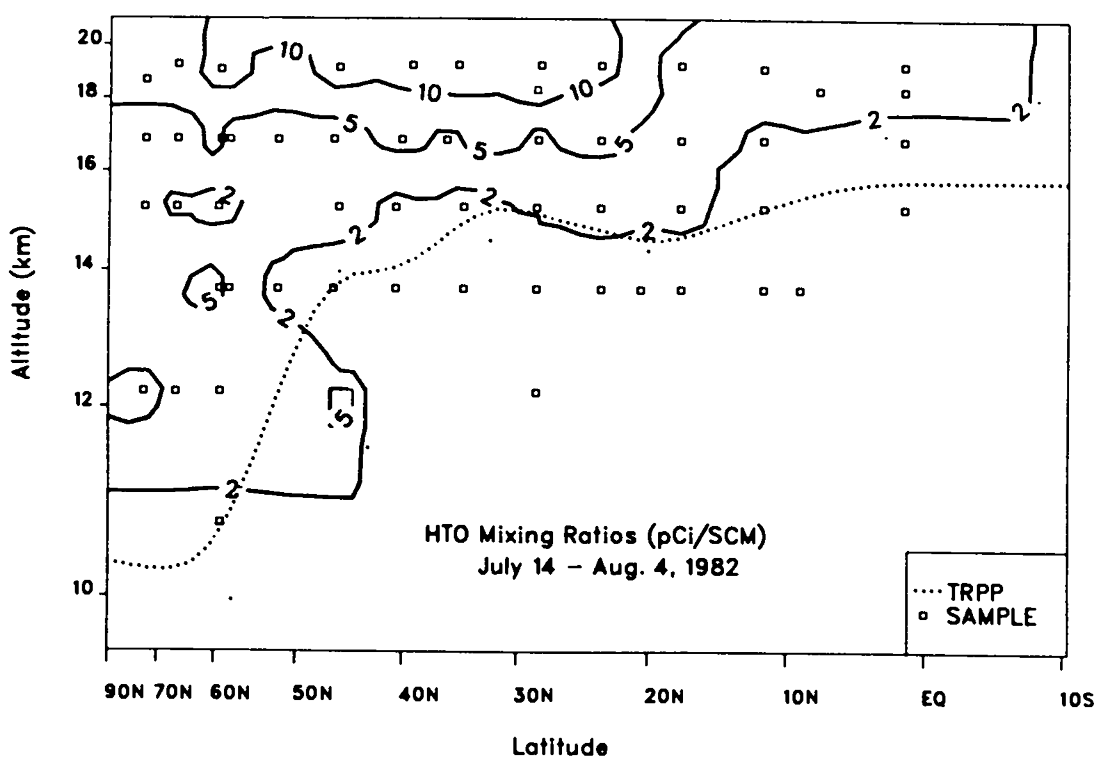

Fig. 2. Airstream mission 25 HTO contours.

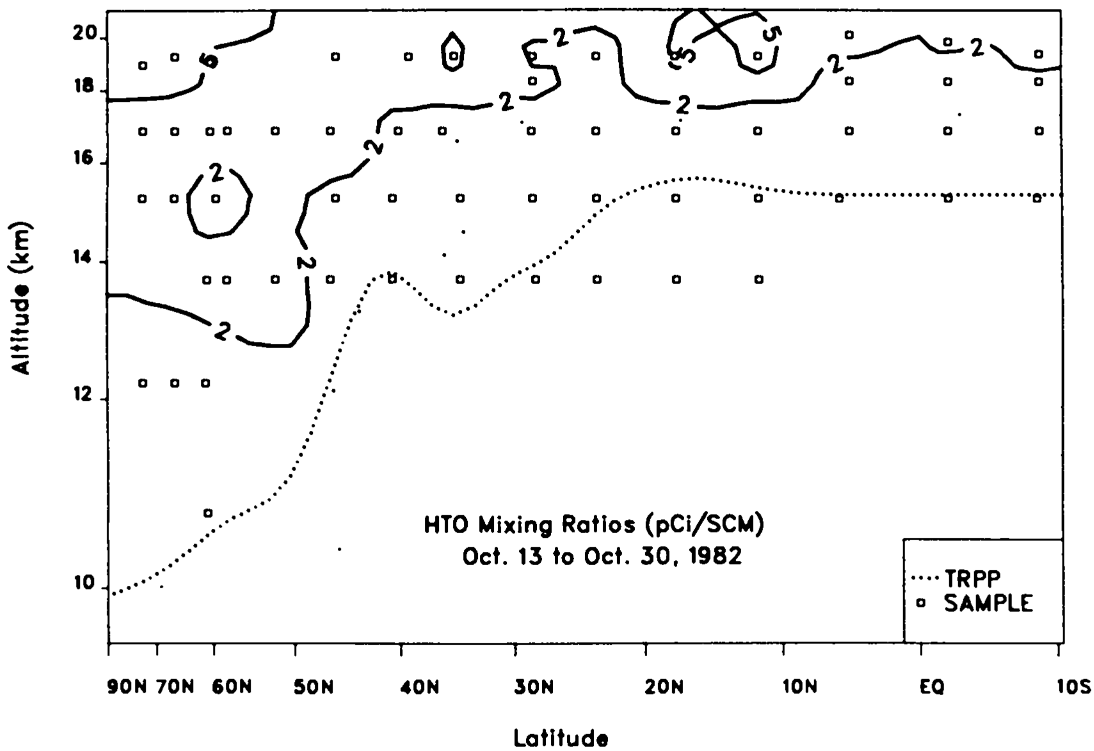

Fig. 3. Airstream mission 26 HTO contours.

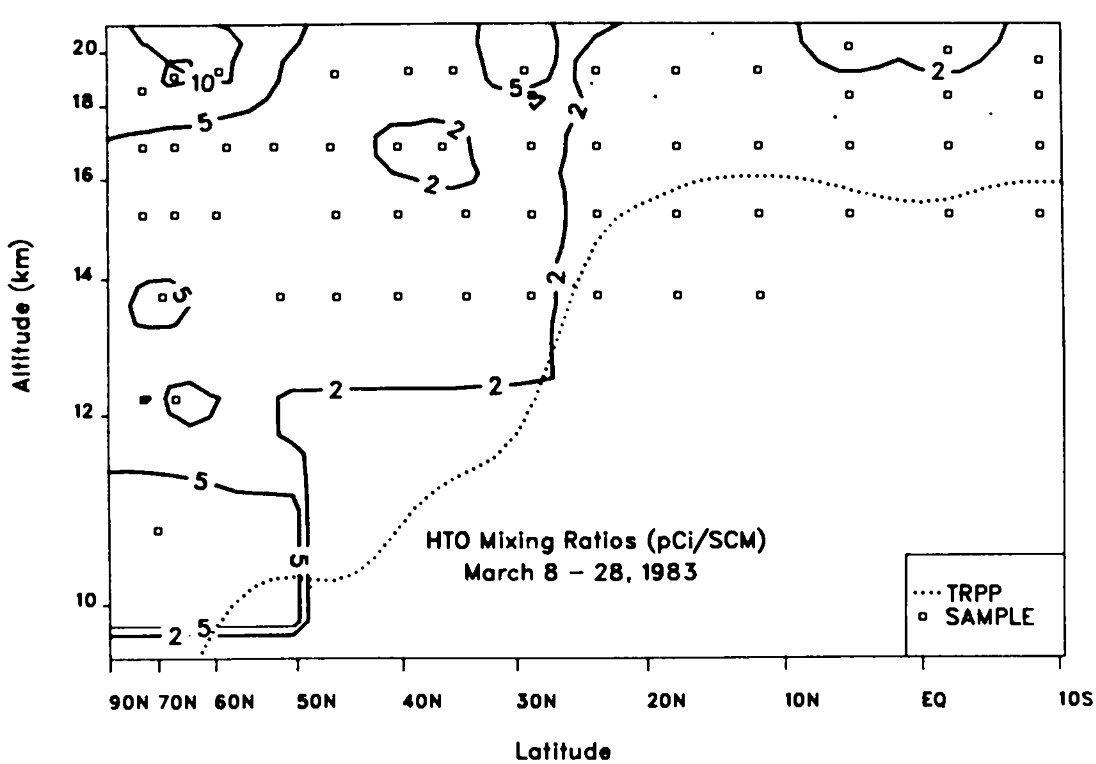

Fig. 4. Airstream mission 27 HTO contours.

III. INTERPRETATION

A. Burden Calculation

It is difficult to calculate the total hemispheric stratospheric burdens from the rather sparse Airstream data sets. Previous estimates were made by hand-contouring and integration of the region from 15.2- to 21.3-km altitude between the equator and 30°N, and from 9.1 to 21.3 km between 30 and 90°N. The troposphere was considered a zero isopleth in this technique. Some extrapolation was involved because the sampling flights provide coverage from 13.5 to 19.2 km between the equator and 60°N, and from 12.2 to 19.2 km between 60 and 75°N. Vertical profiles are taken at about 7, 29, and 61°N at an altitude range from 3 to 19.2 km.

For this report, burdens were calculated between the tropopause and 21.3 km for the entire hemisphere. Again, it was necessary to extrapolate data above the maximum flight altitude and from 75° to the North Pole. The zone north of 75° contains only about 3% of the hemispheric atmosphere, which renders the effect of extrapolation negligible. Reported tropopause-height data for the actual flight days were obtained for upper-air stations lying along the flight path and were smoothed to provide a continuous estimate of the tropopause over the latitude span. Tritium data below that tropopause were forced to zero in the contouring, and the region below was not included in the integration. Burdens from flights before 1982 were recalculated by the technique described below.

Calculations were done by matrix interpolation and contouring routines from the DISSPLA Version 9.0 (Integrated Software Systems Corporation) library. The interpolation consists of calculating HTO mixing ratios at the points of a regular grid of atmospheric pressure and sine of latitude. In this coordinate system, each cell of the grid represents a constant zonal air mass. A 48 by 35 grid was used to represent the area shown in Figs. 1-4. The grid extends to 10°S so that data in that region, collected on the October 1982 and March 1983 deployments, can be used in the contouring procedure. The contouring routine examines the neighborhood of each grid point for data lying within a specified range (in this case, 7 horizontal cells by 5 vertical cells). The routine then calculates a value for the grid point by weighting the data according to a specified function of the distance from the grid point (here, the inverse square). The grid is the basis of the isopleths drawn in Figs. 1-4. The integration is performed by taking as the mixing ratio the arithmetic mean of the four grid-point values that define a cell and multiplying that mixing ratio by the air mass of the cell. The resulting burdens are summed to calculate the hemispheric burden. Cells lying entirely below the tropopause or south of the equator are not included in the summation.

B. Injection in 1980

Table V shows the measured burdens that have been corrected for decay to October 16, 1980, by using the tritium half-life of 12.34 years. Calculated burdens obtained from least squares regression of each year's data are also shown. Following the large atmospheric tests of 1973 and 1976, Mason et al.[6] measured levels of ^{95}Zr and HTO in the lower stratosphere. They found a characteristic residence time (e-fold), excluding radioactive decay, of 14.6 months with a confidence range of 12.0 to 18.6 months. By the same technique, the 3 burdens preceding the October 16, 1980 test had a 12.8-month characteristic residence time, and the 3 posttest burdens in 1981 had a 14.7-month characteristic residence time. These regression lines were extrapolated to the test date. The discontinuity should then represent the injection estimate (shown in Table V and Fig. 5), which has a value of 2100 kCi. The uncertainty of the estimate was calculated by using the reported confidence level range[6] because three burdens are insufficient to calculate a meaningful range. The uncertainty is +430 to -480 kCi. Assuming a value of 20 MCi/MT (Ref. 11), the estimated injection indicates that the fusion yield of the device was about 0.1 MT. This yield is in reasonable agreement with the fusion yield of 0.15 MT inferred from a recent report that estimated the fission yield at 0.45 MT and the total yield at 0.6 MT (Ref. 12). Omitting the stratospheric burden above 21.3 km from the tritium injection calculation would introduce little error because the estimated magnitude of the test indicates that the cloud would not rise above that height.[4]

C. Possible Volcanic Effect

In 1982, the tritium burden decreased at an anomalous rate by comparison with other years. The apparent characteristic time for the three sampling periods in 1982 is 7.8 months, which is roughly half the normal residence time.

TABLE V

STRATOSPHERIC TRITIATED WATER BURDENS

Mission Number	Mid-date of Mission	Measured Burden (kCi)	Measured Burden[a] (kCi)	Calculated Burden[b] (kCi)
16	79/07/15	2351	2191	2172
18	80/04/26	1048	1020	1041
19	80/08/02	836	826	809
c	80/10/16	---	---	667
d	80/10/16	---	---	2768
21	81/04/19	1871	1925	1829
22	81/07/17	1302	1358	1498
23	81/10/24	1187	1257	1200
24	82/04/26	1256	1368	1467
25	82/07/25	957	1057	949
26	82/10/22	513	574	616
27	83/03/18	891	1021	---

[a]Decay-corrected to October 16, 1980.

[b]Annual regression calculation of decay-corrected data by least squares.

[c]Pretest extrapolation.

[d]Posttest back-extrapolation.

The statistical uncertainty on the characteristic time is rather large, but one possible cause of such a decrease might be an event with a direct chemical effect on the stratosphere. Although hydration of the newly formed aerosol consumes water, the mean mixing ratio of sulfate after the El Chichon eruptions is only about 20 ppbm.[1] The aerosol itself is about 30% water by weight; thus, its formation could only affect the free water burden of the stratosphere in areas of locally high sulfur concentrations.[13] Figure 1 appears to show such an effect in the region between the equator and 20° latitude. Selective removal of tritium throughout the entire stratosphere would require an isotopic effect of about 100, which appears unreasonable. This line of argument further assumes that the aerosol is not collected by the tritium sampler. This is a

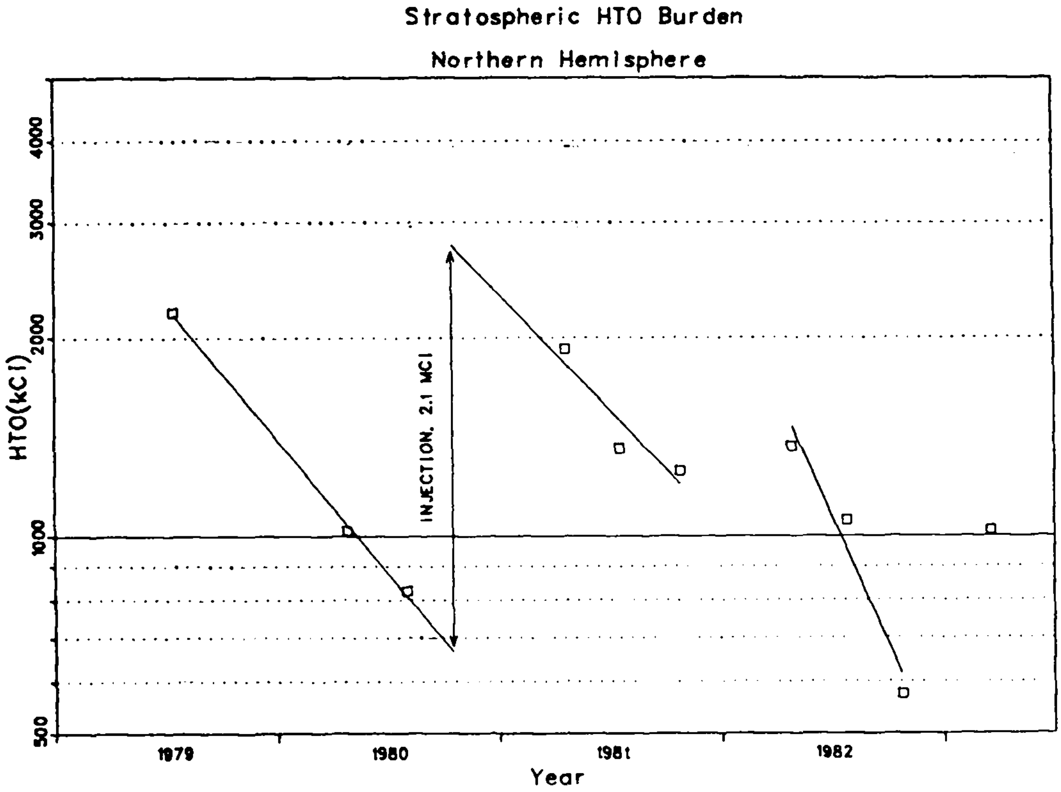

Fig. 5. Measured HTO burdens, regression lines, and injection.

reasonable assumption because aircraft bleed-air is used as the supply for the sampler.[2] A more likely reason for the faster removal of tritium is that the stratosphere-troposphere exchange rate is altered by the radiative effect of the sulfate aerosol. Quiroz reported warming of the atmosphere in the 30-mbar region as a result of the additional volcanic aerosol,[14] and Labitzke et al.[15] reported warming between 30 and 50 mbar. Circulation effects from the Agung eruption of 1963 were discussed by Dunkerton.[16]

D. Winter 1982-83 Exchange

A further observation that may be connected to abnormal depletion of the lower stratosphere is the increase in the sulfate aerosol burden between November 1982 and March 1983 in the absence of significant volcanic injections.[17] A similar observation can been made about the HTO data in this report: the burden increased by about 380 kCi in that interval compared to

70 kCi during the previous winter. The usual source of any increase is air from higher altitudes that bears higher mixing ratios of the species. El Chichon injected large quantities of sulfate precursors above 20 km (Ref. 1). It has long been suspected that higher HTO mixing ratios are present above 20 km because the highest values are located at the top of the altitude range. Thus, enhanced exchange between the troposphere and lower stratosphere would deplete the latter to an abnormally low level, and wintertime exchange with the upper stratosphere would result in a larger than normal increase.

IV. CONCLUSIONS

The tritiated water cycle of the lower stratosphere is subject to both anthropogenic and natural perturbations. The former are direct injections by atmospheric nuclear tests. Such tests provide a readily measureable tracer that appears to follow the water cycle of the region. Previous work has shown that the HTO is removed at a rate very similar to that of aerosol radioactivity. Extrapolating measured burdens to the dates of nuclear tests can provide reasonable estimates of the tests' fusion yields.

It is also possible to speculate about natural events that alter the water circulation of the stratosphere. Tritiated-water burdens measured in 1982 after the massive El Chichon volcanic eruptions decreased at a rate twice normal, and this unprecedented behavior is probably the result when the normal exchange processes between stratosphere and troposphere altered. Enhanced exchange between layers of the stratosphere above and below 20 km may be a related effect.

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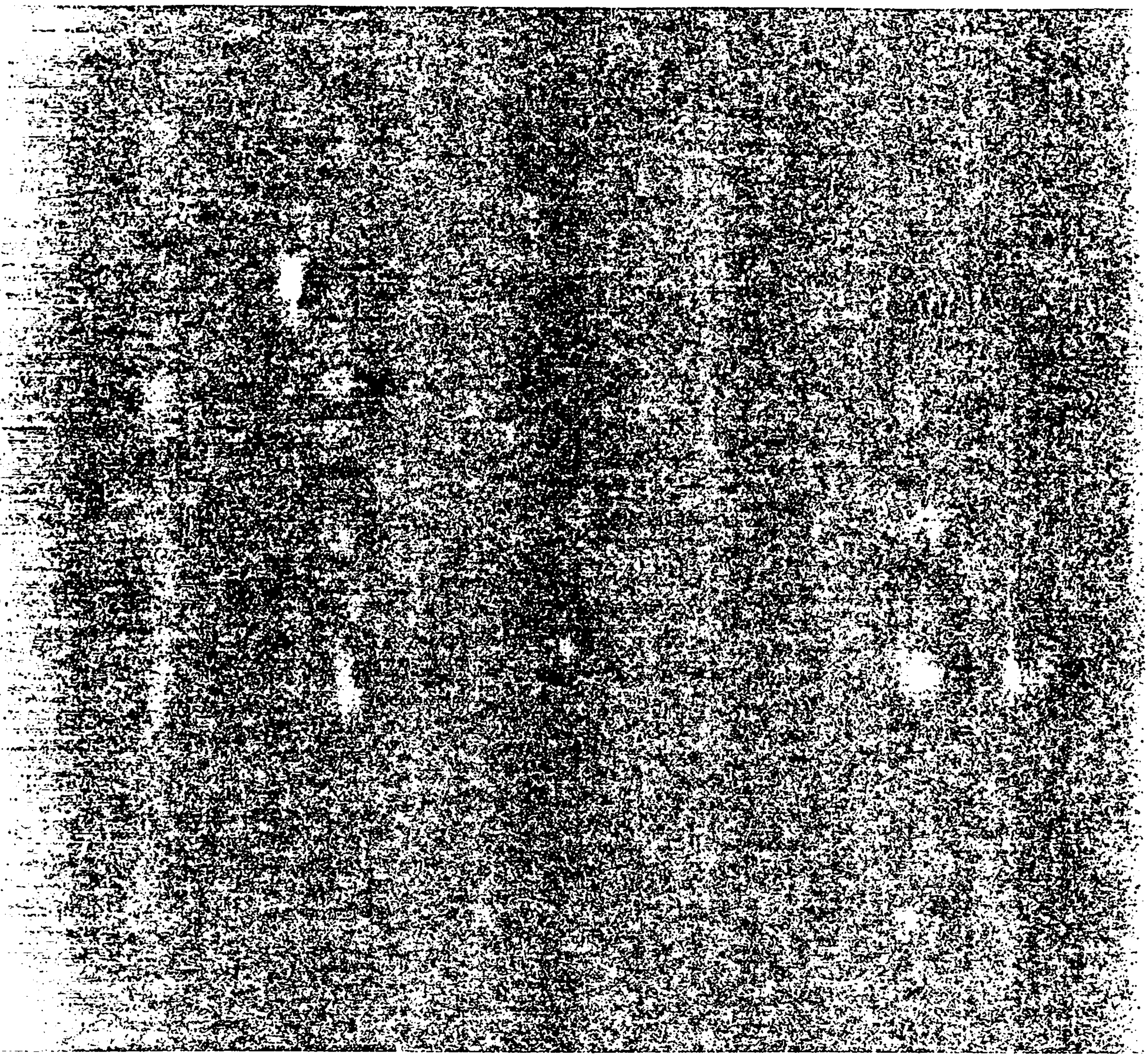

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