Posted

GEORGIA INSTITUTE OF TECHNOLOGY
Office of Contract Administration

SPONSORED PROJECT INITIATION

Date: March 22, 1976

roject Title: A Benefit Assessment of Pollution Monitoring Satellites

roject No: A-1818

roject Director: Mr. R. P. Zimmer

ponsor: NASA - Langley Research Center; Hampton, Virginia 23665

greement Period: From Feb. 26, 1976 Until ~~Feb. 25, 1977~~ ~~5~~ 22 Jun-79

ype Agreement: Contract No. NAS1-14351

mount: $50,000

eports Required: Monthly Financial Mgt. Reports; Final Report

EFENSE PRIORITY RATING: NONE

ponsor Contact Person(s):

Technical Matters

Mr. George F. Lawrence
Mail Stop 323
Mission Analysis Section
Advanced Missions Branch
Space Applications &
Tech. Division
NASA-Langley Res. Center
Hampton, Va. 23665
Phone: (804)827-2977

Contractual Matters
(thru OCA)
ONR Resident Rep.
325 Hinman Res. Bldg.
Campus

ssigned to: Appl. Engr. (School/Laboratory)

opies to:

Project Director
Division Chief (EES)
School/Laboratory Director
Dean/Director-EES
Accounting Office
Procurement Office
Security Coordinator (OCA)
Reports Coordinator (OCA) ✓
Library, Technical Reports Section
Office of Computing Services
Director, Physical Plant
EES Information Office
Project File (OCA)
Project Code (GTRI)
Other ______

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GEORGIA INSTITUTE OF TECHNOLOGY
OFFICE OF CONTRACT ADMINISTRATION

SPONSORED PROJECT TERMINATION

Date: 10/17/79

Project Title: A Benefit Assessment of Pollution Monitoring Satellites (SOW Part II.A)

Project No: A-1818

Project Director: Dr. Peter G. Sassone

Sponsor: NASA - Langley Research Center

Effective Termination Date: 9/5/79

Clearance of Accounting Charges: 9/5/79

Grant/Contract Closeout Actions Remaining:

- x Final Invoice and Closing Documents
- _ Final Fiscal Report
- x Final Report of Inventions
- _ Govt. Property Inventory & Related Certificate
- _ Classified Material Certificate
- _ Other ______

Assigned to: Systems Engineering Lab (School/Laboratory)

COPIES TO:

Project Director
Division Chief (EES)
School/Laboratory Director
Dean/Director—EES
Accounting Office
Procurement Office
Security Coordinator (OCA)
✓ Reports Coordinator (OCA)
Library, Technical Reports Section
EES Information Office
Project File (OCA)
Project Code (GTRI)
Other ______

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

MONTHLY CONTRACTOR FINANCIAL MANAGEMENT REPORT

Form Approved
Budget Bureau No. 104-R0011

2. REPORT FOR MONTH ENDING AND NUMBER OF OPERATING DAYS
31 March 1976

TO: NASA/Langley
Mr. George Lawrence
Advanced Missions, Mail Stop 323
Hampton, Virginia 23665

FROM: Georgia Institute of Technology
Engineering Experiment Station
Atlanta, Georgia 30308

3. CONTRACT VALUE
a. COSTS $ 50
b. FEE $ 0

1. DESCRIPTION OF CONTRACT
a. TYPE
c. SCOPE OF WORK Benefit Assessment of Pollution Monitoring Satellites

b. CONTRACT NO. AND LATEST DEFINITIZED AMENDMENT NO.
NAS1-14351

d. AUTH. CONTR. REP. *(Signature)*
DATE 10/7/76

4. FUND LIMITATION
$ 50 $

5. BILLING
a. INVOICE AMTS BILLED $ 0
b. TOTAL PYTS REC'D $ 0

6. REPORTING CATEGORY	7. COSTS INCURRED/HOURS WORKED: DURING MONTH: ACTUAL a.	DURING MONTH: PLANNED b.	CUM. TO DATE: ACTUAL c.	CUM. TO DATE: PLANNED d.	8. ESTIMATED COSTS/HRS. TO COMPLETE: DETAIL a.	DETAIL b.	BALANCE OF CONTRACT c.	9. ESTIMATED FINAL COSTS/HOURS: CONTRACTOR ESTIMATE a.	CONTRACT VALUE b.	10. UNFILLEC ORDERS OUT-STANDIN
SUB TOTAL P.S.	.1	.1	.1	.1			26.5			
RETIREMENT	0	0	0	0			2.4			
MATERIALS & SUPPLIES	0	0	0	0			1.5			
TRAVEL	0	0	0	0			.8			
TOTAL DIRECT COST	.1	.1	.1	.1			31.2			
OVERHEAD	.07	.07	.07	.07			18.0			
COMPUTER	0	0	0	0			.6			
TOTAL	.2	.2	.2	.2			49.8			

Baseline Plan Identification (Col. 7b & 7d): Revision No. Dated

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

MONTHLY CONTRACTOR FINANCIAL MANAGEMENT REPORT

Form Approved
Budget Bureau No. 104-R0011

2. REPORT FOR MONTH ENDING AND NUMBER OF OPERATING DAYS: 30 April 1976

TO: NASA/Langley
Mr. George Lawrence
Advanced Missions, Mail Stop 323
Hampton, Virginia 23665

FROM: Georgia Institute of Technology
Engineering Experiment Station
Atlanta, Georgia 30308

3. CONTRACT VALUE — a. COSTS: $ 50 — b. FEE: $ 0

1. DESCRIPTION OF CONTRACT
a. TYPE:
b. CONTRACT NO. AND LATEST DEFINITIZED AMENDMENT NO.: NAS1-14351
c. SCOPE OF WORK: Benefit Assessment of Pollution Monitoring Satellites
d. AUTH. CONTR. REP. (Signature):
DATE: 10/7/76

4. FUND LIMITATION: $ 50 — $

5. BILLING — a. INVOICE AMTS BILLED: $ 2182.89 — b. TOTAL PYTS REC'D: $ 0

6. REPORTING CATEGORY	7. COSTS INCURRED/HOURS WORKED — DURING MONTH — ACTUAL a.	PLANNED b.	CUM. TO DATE — ACTUAL c.	PLANNED d.	8. ESTIMATED COSTS/HRS. TO COMPLETE — DETAIL a.	b.	BALANCE OF CONTRACT c.	9. ESTIMATED FINAL COSTS/HOURS — CONTRACTOR ESTIMATE a.	CONTRACT VALUE b.	10. UNFILLED ORDERS OUTSTANDING
SUB TOTAL P.S.	1.2	1.2	1.3	1.3			25.3			
RETIREMENT	.01	.01	.01	.01			2.4			
MATERIALS & SUPPLIES	.01	.01	.01	.01			1.5			
TRAVEL	0	0	0	0			.8			
TOTAL DIRECT COST	1.2	1.2	1.3	1.3			29.9			
OVERHEAD	.8	.8	.9	.9			17.2			
COMPUTER	0	0	0	0			.6			
TOTAL	1.9	1.9	2.2	2.2			47.8			

Baseline Plan Identification (Col. 7b & 7d): Revision No. ______________, Dated ______________.

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
MONTHLY CONTRACTOR FINANCIAL MANAGEMENT REPORT

Form Approved
Budget Bureau No. 104-R0011

2. REPORT FOR MONTH ENDING AND NUMBER OF OPERATING DAYS: 31 May 1976

TO: NASA/Langley
Mr. George Lawrence
Advanced Missions, Mail Stop 323
Hampton, Virginia 23665

FROM: Georgia Institute of Technology
Engineering Experiment Station
Atlanta, Georgia 30308

3. CONTRACT VALUE
a. COSTS: $ 50
b. FEE: $ 0

1. DESCRIPTION OF CONTRACT
a. TYPE:
b. CONTRACT NO. AND LATEST DEFINITIZED AMENDMENT NO.: NAS1-14351
c. SCOPE OF WORK: Benefit Assessment of Pollution Monitoring Satellites
d. AUTH. CONTR. REP. (Signature):
DATE: 10/7/76

4. FUND LIMITATION: $ 50 $

5. BILLING
a. INVOICE AMTS BILLED: $ 1793.64
b. TOTAL PYTS REC'D: $ 190.24

6. REPORTING CATEGORY	7. COSTS INCURRED/HOURS WORKED — DURING MONTH — ACTUAL a.	7. DURING MONTH — PLANNED b.	7. CUM. TO DATE — ACTUAL c.	7. CUM. TO DATE — PLANNED d.	8. ESTIMATED COSTS/HRS. TO COMPLETE — DETAIL a.	8. DETAIL b.	8. BALANCE OF CONTRACT c.	9. ESTIMATED FINAL COSTS/HOURS — CONTRACTOR ESTIMATE a.	9. CONTRACT VALUE b.	10. UNFILLED ORDERS OUTSTANDING
SUBTOTAL P.S.	.8	.8	2.1	2.1			25.5			
RETIREMENT	.1	.1	.1	.1			2.3			
MATERIALS & SUPPLIES	.01	.01	.2	.2			1.5			
TRAVEL	.3	.3	.3	.3			.5			
TOTAL DIRECT COST	1.2	1.2	2.5	2.5			28.7			
OVERHEAD	.6	.6	1.4	1.4			16.7			
COMPUTER	0	0	0	0			.6			
TOTAL	1.8	1.8	4.0	4.0			46.0			

Baseline Plan Identification (Col. 7b & 7d): Revision No. Dated

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION MONTHLY CONTRACTOR FINANCIAL MANAGEMENT REPORT	Form Approved Budget Bureau No. 104-R0011	2. REPORT FOR MONTH ENDING AND NUMBER OF OPERATING DAYS 30 June 1976

TO:	FROM:	3. CONTRACT VALUE
NASA/Langley Mr. George Lawrence Advanced Mission, Mail Stop 323 Hampton, Virginia 23665	Georgia Institute of Technology Engineering Experiment Station Atlanta, Ga. 30308	a. COSTS $ 50 b. FEE $ 0

1. DESCRIPTION OF CONTRACT			
a. TYPE	b. CONTRACT NO. AND LATEST DEFINITIZED AMENDMENT NO. NAS1-14351		4. FUND LIMITATION $ 50 $
c. SCOPE OF WORK Benefit Assessment of Pollution Monitoring Satellites	d. AUTH. CONTR. REP. (Signature)	DATE 10/7/76	5. BILLING a. INVOICE AMTS BILLED $ 1995.72 b. TOTAL PYTS REC'D $ 1991.65

6. REPORTING CATEGORY	7. COSTS INCURRED/HOURS WORKED				8. ESTIMATED COSTS/HRS. TO COMPLETE			9. ESTIMATED FINAL COSTS/HOURS		10. UNFILLED ORDERS OUTSTANDING
	DURING MONTH		CUM. TO DATE		DETAIL		BALANCE OF CONTRACT			
	ACTUAL a.	PLANNED b.	ACTUAL c.	PLANNED d.	a.	b.	c.	CONTRACTOR ESTIMATE a.	CONTRACT VALUE b.	
SUBTOTAL P.S.	1.1	1.1	3.2	3.2			23.4			
RETIREMENT	.07	.07	.2	.2			2.2			
MATERIALS & SUPPLIES	.4	.4	.6	.6			1.4			
TRAVEL	0	0	.3	.3			.5			
TOTAL DIRECT COST	1.2	1.2	3.8	3.8			27.5			
OVERHEAD	.8	.8	2.2	2.2			15.9			
COMPUTER	0	0	0	0			.6			
TOTAL	2.0	2.0	6.0	6.0			44.0			

Baseline Plan Identification (Col. 7b & 7d): Revision No. ______________, Dated ______________.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

MONTHLY CONTRACTOR FINANCIAL MANAGEMENT REPORT

Form Approved
Budget Bureau No. 104-R0011

2. REPORT FOR MONTH ENDING AND NUMBER OF OPERATING DAYS: 31 July 1976

TO: NASA/Langley
Mr. George Lawrence
Advanced Missions, Mail Stop 323
Hampton, Virginia 23665

FROM: Georgia Institute of Technology
Engineering Experiment Station
Atlanta, Georgia 30308

3. CONTRACT VALUE
a. COSTS $50
b. FEE $ 0

1. DESCRIPTION OF CONTRACT
a. TYPE
c. SCOPE OF WORK: Benefit Assessment of Pollution Monitoring Satellies

b. CONTRACT NO. AND LATEST DEFINITIZED AMENDMENT NO.: NAS1-14351

d. AUTH. CONTR. REP. (*Signature*)
DATE: 10/7/76

4. FUND LIMITATION: $ 50 $

5. BILLING
a. INVOICE AMTS BILLED: $ 5632.51
b. TOTAL PYTS REC'D: $1793.64

6. REPORTING CATEGORY	7. COSTS INCURRED/HOURS WORKED — DURING MONTH — ACTUAL a.	DURING MONTH — PLANNED b.	CUM. TO DATE — ACTUAL c.	CUM. TO DATE — PLANNED d.	8. ESTIMATED COSTS/HRS. TO COMPLETE — DETAIL a.	DETAIL b.	BALANCE OF CONTRACT c.	9. ESTIMATED FINAL COSTS/HOURS — CONTRACTOR ESTIMATE a.	CONTRACT VALUE b.	10. UNFILLED ORDERS OUTSTANDIN
SUBTOTAL P.S.	3.3	3.3	3.3	3.3			20.6			
RETIREMENT	.1	.1	.1	.1			2.1			
MATERIALS & SUPPLIES	.03	.03	.03	.03			1.4			
TRAVEL	0	0	0	0			.5			
TOTAL DIRECT COST	3.4	3.4	3.4	3.4			24.1			
OVERHEAD	2.2	2.2	2.2	2.2			13.7			
COMPUTER	0	0	0	0			.6			
TOTAL	5.6	5.6	5.6	5.6			38.4			

Baseline Plan Identification (Col. 7b & 7d): Revision No. ____________, Dated ____________

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
MONTHLY CONTRACTOR FINANCIAL MANAGEMENT REPORT

Form Approved
Budget Bureau No. 104-R0011

2. REPORT FOR MONTH ENDING AND NUMBER OF OPERATING DAYS: 31 August 1976

TO: NASA/Langley
Mr. George Lawrence
Advanced Missions, Mail Stop 323
Hampton, Virginia 23665

FROM: Georgia Institute of Technology
Engineering Experiment Station
Atlanta, Georgia 30308

3. CONTRACT VALUE: a. COSTS $ 50; b. FEE $ 0

4. FUND LIMITATION: $ 50; $

5. BILLING: a. INVOICE AMTS BILLED $ 6490.90; b. TOTAL PYTS REC'D $ 1995.72

1. DESCRIPTION OF CONTRACT
a. TYPE:
b. CONTRACT NO. AND LATEST DEFINITIZED AMENDMENT NO.: NAS1-14351
c. SCOPE OF WORK: Benefit Assessment of Pollution Monitoring Satellites
d. AUTH. CONTR. REP. (Signature):
DATE: 10/7/76

6. REPORTING CATEGORY	7. COSTS INCURRED/HOURS WORKED: DURING MONTH: ACTUAL a.	PLANNED b.	CUM. TO DATE: ACTUAL c.	PLANNED d.	8. ESTIMATED COSTS/HRS. TO COMPLETE: DETAIL a.	b.	BALANCE OF CONTRACT c.	9. ESTIMATED FINAL COSTS/HOURS: CONTRACTOR ESTIMATE a.	CONTRACT VALUE b.	10. UNFILLED ORDERS OUTSTANDING
SUBTOTAL P.S.	3.7	3.7	6.9	6.9			16.5			
RETIREMENT	.3	.3	.4	.4			1.8			
MATERIALS & SUPPLIES	.03	.03	.06	.06			1.4			
TRAVEL	0	0	0	0			.5			
TOTAL DIRECT COST	4.0	4.0	7.4	7.4			20.1			
OVERHEAD	2.5	2.5	4.7	4.7			11.2			
COMPUTER	0	0	0	0			.6			
TOTAL	6.5	6.5	12.1	12.1			31.9			

Baseline Plan Identification (Col. 7b & 7d): Revision No. ______________, Dated ______________

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
MONTHLY CONTRACTOR FINANCIAL MANAGEMENT REPORT

Form Approved
Budget Bureau No. 104-R0011

2. REPORT FOR MONTH ENDING AND NUMBER OF OPERATING DAYS: 9/30/76

TO:
NASA/Langley
Mr. George Lawrence
Advanced Missions, Mail Stop 323
Hampton, Va. 23665

FROM:
Dr. P. G. Sassone
SED/EES
Georgia Tech

3. CONTRACT VALUE
a. COSTS $ 50,000
b. FEE $ 0

1. DESCRIPTION OF CONTRACT
a. TYPE
b. CONTRACT NO. AND LATEST DEFINITIZED AMENDMENT NO.: NAS1-14351
c. SCOPE OF WORK: Benefit Assessment of Pollution Monitoring Satellites
d. AUTH. CONTR. REP. (Signature)
DATE: 11/12/76

4. FUND LIMITATION $ $

5. BILLING
a. INVOICE AMTS BILLED $ 24,964.81
b. TOTAL PYTS REC'D $18,094.60

6. REPORTING CATEGORY	7. COSTS INCURRED/HOURS WORKED – DURING MONTH – ACTUAL a.	DURING MONTH – PLANNED b.	CUM. TO DATE – ACTUAL c.	CUM. TO DATE – PLANNED d.	8. ESTIMATED COSTS/HRS. TO COMPLETE – DETAIL a.	DETAIL b.	BALANCE OF CONTRACT c.	9. ESTIMATED FINAL COSTS/HOURS – CONTRACTOR ESTIMATE a.	CONTRACT VALUE b.	10. UNFILLED ORDERS OUTSTANDING
Personal Services	$3840	$3800	$13,999	$14,000			$12,600			
Retirement	315	315	898	900			1,481			
Material & Supplies	104	100	299	250			1,240			
Travel	0	0	318	350			482			
Computer	35	50	240	300			360			
Overhead	2611	2600	9,520	9,520			8,589			

Baseline Plan Identification (Col. 7b & 7d): Revision No. ____________, Dated ____________.

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
MONTHLY CONTRACTOR FINANCIAL MANAGEMENT REPORT

Form Approved
Budget Bureau No. 104-R0011

2. REPORT FOR MONTH ENDING AND NUMBER OF OPERATING DAYS: 10/31/76

TO: NASA/Langley
Mr. George Lawrence
Advanced Missions Mail Stop 323
Hampton, Va. 23665

FROM:
Dr. P. G. Sassone
SED/EES
Georgia Tech

3. CONTRACT VALUE
a. COSTS $
b. FEE $

1. DESCRIPTION OF CONTRACT
a. TYPE
c. SCOPE OF WORK: Benefit Assessment of Pollution Montioring Satellites

b. CONTRACT NO. AND LATEST DEFINITIZED AMENDMENT NO.: NAS1-14351

d. AUTH. CONTR. REP. (Signature) | DATE

4. FUND LIMITATION
$ $

5. BILLING
a. INVOICE AMTS BILLED: $ 6,870.15
b. TOTAL PYTS REC'D: $ 24,964.81

6. REPORTING CATEGORY	7. COSTS INCURRED/ During Month Actual a.	During Month Planned b.	Cum. to Date Actual c.	Cum. to Date Planned d.	8. ESTIMATED COSTS/HRS. TO COMPLETE Detail a.	Detail b.	Balance of Contract c.	9. ESTIMATED FINAL COSTS/HOURS Contractor Estimate a.	Contract Value b.	10. UNFILLED ORDERS OUTSTANDING
Personal Services	2545	2500	16545	16500			10086			
Retirement	339	300	1236	1200			1143			
Material & Supplies	244	200	437	450			1007			
Travel	0	0	318	350			421			
Computer	206	200	208	200			394			
Overhead	1731	1700	11250	11220			6858			

Baseline Plan Identification (Col. 7b & 7d): Revision No. ______________, Dated ______________.

NASA FORM 533M SEP 71 REPLACES NASA FORMS 533a, b AND c WHICH ARE OBSOLETE.

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
MONTHLY CONTRACTOR FINANCIAL MANAGEMENT REPORT

Form Approved
Budget Bureau No. 104-R0011

2. REPORT FOR MONTH ENDING AND NUMBER OF OPERATING DAYS: 11/30/76

TO: NASA/Langley
Mr. George Lawrence
Advanced Missions Mail Stop 323
Hampton, Va. 23665

FROM: Dr. P. G. Sassone
SED/EES
Georgia Tech

3. CONTRACT VALUE
a. COSTS $
b. FEE $

1. DESCRIPTION OF CONTRACT
a. TYPE
b. CONTRACT NO. AND LATEST DEFINITIZED AMENDMENT NO.: NAS1-14351
c. SCOPE OF WORK: Benefit Assessment of Pollution Monitoring Satellites
d. AUTH. CONTR. REP. (Signature) | DATE

4. FUND LIMITATION
$ $

5. BILLING
a. INVOICE AMTS BILLED: $ 5,064.40
b. TOTAL PYTS REC'D: $ 30,029.31

6. REPORTING CATEGORY	7. COSTS INCURRED/HOURS WORKED — DURING MONTH — ACTUAL a.	PLANNED b.	CUM. TO DATE — ACTUAL c.	PLANNED d.	8. ESTIMATED COSTS/HRS. TO COMPLETE — DETAIL a.	b.	BALANCE OF CONTRACT c.	9. ESTIMATED FINAL COSTS/HOURS — CONTRACTOR ESTIMATE a.	CONTRACT VALUE b.	10. UNFILLED ORDERS OUTSTANDING
Personal Services	4930	4900	21475	21400			5156			
Retirement	213	200	1449	1400			930			
Material & Supplies	78	100	552	550			929			
Travel	675	450	992	800			-192			
Computer	37	40	243	240			357			
Overhead	3352	3350	14603	14570			3506			

Baseline Plan Identification (Col. 7b & 7d): Revision No. ________, Dated ________.

NASA FORM 533M SEP 71 REPLACES NASA FORMS 533a, b AND c WHICH ARE OBSOLETE.

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
MONTHLY CONTRACTOR FINANCIAL MANAGEMENT REPORT

Form Approved
Budget Bureau No. 104-R0011

2. REPORT FOR MONTH ENDING AND NUMBER OF OPERATING DAYS: 12/30/76

TO: NASA/Langley
Mr. George Lawrence
Advanced Missions Mail Stop 323
Hampton, Va. 23665

FROM: Dr. P. G. Sassone
SED/EES
Georgia Tech

3. CONTRACT VALUE: a. COSTS $ | b. FEE $

1. DESCRIPTION OF CONTRACT
a. TYPE
b. CONTRACT NO. AND LATEST DEFINITIZED AMENDMENT NO.
c. SCOPE OF WORK: Benefit Assessment of Pollution Monitoring Satellites
d. AUTH. CONTR. REP. (Signature) | DATE
NAS1-14351

4. FUND LIMITATION: $ | $

5. BILLING: a. INVOICE AMTS BILLED $ 9,284.88 | b. TOTAL PYTS REC'D $ 39,314.09

6. REPORTING CATEGORY	7. COSTS INCURRED/HOURS WORKED				8. ESTIMATED COSTS/HRS. TO COMPLETE			9. ESTIMATED FINAL COSTS/HOURS		10. UNFILLED ORDERS OUTSTANDING
	DURING MONTH		CUM. TO DATE		DETAIL					
	ACTUAL a.	PLANNED b.	ACTUAL c.	PLANNED d.	a.	b.	BALANCE OF CONTRACT c.	CONTRACTOR ESTIMATE a.	CONTRACT VALUE b.	
Personal Services	2378	2400	23853	23800			2778			
Retirement	333	340	1782	1740			596			
Material & Supplies	54	50	605	600			875			
Travel	0	0	992	800			-192			
Computer	185	200	428	440			172			
Overhead	1617	1620	16220	16190			1889			

Baseline Plan Identification (Col. 7b & 7d): Revision No. ____________, Dated ____________.

NASA FORM 533M SEP 71 REPLACES NASA FORMS 533a, b AND c WHICH ARE OBSOLETE.

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
MONTHLY CONTRACTOR FINANCIAL MANAGEMENT REPORT

Form Approved
Budget Bureau No. 104-R0011

2. REPORT FOR MONTH ENDING AND NUMBER OF OPERATING DAYS: 1/30/77

TO:
NASA/Langley
Mr. George Lawrence
Advanced Mission Mail Stop 323
~~Hampton, Va. 23665~~

FROM:
Dr. P. G. Sassone
SED/EES
Georgia Tech

3. CONTRACT VALUE
a. COSTS $
b. FEE $

1. DESCRIPTION OF CONTRACT
a. TYPE
b. CONTRACT NO. AND LATEST DEFINITIZED AMENDMENT NO.: NAS1-14351
c. SCOPE OF WORK: Benefit Assessment of Pollution Monitoring Satellites
d. AUTH. CONTR. REP. (Signature) DATE

4. FUND LIMITATION $ $

5. BILLING
a. INVOICE AMTS BILLED: $ 4,567.48
b. TOTAL PYTS REC'D: $ 43,881.57

6. REPORTING CATEGORY	7. COSTS INCURRED/HOURS WORKED — DURING MONTH — ACTUAL a.	PLANNED b.	CUM. TO DATE — ACTUAL c.	PLANNED d.	8. ESTIMATED COSTS/HRS. TO COMPLETE — DETAIL a.	b.	BALANCE OF CONTRACT c.	9. ESTIMATED FINAL COSTS/HOURS — CONTRACTOR ESTIMATE a.	CONTRACT VALUE b.	10. UNFILLED ORDERS OUTSTANDING
Personal Services	1604	1600	25451	25400			1174			
Retirement	165	160	1947	1900			431			
Material & Supplies	47	50	652	650			829			
Travel	0	0	992	800			-192			
Computer	0	0	428	440			172			
Overhead	1091	1090	17311	17280			798			

Baseline Plan Identification (Col. 7b & 7d): Revision No. ________, Dated ________.

NASA FORM 533M SEP 71 REPLACES NASA FORMS 533a, b AND c WHICH ARE OBSOLETE.

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
MONTHLY CONTRACTOR FINANCIAL MANAGEMENT REPORT

Form Approved
Budget Bureau No. 104-R0011

2. REPORT FOR MONTH ENDING AND NUMBER OF OPERATING DAYS: 2/28/77

TO: NASA/Langley
Mr. George Lawrence
Advanced Missions Mail Stop 323
Hampton, Va. 23665

FROM: Dr. P. G. Sassone
SED/EES
Georgia Tech

3. CONTRACT VALUE: a. COSTS $ b. FEE $

1. DESCRIPTION OF CONTRACT
a. TYPE
b. CONTRACT NO. AND LATEST DEFINITIZED AMENDMENT NO.: NAS1-14351
c. SCOPE OF WORK: Benefit Assessment of Pollution Monitoring Satellites
d. AUTHORIZED REP. (Signature) DATE

4. FUND LIMITATION: $ $

5. BILLING: a. INVOICE AMTS BILLED $ 2,906.86 b. TOTAL PYTS REC'D $ 46,778.43

6. REPORTING CATEGORY	7. COSTS INCURRED/HOURS WORKED: DURING MONTH – ACTUAL a.	DURING MONTH – PLANNED b.	CUM. TO DATE – ACTUAL c.	CUM. TO DATE – PLANNED d.	8. ESTIMATED COSTS/HRS. TO COMPLETE: DETAIL a.	DETAIL b.	BALANCE OF CONTRACT c.	9. ESTIMATED FINAL COSTS/HOURS: CONTRACTOR ESTIMATE a.	CONTRACT VALUE b.	10. UNFILLED ORDERS OUTSTANDING
Personal Services	1045	1050	26502	26450			129			
Retirement	94	90	2041	1990			338			
Material & Supplies	2	0	654	650			810			
Travel	0	0	992	800			-192			
Computer	103	50	531	510			69			
Overhead	710	710	18021	17990			88			

Baseline Plan Identification (Col. 7b & 7d): Revision No. ____________, Dated ____________.

NASA FORM 533M SEP 71 REPLACES NASA FORMS 533a, b AND c WHICH ARE OBSOLETE.

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION **MONTHLY CONTRACTOR FINANCIAL MANAGEMENT REPORT**	Form Approved Budget Bureau No. 104-R0011	2. REPORT FOR MONTH ENDING AND NUMBER OF OPERATING DAYS 3/30/77
TO: NASA/Langley Mr. George Lawrence Advanced Missions Mail Stop 323 Hampton, Va. 23665	FROM: Dr. P. G. Sassone SED/EES Georgia Tech	3. CONTRACT VALUE a. COSTS $ b. FEE $
1. DESCRIPTION OF CONTRACT — a. TYPE	b. CONTRACT NO. AND LATEST DEFINITIZED AMENDMENT NO. NAS1-14351	4. FUND LIMITATION $ $
c. SCOPE OF WORK Benefit Assessment of Pollution Monitoring Satellites	d. AUTH. CONTR. REP. (Signature) DATE	5. BILLING a. INVOICE AMTS BILLED $ 1,953.80 b. TOTAL PYTS REC'D $ 48,742.23

6. REPORTING CATEGORY	7. COSTS INCURRED/HOURS WORKED — DURING MONTH — ACTUAL a.	DURING MONTH — PLANNED b.	CUM. TO DATE — ACTUAL c.	CUM. TO DATE — PLANNED d.	8. ESTIMATED COSTS/HRS. TO COMPLETE — DETAIL a.	DETAIL b.	BALANCE OF CONTRACT c.	9. ESTIMATED FINAL COSTS/HOURS — CONTRACTOR ESTIMATE a.	CONTRACT VALUE b.	10. UNFILLED ORDERS OUTSTANDING
Personal Services	3325	3300	29827	29750			*-3197			
Retirement	43	40	2083	2030			295			
Material & Supplies	134	100	788	750			676			
Travel	0	0	992	800			-192			
Computer	33	30	563	540			37			
Overhead	2261	2250	20283	20240			-2174			

*negative balance resulted from advance work on follow-on project

Baseline Plan Identification (Col. 7b & 7d): Revision No. ____, Dated ____.

NASA FORM 533M SEP 71 REPLACES NASA FORMS 533a, b AND c WHICH ARE OBSOLETE.

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION **MONTHLY CONTRACTOR FINANCIAL MANAGEMENT REPORT**	Form Approved Budget Bureau No. 104-R0011	2. REPORT FOR MONTH ENDING AND NUMBER OF OPERATING DAYS 4/30/77
TO: NASA/Langley Mr. George Lawrence Advanced Missions Mail Stop 323 Hampton, Va. 23665	FROM: Dr. P. G. Sassone SED/EES Georgia Tech	3. CONTRACT VALUE a. COSTS $ b. FEE $
1. DESCRIPTION OF CONTRACT a. TYPE c. SCOPE OF WORK Benefit Assessment of Pollution Monitoring Satellites	b. CONTRACT NO. AND LATEST DEFINITIZED AMENDMENT NO. NAS1-14351 d. AUTH. CONTR. REP. (Signature) DATE	4. FUND LIMITATION $ $ 5. BILLING a. INVOICE AMTS BILLED $ 5,795.65 b. TOTAL PYTS REC'D $ 54,537.88

6. REPORTING CATEGORY	7. COSTS INCURRED/HOURS WORKED				8. ESTIMATED COSTS/HRS. TO COMPLETE			9. ESTIMATED FINAL COSTS/HOURS		10. UNFILLED ORDERS OUTSTANDING
	DURING MONTH		CUM. TO DATE		DETAIL		BALANCE OF CONTRACT			
	ACTUAL a.	PLANNED b.	ACTUAL c.	PLANNED d.	a.	b.	c.	CONTRACTOR ESTIMATE a.	CONTRACT VALUE b.	
Personal Services	2457	2500	32284	32250			26479			
Retirement	247	250	2331	2280			2972			
Material & Supplies	138	100	926	850			2355			
Travel	563	600	1555	1400			1745			
Computer	11	30	574	570			1226			
Overhead	1670	1700	21953	21940			18006			

Baseline Plan Identification (Col. 7b & 7d): Revision No. ____________, Dated ____________.

NASA FORM 533M SEP 71 REPLACES NASA FORMS 533a, b AND c WHICH ARE OBSOLETE.

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
MONTHLY CONTRACTOR FINANCIAL MANAGEMENT REPORT

Form Approved
Budget Bureau No. 104-R0011

2. REPORT FOR MONTH ENDING AND NUMBER OF OPERATING DAYS: 5/30/77

TO: NASA LARC
Mr. George Lawrence
Advanced Missions Mail Stop 323
Hampton, Va. 23665

FROM: Dr. P. G. Sassone
EES/SED
Georgia Tech

3. CONTRACT VALUE: a. COSTS $ | b. FEE $

1. DESCRIPTION OF CONTRACT
a. TYPE
b. CONTRACT NO. AND LATEST DEFINITIZED AMENDMENT NO.: NAS1-14351
c. SCOPE OF WORK: Benefit Assessment of Pollution Monitoring Satellites
d. AUTH. CONTR. REP. (Signature) | DATE

4. FUND LIMITATION: $ | $

5. BILLING: a. INVOICE AMTS BILLED $ 5,864.04 | b. TOTAL PYTS REC'D $ 60,401.92

6. REPORTING CATEGORY	7. COSTS INCURRED/HOURS WORKED: During Month, Actual a.	During Month, Planned b.	Cum. to Date, Actual c.	Cum. to Date, Planned d.	8. ESTIMATED COSTS/HRS. TO COMPLETE: Detail a.	Detail b.	Balance of Contract c.	9. ESTIMATED FINAL COSTS/HOURS: Contractor Estimate a.	Contract Value b.	10. UNFILLED ORDERS OUTSTANDING
Personal Services	2641	2600	34925	34850			23837			
Retirement	184	180	2515	2460			2788			
Material & Supplies	58	100	984	950			2297			
Travel	0	0	1555	1440			1745			
Computer	1534	20	589	590			1210			
Overhead	1796	1800	23750	23740			16210			

Baseline Plan Identification (Col. 7b & 7d): Revision No. ____________, Dated ____________.

NASA FORM 533M SEP 71 REPLACES NASA FORMS 533a, b AND c WHICH ARE OBSOLETE.

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

MONTHLY CONTRACTOR FINANCIAL MANAGEMENT REPORT

Form Approved
Budget Bureau No. 104-R0011

2. REPORT FOR MONTH ENDING AND NUMBER OF OPERATING DAYS: 30 June 1977

TO:
NASA LaRC
Mr. George Lawrence
Advanced Missions, Mail Stop 323, Hampton Va. (23665

FROM:
Dr. Peter G. Sassone
EES/SED
Ga. Institute of Technology

3. CONTRACT VALUE: a. COSTS $ b. FEE $

1. DESCRIPTION OF CONTRACT: a. TYPE
c. SCOPE OF WORK: Benefit Assessment of Pollution Monitoring Satellites

b. CONTRACT NO. AND LATEST DEFINITIZED AMENDMENT NO.: NAS-14351

d. AUTH. CONTR. REP. (Signature) DATE

4. FUND LIMITATION: $ 112.4 K $

5. BILLING: a. INVOICE AMTS BILLED $ 64,318.16 b. TOTAL PYTS REC'D $ 59,623.92

6. REPORTING CATEGORY	7. COSTS INCURRED/HOURS WORKED — DURING MONTH — ACTUAL a.	DURING MONTH — PLANNED b.	CUM. TO DATE — ACTUAL c.	CUM. TO DATE — PLANNED d.	8. ESTIMATED COSTS/HRS. TO COMPLETE — DETAIL a.	DETAIL b.	BALANCE OF CONTRACT c.	9. ESTIMATED FINAL COSTS/HOURS — CONTRACTOR ESTIMATE a.	CONTRACT VALUE b.	10. UNFILLED ORDERS OUTSTANDING
Personal Services	1882/ 188 HR	1900/ 190 HR	36808/ 3680 HR	36750/ 3675/HR			21955			
Retirement	195	200	2710	2660			2593			
Materials and Supplies	116	100	1100	1050			2181			
Travel	406	400	1961	1840			1334			
Computer	47	50	636	640			1164			
Overhead	1280	1300	25029	25040			14930			
Total	3926	3950	68244	67980			44157			

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NASA FORM 533M SEP 71 REPLACES NASA FORMS 533a, b AND c WHICH ARE OBSOLETE.

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
MONTHLY CONTRACTOR FINANCIAL MANAGEMENT REPORT

Form Approved
Budget Bureau No. 104-R0011

2. REPORT FOR MONTH ENDING AND NUMBER OF OPERATING DAYS
July 30, 1977

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TO:
NASA LaRC
Mr. George Lawrence
Advanced Missions, Mail Stop 323
Hampton, Va. 23665

FROM:
Dr. Peter G. Sassone
EES/SED
Georgia Tech

3. CONTRACT VALUE
a. COSTS $
b. FEE $

4. FUND LIMITATION
$ 112.4K
$

5. BILLING
a. INVOICE AMTS BILLED $ 68,243.70
b. TOTAL PYTS REC'D $ 64,318.16

1. DESCRIPTION OF CONTRACT
a. TYPE
b. CONTRACT NO. AND LATEST DEFINITIZED AMENDMENT NO.: NAS1-14351
c. SCOPE OF WORK: Benefit Assessment of Pollution Monitoring Satellites
(Signature) | DATE

6. REPORTING CATEGORY	7. COSTS INCURRED/HOURS WORKED: DURING MONTH, ACTUAL a.	DURING MONTH, PLANNED b.	CUM. TO DATE, ACTUAL c.	CUM. TO DATE, PLANNED d.	8. ESTIMATED COSTS/HRS. TO COMPLETE: DETAIL a.	DETAIL b.	BALANCE OF CONTRACT c.	9. ESTIMATED FINAL COSTS/HOURS: CONTRACTOR ESTIMATE a.	CONTRACT VALUE b.	10. UNFILLED ORDERS OUTSTANDING
Personal Services	2315/ 193 hr	2313/ 193 hr	39123/ 3261 hr	39212/ 3260 hr			19639			
Retirement	110	200	2820	2860			2483			
Material and Supplies	9	20	1108	1070			2172			
Travel	0	0	1961	1840			1339			
Computer	0	50	636	690			1164			
Overhead	1574	1700	26604	26740			13355			
Total	4008	4537	72252	72781			40152			

Baseline Plan Identification (Col. 7b & 7d): Revision No. ________________, Dated ________________.

NASA FORM 533M SEP 71 REPLACES NASA FORMS 533a, b AND c WHICH ARE OBSOLETE.

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
MONTHLY CONTRACTOR FINANCIAL MANAGEMENT REPORT

Form Approved
Budget Bureau No. 104-R0011

2. REPORT FOR MONTH ENDING AND NUMBER OF OPERATING DAYS: August 30, 1977

TO:
NASA LaRC, Mr. George Lawrence
Advanced Missions, Mail Stop 323
Hampton, Va. 23665

FROM:
Dr. Peter G. Sassone
EES/SED/STB
Georgia Tech

3. CONTRACT VALUE
a. COSTS $
b. FEE $

1. DESCRIPTION OF CONTRACT
a. TYPE
b. CONTRACT NO. AND LATEST DEFINITIZED AMENDMENT NO.: NAS1-14351
c. SCOPE OF WORK: Benefit Assessment of Pollution Monitoring Satellites
d. AUTH. CONTR. REP. (Signature)
DATE

4. FUND LIMITATION: $ 112.4K $

5. BILLING
a. INVOICE AMTS BILLED: $ 72,252.18
b. TOTAL PYTS REC'D: $ 68,243

6. REPORTING CATEGORY	7. COSTS INCURRED/HOURS WORKED — DURING MONTH — ACTUAL a.	PLANNED b.	CUM. TO DATE — ACTUAL c.	PLANNED d.	8. ESTIMATED COSTS/HRS. TO COMPLETE — DETAIL a.	b.	BALANCE OF CONTRACT c.	9. ESTIMATED FINAL COSTS/HOURS — CONTRACTOR ESTIMATE a.	CONTRACT VALUE b.	10. UNFILLED ORDERS OUTSTANDING
Personal Services	3365/ 330 hr	2500	42488/ 4240	41621			16,275			
Retirement	195	225	3015	3085			2287			
Materials & Supplies	46	50	1155	1120			2117			
Travel	0	0	1961	1840			1339			
Computer	0	50	636	740			1164			
Overhead	2288	1700	28892	28440			11067			
Total	5894	4525	78147	76846			34249			

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
MONTHLY CONTRACTOR FINANCIAL MANAGEMENT REPORT

Form Approved
Budget Bureau No. 104-R0011

2. REPORT FOR MONTH ENDING AND NUMBER OF OPERATING DAYS: 30 September 1977

TO:
NASA LARC
Mr. George Lawrence
Advanced Missions Mail Stop 323
Hampton, VA. 23665

FROM:
Dr. Peter G. Sassone
EES/SED
Georgia Tech

3. CONTRACT VALUE
a. COSTS $
b. FEE $

1. DESCRIPTION OF CONTRACT
a. TYPE
b. CONTRACT NO AND LATEST DEFINITIZED AMENDMENT NO: NAS1-14351
c. SCOPE OF WORK: Benefit Assessment of Pollution Monitoring Satellites
d. AUTH. CONTR. REP. (Signature)
DATE: 10/13/77

4. FUND LIMITATION: $ 112.4K $

5. BILLING
a. INVOICE AMTS BILLED: $ 78,146.50
b. TOTAL PYTS REC'D: $ 72,252.18

6. REPORTING CATEGORY	7. COSTS INCURRED HOURS WORKED — DURING MONTH — ACTUAL a.	PLANNED b.	CUM. TO DATE — ACTUAL c.	PLANNED d.	8. ESTIMATED COSTS/HRS. TO COMPLETE — DETAIL a.	b.	BALANCE OF CONTRACT c.	9. ESTIMATED FINAL COSTS/HOURS — CONTRACTOR ESTIMATE a.	CONTRACT VALUE b.	10. UNFILLED ORDERS OUTSTANDING
Personal Services	2987/ 298 hr	2500/ 250 hr	45475/ 4547 hr	44121/ 4412 hr			13283			
Retirement	207	225	3221	3310			2082			
Materials and Supplies	33	50	1187	1170			2084			
Travel	0	0	1960	1840			1339			
Computer	216	50	852	790			947			
Overhead	2031	1700	30923	30140			9035			
Total	5474	4525	83618	81371			28770			

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

MONTHLY CONTRACTOR FINANCIAL MANAGEMENT REPORT

Form Approved
Budget Bureau No. 104-R0011

2. REPORT FOR MONTH ENDING AND NUMBER OF OPERATING DAYS: 30 October 1977

TO: NASA LaRC
Mr. George Lawrence
Advanced Missions, Mail Stop 323
Hampton, Va. 23665

FROM: Dr. Peter G. Sassone
EES/SED
Georgia Tech

3. CONTRACT VALUE: a. COSTS $ b. FEE $

1. DESCRIPTION OF CONTRACT
a. TYPE:
b. CONTRACT NO. AND LATEST DEFINITIZED AMENDMENT NO.: NAS1-14351
c. SCOPE OF WORK: Benefit Assessment of Pollution Monitoring Satellites
d. AUTH. CONTR. REP. (Signature): DATE:

4. FUND LIMITATION: $112K $

5. BILLING: a. INVOICE AMTS BILLED $83,620.09 b. TOTAL PYTS REC'D $83,620.09

6. REPORTING CATEGORY	7. COSTS INCURRED/HOURS WORKED: DURING MONTH ACTUAL a.	DURING MONTH PLANNED b.	CUM. TO DATE ACTUAL c.	CUM. TO DATE PLANNED d.	8. ESTIMATED COSTS/HRS. TO COMPLETE: DETAIL a.	DETAIL b.	BALANCE OF CONTRACT c.	9. ESTIMATED FINAL COSTS/HOURS: CONTRACTOR ESTIMATE a.	CONTRACT VALUE b.	10. UNFILLED ORDERS OUTSTANDING
Personal Services	1716/ 172 hr.	2500/ 250 hr	47191/ 4720 hr	46621/ 4662 hr			11572			
Retirement	196	225	3417	3535			1886			
Materials & Supplies	19	50	1206	1220			2075			
Travel	0	0	1961	1840			1339			
Computer	61	50	913	840			887			
Overhead	1167	1700	32090	31840			7869			
Total	3159	4525	86778	85896			25628			

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

MONTHLY CONTRACTOR FINANCIAL MANAGEMENT REPORT

Form Approved
Budget Bureau No. 104-R0011

2. REPORT FOR MONTH ENDING AND NUMBER OF OPERATING DAYS: November 30, 1977

TO: NASA LaRC
Mr. George Lawrence
Advance Missions Mail Stop 323
Hampton, VA 23665

FROM: Dr. Peter G. Sassone
EES/SED
Georgia Institute of
Technology, Atlanta, Ga. 30332

3. CONTRACT VALUE
a. COSTS $ 112 K
b. FEE $

1. DESCRIPTION OF CONTRACT
a. TYPE
b. CONTRACT NO. AND LATEST DEFINITIZED AMENDMENT NO: NAS1-14351
c. SCOPE OF WORK: Benefit Assessment of Pollution Monitoring Satellite
d. AUTHORIZED CONTR. REP. (Signature) DATE

4. FUND LIMITATION
$ $

5. BILLING
a. INVOICE AMTS BILLED $ 86,777.55
b. TOTAL PYTS REC'D $ 83,620.09

6. REPORTING CATEGORY	7. COSTS INCURRED/HOURS WORKED: DURING MONTH		CUM TO DATE		8. ESTIMATED COSTS HRS. TO COMPLETE: DETAIL			9. ESTIMATED FINAL COSTS/HOURS		10. UNFILLED ORDERS OUTSTANDING
	ACTUAL a.	PLANNED b.	ACTUAL c.	PLANNED d.	a.	b.	BALANCE OF CONTRACT c.	CONTRACTOR ESTIMATE a.	CONTRACT VALUE b.	
Personal Services	3909/ 39 hr	2500/ 25 hr	51100/ 5110 hr	49121/ 4912 hr			7663/ 766 hr			
Retirement	108	225	3524	3760			1778			
Material & Supplies	33	50	1239	1270			2642			
Travel	0	0	1960	1840			1339			
Computer	36	50	950	890			850			
Overhead	2659	1700	34748	35540			5211			
Total	6745	4525	93521	92421			18883			

Baseline Plan Identification (Col. 7b & 7d): Revision No. ______________, Dated ______________.

NASA FORM 533M SEP 71 REPLACES NASA FORMS 533a, b AND c WHICH ARE OBSOLETE.

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
MONTHLY CONTRACTOR FINANCIAL MANAGEMENT REPORT

Form Approved
Budget Bureau No. 104-R0011

2. REPORT FOR MONTH ENDING AND NUMBER OF OPERATING DAYS: 31 December 77

TO: NASA L RC - Mr. George Lawrence
Advanced Missions Mail Stop 323
Hampton, VA 23665

FROM: Dr. Peter G. Sassone
EES/SED
Georgia Tech

3. CONTRACT VALUE
a. COSTS $
b. FEE $

1. DESCRIPTION OF CONTRACT
a. TYPE
b. CONTRACT NO. AND LATEST DEFINITIZED AMENDMENT NO.: NAS1 - 14351
c. SCOPE OF WORK: Benefit Asses. of Pol. Monit. Satellites
DATE: 2/14/78

4. FUND LIMITATION: $ 112.4K $

5. BILLING
a. INVOICE AMTS BILLED: $ 93,522.57
b. TOTAL PYTS REC'D: $ 86,777.55

6. REPORTING CATEGORY	7. COSTS INCURRED/HOURS WORKED — DURING MONTH — ACTUAL a.	PLANNED b.	CUM. TO DATE — ACTUAL c.	PLANNED d.	8. ESTIMATED COSTS/HRS. TO COMPLETE — DETAIL a.	b.	BALANCE OF CONTRACT c.	9. ESTIMATED FINAL COSTS/HOURS — CONTRACTOR ESTIMATE a.	CONTRACT VALUE b.	10. UNFILLED ORDERS OUTSTANDING
Personnel Services	2841/284	2500/250	53942/5394	51621/5162			4821			
Retirement	307	225	3832	3985			1471			
Material & Supplies	0	50	1239	1320			2042			
Travel	0	0	1963	1840			1139			
Computer	0	50	950	940			850			
Overhead	1932	1700	36680	37240			3279			
TOTAL	5080	4525	98606	96946			13602			

Baseline Plan Identification (Col. 7b & 7d): Revision No. Dated

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
MONTHLY CONTRACTOR FINANCIAL MANAGEMENT REPORT

Form Approved
Budget Bureau No. 104-R0011

2. REPORT FOR MONTH ENDING AND NUMBER OF OPERATING DAYS: January 31, 1978

TO: NASA LaRC - Mr. George Lawrence
Advanced Missions Mail Stop 323
Hampton, VA 23665

FROM: Dr. Peter G. Sassone
EES/SED, Ga. Tech
Atlanta, Georgia 30332

3. CONTRACT VALUE
a. COSTS $ 112.4K
b. FEE $

4. FUND LIMITATION $ 112.4K $

5. BILLING
a. INVOICE AMTS BILLED $ 98,604.71
b. TOTAL PYTS REC'D $ 86,777.55

1. DESCRIPTION OF CONTRACT
a. TYPE
b. CONTRACT NO. AND LATEST DEFINITIZED AMENDMENT NO.: NAS1-14351
c. SCOPE OF WORK
d. AUTH. CONTR. REP. (Signature)
DATE

6. REPORTING CATEGORY	7. COSTS INCURRED/HOURS WORKED: DURING MONTH: ACTUAL a.	PLANNED b.	CUM TO DATE: ACTUAL c.	PLANNED d.	8. ESTIMATED COSTS/HRS. TO COMPLETE: DETAIL a.	b.	BALANCE OF CONTRACT c.	9. ESTIMATED FINAL COSTS/HOURS: CONTRACTOR ESTIMATE a.	CONTRACT VALUE b.	10. UNFILLED ORDERS OUTSTANDING
Personal Services	2695/270	2500/250	56637/5664	54121/5412			2126/213			
Retirement	226	225	4058	4210			1245			
Materials & Supplies	146	50	1385	1370			1844			
Travel	166	0	2129	1840			1171			
Computer	293	50	1243	990			557			
Overhead	1833	1700	38513	38940			1446			
Total	5359	4525	103965	101471			8389			

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
MONTHLY CONTRACTOR FINANCIAL MANAGEMENT REPORT

Form Approved
Budget Bureau No. 104-R0011

2. REPORT FOR MONTH ENDING AND NUMBER OF OPERATING DAYS: February 28, 1978

TO: NASA LaRC
Mr. George Lawrence
Advanced Missions, Mail Stop 323
Hampton, Va. 23665

FROM: Dr. Peter G. Sassone
EES/SED
Georgia Tech

3. CONTRACT VALUE: a. COSTS $; b. FEE $

1. DESCRIPTION OF CONTRACT
a. TYPE:
b. CONTRACT NO. AND LATEST DEFINITIZED AMENDMENT NO.: NASA1-14351
c. SCOPE OF WORK: Benefit Assessment of Pollution Monitoring Satellites
d. AUTH. CONTR. REP. (Signature):
DATE: 3/31/78

4. FUND LIMITATION: $ $112.4K; $

5. BILLING: a. INVOICE AMTS BILLED $ 102,841.55; b. TOTAL PYTS REC'D $ 97,480.65

6. REPORTING CATEGORY	7. COSTS INCURRED/HOURS WORKED — DURING MONTH — ACTUAL a.	PLANNED b.	CUM TO DATE — ACTUAL c.	PLANNED d.	8. ESTIMATED COSTS/HRS. TO COMPLETE — DETAIL a.	b.	BALANCE OF CONTRACT c.	9. ESTIMATED FINAL COSTS/HOURS — CONTRACTOR ESTIMATE a.	CONTRACT VALUE b.	10. UNFILLED ORDERS OUTSTANDING
Personal Services	3046/ 305	2500/ 250	59683/ 5968	56621/ 5662			-920			
Retirement	211	225	4269	4435			1034			
Materials & Supplies	2	50	1387	1420			1842			
Travel	0	0	2129	1840			1171			
Computer	61	50	1304	1040			496			
Overhead	2071	1700	40584	40640			-625			
Total	5391	4525	109356	105996			2998			

Baseline Plan Identification (Col. 7b & 7d): Revision No. ________, Dated ________.

NASA FORM 533M MAR 73 PREVIOUS EDITION MAY BE USED.

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
MONTHLY CONTRACTOR FINANCIAL MANAGEMENT REPORT

Form Approved
Budget Bureau No. 104-R0011

2. REPORT FOR MONTH ENDING AND NUMBER OF OPERATING DAYS: March 31, 1978

TO: NASA L & RC
Mr. George Lawrence
Advanced Missions Mail Stop 323
Hampton, Virginia 23665

FROM: Dr. Peter G. Sassone
EES/SED
Georgia Tech

3. CONTRACT VALUE: a. COSTS $ b. FEE $

1. DESCRIPTION OF CONTRACT
a. TYPE
c. SCOPE OF WORK: Benefit Assessment of Pollution Monitoring Satellites

b. CONTRACT NO. AND LATEST DEFINITIZED AMENDMENT NO.: NAS1 - 14351

d. AUTH. DATE

4. FUND LIMITATION: $112.4K $

5. BILLING: a. INVOICE AMTS BILLED $108,233.06 b. TOTAL PYTS REC'D $102,841.55

6. REPORTING CATEGORY	7. COSTS INCURRED/HOURS WORKED - DURING MONTH - ACTUAL a.	DURING MONTH - PLANNED b.	CUM. TO DATE - ACTUAL c.	CUM. TO DATE - PLANNED d.	8. ESTIMATED COSTS/HRS. TO COMPLETE - DETAIL a.	DETAIL b.	BALANCE OF CONTRACT c.	9. ESTIMATED FINAL COSTS/HOURS - CONTRACTOR ESTIMATE a.	CONTRACT VALUE b.	10. UNFILLED ORDERS OUTSTANDING
Personal Services	1188/ 117 hr	2500/ 250 hr	60871/ 6087 hr	59121/ 5912hr			-2108			
Retirement	340	225	4609	4660			694			
Material & Supplies	266	50	1653	1470			1618			
Travel	0	0	2129	1840			1171			
Computer	78	50	1382	1090			418			
Overhead	808	1700	41392	42340			-1433			
Total	2680	4525	112036	110521			360			

Baseline Plan Identification (Col. 7b & 7d): Revision No. Date

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
MONTHLY CONTRACTOR FINANCIAL MANAGEMENT REPORT

Form Approved
Budget Bureau No. 104-R0011

2. REPORT FOR MONTH ENDING AND NUMBER OF OPERATING DAYS: April 30, 1978

TO: NASA L & RC
Mr. George Lawrence
Advanced Missions Mail Stop 323
Hampton, Virginia 23665

FROM: Dr. Peter G. Sassone
EES/SED Georgia Tech

3. CONTRACT VALUE: a. COSTS $ b. FEE $

1. DESCRIPTION OF CONTRACT
a. TYPE
b. CONTRACT NO. AND LATEST DEFINITIZED AMENDMENT NO.: NAS1 - 14351
c. SCOPE OF WORK: Benefit Assessment of Pollution Monitoring Satellites
d. AUTH. CONTR. REP. (Signature) DATE

4. FUND LIMITATION: $ 112.4K $

5. BILLING: a. INVOICE AMTS BILLED $ 108,233.06 b. TOTAL PYTS REC'D $108,233.06

6. REPORTING CATEGORY	7. COSTS INCURRED/HOURS WORKED: DURING MONTH a. ACTUAL	b. PLANNED *	CUM. TO DATE c. ACTUAL	d. PLANNED *	8. ESTIMATED COSTS/HRS. TO COMPLETE: DETAIL a.	b.	BALANCE OF CONTRACT *	9. ESTIMATED FINAL COSTS/HOURS: CONTRACTOR ESTIMATE a.	CONTRACT VALUE b.	10. UNFILLED ORDERS OUTSTANDING
Personal Services	1098/ 110 hr	2262/ 226 hr	61969/ 6197 hr	61383/ 6138 hr			30565/ 3065 hr			
Retirement	89	194	4698	4854			2628			
Material & Supplies	66	90	1719	1560			1214			
Travel	0	129	2129	1969			1800			
Computer	0	71	1382	1161			1000			
Overhead	747	1538	42139	43878			20784			
Total	2000	4284	114036	114805			57991			

* Contract addition, anticipated

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION MONTHLY CONTRACTOR FINANCIAL MANAGEMENT REPORT	Form Approved Budget Bureau No. 104-R0011	2. REPORT FOR MONTH ENDING AND NUMBER OF OPERATING DAYS May 30, 1978
TO: NASA L & RC Mr. George Lawrence Advanced Missions Mail Stop 323 Hampton, VA 23665	FROM: Dr. Peter G. Sassone EES/SED Georgia Tech	3. CONTRACT VALUE a. COSTS $ b. FEE $
1. DESCRIPTION OF CONTRACT a. TYPE c. SCOPE OF WORK Benefit Assessment of Pollution Monitoring Satel	b. CONTRACT NO. AND LATEST DEFINITIZED AMENDMENT NO.	4. FUND LIMITATION $ 172.3K $ 5. BILLING a. INVOICE AMTS BILLED 10,281.94 b. TOTAL PYTS REC'D $110,281.94

6. REPORTING CATEGORY	7. COSTS INCURRED/HOURS WORKED — DURING MONTH — ACTUAL a.	PLANNED b.	CUM. TO DATE — ACTUAL c.	PLANNED d.	8. ESTIMATED COSTS/HRS. TO COMPLETE — DETAIL a.	b.	BALANCE OF CONTRACT c.	9. ESTIMATED FINAL COSTS/HOURS — CONTRACTOR ESTIMATE a.	CONTRACT VALUE b.	10. UNFILLED ORDERS OUTSTANDING
Personal Services	1.2K/ 120 hr	2.3K/ 230 hr	63.2K/ 6320 hr	64.1K/ 6410hr			27.2K			
Retirement	.1K	.2K	4.8K	5.1K			3.5K			
Material & Supplies	.03K	.09K	1.7K	1.6K			2.7K			
Travel	0	.1K	2.1K	1.8K			2.8K			
Computer	.02K	.07K	1.4K	1.2K			1.4K			
Overhead	.8K	1.5K	43K	45.7K			18.5K			
Total	2.2K	4.3K	116.2K	119.5K			56.1K			

Baseline Plan Identification (C.L.7) A.7) Revision No. Dated

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
MONTHLY CONTRACTOR FINANCIAL MANAGEMENT REPORT

Form Approved
Budget Bureau No. 104-R0011

2. REPORT FOR MONTH ENDING AND NUMBER OF OPERATING DAYS: June 30, 1978

TO: NASA L & RC
Mr. George Lawrence
Advanced Missions Mail Stop 323
Hampton, VA 23665

FROM: Dr. Peter G. Sassone
EES/SED
Georgia Tech

3. CONTRACT VALUE
a. COSTS $
b. FEE $

4. FUND LIMITATION $ 172.3K $

1. DESCRIPTION OF CONTRACT
a. TYPE
b. CONTRACT NO. AND LATEST DEFINITIZED AMENDMENT NO.: NAS1-14351
c. SCOPE OF WORK: Benefit Assessment of Pollution Monitoring Satellites
d.

5. BILLING
a. INVOICE AMTS BILLED: 110,281.94
b. TOTAL PYTS REC'D: $110,281.94

6. REPORTING CATEGORY	7. COSTS INCURRED/ DURING MONTH ACTUAL a.	DURING MONTH PLANNED b.	CUM. TO DATE ACTUAL c.	CUM. TO DATE PLANNED d.	DETAIL a.	DETAIL b.	COMPLETE BALANCE OF CONTRACT c.	9. ESTIMATED FINAL COSTS/HOURS CONTRACTOR ESTIMATE a.	CONTRACT VALUE b.	10. UNFILLED ORDERS OUTSTANDING
Personal Services	1.1K/ 110 hr	2.3K/ 230 hr	64.3K/ 6430 hr				26.1K/ 2610hr			
Retirement	.01K	.2K	4.9K				3.3K			
Material & Supplies	.0K	.09K	1.8K				2.7K			
Travel	0	.1K	2.1K				2.8K			
Computer	.0K	.07K	1.4K				1.4K			
Overhead	.7K	1.5K	43.7K				17.7K			
Total	1.8K	4.2K	118.2K				54.0K			

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
MONTHLY CONTRACTOR FINANCIAL MANAGEMENT REPORT

Form Approved
Budget Bureau No. 104-R0011

2. REPORT FOR MONTH ENDING AND NUMBER OF OPERATING DAYS: July 1978

TO: NASA L&RC
Mr. George Lawrence
Advanced Missions, Mail Stop 323
Hampton, Va. 23665

FROM: Dr. Peter G. Sassone
EES/SED
Georgia Tech

3. CONTRACT VALUE: a. COSTS $ b. FEE $

1. DESCRIPTION OF CONTRACT
a. TYPE
b. CONTRACT NO. AND LATEST DEFINITIZED AMENDMENT NO.: NAS1-14351
c. SCOPE OF WORK: Benefit Assessment of Pollution Monitoring Satellites
d. AUTH. CONTR. REP. (Signature) DATE

4. FUND LIMITATION: $ 172.4K $

5. BILLING: a. INVOICE AMTS BILLED $110,281.94 b. TOTAL PYTS REC'D $110,281.94

6. REPORTING CATEGORY	7. COSTS INCURRED/HOURS WORKED – DURING MONTH – ACTUAL a.	DURING MONTH – PLANNED b.	CUM. TO DATE – ACTUAL c.	CUM. TO DATE – PLANNED d.	8. ESTIMATED COSTS/HRS. TO COMPLETE – DETAIL a.	DETAIL b.	BALANCE OF CONTRACT c.	9. ESTIMATED FINAL COSTS/HOURS – CONTRACTOR ESTIMATE a.	CONTRACT VALUE b.	10. UNFILLED ORDERS OUTSTANDING
Personal Services	2.2K/ 220 HR	2.3K/ 230 HR	66.5K/ 6650HR	68.7K/ 6870HR			23.9K/ 2390HR			
Retirement	.2K	.2K	5.1K	5.5K			3.1K			
Material & Supplies	.0K	.1K	1.8K	1.8K			2.7K			
Travel	0	.1K	2.1K	2.0K			2.8K			
Computer	.0K	.1K	1.4K	1.4K			1.4K			
Overhead	1.6K	1.5K	45.4K	48.7K			16.1K			
Total	4K	4.3K	122.3K	128.1K			50K			

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
MONTHLY CONTRACTOR FINANCIAL MANAGEMENT REPORT

Form Approved
Budget Bureau No. 104-R0011

2. REPORT FOR MONTH ENDING AND NUMBER OF OPERATING DAYS: August 1978

TO: NASA L&RC
Mr. George Lawrence-Advanced
Missions, Mail Stop 323, Hampton, VA
23665

FROM: Dr. Peter G. Sassone
EES/SED
Georgia Tech

3. CONTRACT VALUE
a. COSTS $
b. FEE $

4. FUND LIMITATION
$ 172.4K $

5. BILLING
a. INVOICE AMTS BILLED $ 110,281.94
b. TOTAL PYTS REC'D $110,281.94

1. DESCRIPTION OF CONTRACT
a. TYPE
b. CONTRACT NO. AND LATEST DEFINITIZED AMENDMENT NO. NAS1-14351
c. SCOPE OF WORK Benefit Assessment of Pollution Monitori
DATE

6. REPORTING CATEGORY	7. COSTS INCURRED/HOURS WORKED — DURING MONTH — ACTUAL a.	DURING MONTH — PLANNED b.	CUM. TO DATE — ACTUAL c.	CUM. TO DATE — PLANNED d.	8. ESTIMATED COSTS/HRS. TO COMPLETE — DETAIL a.	DETAIL b.	BALANCE OF CONTRACT c.	9. ESTIMATED FINAL COSTS/HOURS — CONTRACTOR ESTIMATE a.	CONTRACT VALUE b.	10. UNFILLED ORDERS OUTSTANDING
Personal Services	1.8k/ 180Hr.	2.3k/ 230Hr.	68.3k/ 6830Hr.	71k/ 7100Hr.			22.1/ 2210Hr			
Retirement	.2k	.2k	5.3k	5.7			3.0			
Materials & Supplies	.0k	.1k	1.8k	1.9			2.7			
Travel	.1k	.1k	2.3k	2.1			2.5			
Computer	.1k	.1k	1.5k	1.5			1.3			
Overhead	1.4k	1.5k	46.8k	50.2			14.7			
Total	3.6k	4.3k	126k	132.4k			46.3			

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
MONTHLY CONTRACTOR FINANCIAL MANAGEMENT REPORT

Form Approved
Budget Bureau No. 104-R0011

2. REPORT FOR MONTH ENDING AND NUMBER OF OPERATING DAYS: September 30, 1978

TO: NASA L & RC, Mr. George Lawrence
Advanced Missions Mail Stop 323
Hampton, Va. 23665

FROM: Dr. Peter G. Sassone
EES/SED
Georgia Tech

3. CONTRACT VALUE: a. COSTS $ | b. FEE $

1. DESCRIPTION OF CONTRACT
a. TYPE
b. CONTRACT NO. AND LATEST DEFINITIZED AMENDMENT NO.: NAS1-14351
c. SCOPE OF WORK: Benefit Assessment of Pollution Monitoring ..
d. AUTHORIZED CONTRACTOR (Signature) | DATE

4. FUND LIMITATION: $ | $

5. BILLING: a. INVOICE AMTS BILLED $125,914.64 | b. TOTAL PYTS REC'D $125,914.64

6. REPORTING CATEGORY	7. COSTS INCURRED/HOURS WORKED — DURING MONTH — ACTUAL a.	PLANNED b.	CUM TO DATE — ACTUAL c.	PLANNED d.	8. ESTIMATED COSTS/HRS. TO COMPLETE — DETAIL a.	b.	BALANCE OF CONTRACT c.	9. ESTIMATED FINAL COSTS/HOURS — CONTRACTOR ESTIMATE a.	CONTRACT VALUE b.	10. UNFILLED ORDERS OUTSTANDING
Personal Services	2.5K/ 250Hr	2.3K 230Hr	70.8K/ 7080Hr	73.3K/ 7330Hr			19.6K/ 1960Hr			
Retirement	.25K	.2K	5.5K	5.9K			2.7K			
Material & Supplies	.03K	.1K	1.8K	2K			2.6K			
Travel	.22K	.1K	2.4K	2.2K			2.4K			
Computer	.05K	.1K	1.6K	1.6K			1.2K			
Overhead	1.9K	1.5K	48.7K	51.7K			12.8K			
Total	4.95K	4.3K	130.8K	136.7K			41.8K			

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
MONTHLY CONTRACTOR FINANCIAL MANAGEMENT REPORT

Form Approved
Budget Bureau No. 104-R0011

2. REPORT FOR MONTH ENDING AND NUMBER OF OPERATING DAYS: October, 1978

TO: NASA L&RC
Mr. George Lawrence
Advanced Missions, MS 323
Hampton, Va 23665

FROM: Dr. Peter G. Sassone
EES/SED
Georgia Tech

3. CONTRACT VALUE
a. COSTS $
b. FEE $

1. DESCRIPTION OF CONTRACT
a. TYPE
b. CONTRACT NO. AND LATEST DEFINITIZED AMENDMENT NO.: NAS1-14351
c. SCOPE OF WORK: Benefit Assessment of Pollution Monitoring...
d. [illegible] DATE: 11-30-78

4. FUND LIMITATION
$ $

5. BILLING
a. INVOICE AMTS BILLED: $130,910.24
b. TOTAL PYTS REC'D: $125,914.64

6. REPORTING CATEGORY	7. COSTS INCURRED/HOURS WORKED: DURING MONTH, ACTUAL a.	DURING MONTH, PLANNED b.	CUM. TO DATE, ACTUAL c.	CUM. TO DATE, PLANNED d.	8. ESTIMATED COSTS/HRS. TO COMPLETE: DETAIL a.	DETAIL b.	BALANCE OF CONTRACT c.	9. ESTIMATED FINAL COSTS/HOURS: CONTRACTOR ESTIMATE a.	CONTRACT VALUE b.	10. UNFILLED ORDERS OUTSTANDING
Personal Services	1.6K/ 160HR	2.3K/ 230HR	72.4K/ 7240HR	75.6K/ 7560HR	2.3K/ 230HR	2.3K/ 230HR	18.0K/ 1800HR			
Retirement	.2K	.2K	5.7K	6.1K	.2K	.2K	2.6K			
Material & Supplies	.0K	.1K	1.8K	2.1K	.1K	.1K	2.6K			
Travel	.1K	.1K	2.5K	2.3K	.1K	.1K	2.4K			
Computer	.0K	.1K	1.6K	1.7K	.1K	.1K	1.2K			
Overhead	1.3K	1.5K	49.9K	53.2K	1.5K	1.5K	11.6K			
Total	3.2K	4.3K	133.9 K	141K	4.3K	4.3K	38.4K			

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

MONTHLY CONTRACTOR FINANCIAL MANAGEMENT REPORT

Form Approved
Budget Bureau No. 104-R0011

2. REPORT FOR MONTH ENDING AND NUMBER OF OPERATING DAYS: 30 November 1978

TO: NASA L & RC
Mr. George Lawrence
Advanced Missions-Mail Stop 323
Hampton, Va. 23665

FROM: Dr. Peter G. Sassone
EES/SED Georgia Tech

3. CONTRACT VALUE
a. COSTS $
b. FEE $

1. DESCRIPTION OF CONTRACT
a. TYPE
b. CONTRACT NO. AND LATEST DEFINITIZED AMENDMENT NO.: NAS1-14351
c. SCOPE OF WORK: Benefit Assessment of Pollution Monitoring...
DATE: 12-14-78

4. FUND LIMITATION
$
$

5. BILLING
a. INVOICE AMTS BILLED: $133,549.60
b. TOTAL PYTS REC'D: $130,870.24

6. REPORTING CATEGORY	7. COSTS INCURRED/HOURS WORKED — DURING MONTH — ACTUAL a.	PLANNED b.	CUM. TO DATE — ACTUAL c.	PLANNED d.	8. ESTIMATED COSTS/HRS. TO COMPLETE — DETAIL a.	b.	BALANCE OF CONTRACT c.	9. ESTIMATED FINAL COSTS/HOURS — CONTRACTOR ESTIMATE a.	CONTRACT VALUE b.	10. UNFILLED ORDERS OUTSTANDING
Personal Services	3.5K	2.3K	75.9K	77.9K	2.3K	2.3K	14.5K			
Retirement	.3K	.2K	6.0K	6.3K	.2K	.2K	2.2K			
Material & Supplies	.1K	.1K	.2K	2.2K	.1K	.1K	2.5K			
Travel	.0K	.1K	2.5K	2.4K	.1K	.1K	2.3K			
Computer	.0K	.1K	1.6K	1.8K	.1K	.1K	1.1K			
Overhead	2.6K	1.5K	52.5K	54.7K	1.5K	1.5K	8.9K			
Total	6.5K	4.3K	138.7K	145.3K	4.3K	4.3K	31.5K			

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
MONTHLY CONTRACTOR FINANCIAL MANAGEMENT REPORT

Form Approved
Budget Bureau No. 104-R0011

2. REPORT FOR MONTH ENDING AND NUMBER OF OPERATING DAYS: December 1978

TO:
NASA LaRC/ Mr. George Lawrence
Advanced Missions, Mail Stop 323
Hampton, VA 23665

FROM:
Dr. Peter G. Sassone
EES/SED, Georgia Tech.

3. CONTRACT VALUE — a. COSTS $ — b. FEE $

1. DESCRIPTION OF CONTRACT
a. TYPE
b. CONTRACT NO. AND LATEST DEFINITIZED AMENDMENT NO.: NAS1-14351
c. SCOPE OF WORK: Benefit Assessment of Pollution Monitoring Satellites

DATE: 1-17-79

4. FUND LIMITATION $ $

5. BILLING — a. INVOICE AMTS BILLED: $ 138,856.73 — b. TOTAL PYTS REC'D: $132,304.03

6. REPORTING CATEGORY	7. COSTS INCURRED/HOURS WORKED — DURING MONTH — ACTUAL K$ a.	PLANNED K$ b.	CUM. TO DATE — ACTUAL K$ c.	PLANNED K$ d.	8. ESTIMATED COSTS/HRS. TO COMPLETE — DETAIL — Est. Jan. a. K$	Est. Feb. b. K$	BALANCE OF CONTRACT c.	9. ESTIMATED FINAL COSTS/HOURS — CONTRACTOR ESTIMATE a.	CONTRACT VALUE b.	10. UNFILLED ORDERS OUTSTANDING
Personal Services	2.7/	2.3/	78.6/	80.2/	2.3/	2.3/	11.8			
	270 hr	230 hr	7860hr	8020hr	230 hr	230 hr	1180 hr			
Retirement	.3	.2	6.3	6.5	.2	.2	.2			
Materials & Supplies	.1	.1	2.7	2.3	.1	.1	2.4			
Travel	.0	.1	2.5	2.5	.1	.1	2.3			
Computer	.0	.1	1.6	1.9	.1	.1	1.1			
Overhead	2.0	1.5	54.0	56.3	1.5	1.5	6.9			
TOTAL	5.0	4.3	145.7	149.7	4.3	4.3	26.5			

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
MONTHLY CONTRACTOR FINANCIAL MANAGEMENT REPORT

Form Approved
Budget Bureau No. 104-R0011

2. REPORT FOR MONTH ENDING AND NUMBER OF OPERATING DAYS: January 1979

TO: NASA L&RC
Mr. George Lawrence, Advanced Missions, MS323, Hampton, VA 23665

FROM: Dr. Peter G. Sassone
EES/SED
Georgia Tech

3. CONTRACT VALUE: a. COSTS $ | b. FEE $

1. DESCRIPTION OF CONTRACT
a. TYPE
b. CONTRACT NO. AND LATEST DEFINITIZED AMENDMENT NO.: NAS1-14351
c. SCOPE OF WORK: Benefit Assessment of Pollution Monitoring...
d. AUTH. CONTR. REP. (Signature)
DATE: 2-5-79

4. FUND LIMITATION: $ 172K | $

5. BILLING: a. INVOICE AMTS BILLED $ 143,909.89 | b. TOTAL PYTS REC'D $138,856.73

6. REPORTING CATEGORY	7. COSTS INCURRED/HOURS WORKED — DURING MONTH — ACTUAL a.	DURING MONTH — PLANNED b.	CUM. TO DATE — ACTUAL c.	CUM. TO DATE — PLANNED d.	8. ESTIMATED COSTS/HRS. TO COMPLETE — DETAIL — Feb. est. a.	DETAIL — Mar. est. b.	BALANCE OF CONTRACT c.	9. ESTIMATED FINAL COSTS/HOURS — CONTRACTOR ESTIMATE a.	CONTRACT VALUE b.	10. UNFILLED ORDERS OUTSTANDING
Personal Services	2.4K/ 240HR	2.3K/ 230HR	81K/ 8100HR	82.5K/ 8250HR	2.3K/ 230HR	2.3K/ 230HR	9.4K/ 940HR			
Retirement	.2K	.2K	6.5K	6.7K	.2K	.2K	1.8K			
Material & Supplies	.1K	.1K	2.8K	2.4K	.1K	.1K	2.3K			
Travel	0	.1K	2.5K	2.6K	.1K	.1K	2.2K			
Computer	.1K	.1K	1.7K	2.0K	.1K	.1K	1.0K			
Overhead	1.8K	1.5K	55.8K	57.8K	1.5K	1.5K	5.1K			
Total	4.6K	4.3K	150.3K	154K	4.3K	4.3K	23.9K			

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
MONTHLY CONTRACTOR FINANCIAL MANAGEMENT REPORT

Form Approved
Budget Bureau No. 104-R0011

2. REPORT FOR MONTH ENDING AND NUMBER OF OPERATING DAYS: Feb. 1979

TO: NASA L & RC; Mr. George Lawerence
Advanced Missions Mail Stop 323
Hampton, VA 23665

FROM: Mr. Peter G. Sassone
EES/SED
Georgia Tech

3. CONTRACT VALUE — a. COSTS: $ — b. FEE: $

1. DESCRIPTION OF CONTRACT — a. TYPE:

b. CONTRACT NO. AND LATEST DEFINITIZED AMENDMENT NO.: NASA - 14351

4. FUND LIMITATION: $172.4K $

c. SCOPE OF WORK:

Scope of work

Benefit assessment of pollution monitoring Satellites

d. AUTH. CON. TR. REP. (Signature) — DATE

5. BILLING — a. INVOICE AMTS BILLED: $ 146,963.20 — b. TOTAL PYTS REC'D: $ 143,909.89

6. REPORTING CATEGORY	7. COSTS INCURRED/HOURS WORKED — DURING MONTH — a. ACTUAL $K	b. PLANNED $K	CUM. TO DATE — c. ACTUAL $K	d. PLANNED	8. ESTIMATED COSTS/HRS. TO COMPLETE — DETAIL — a. March $K	b. Spril $K	c. BALANCE OF CONTRACT $K	9. ESTIMATED FINAL COSTS/HOURS — a. CONTRACTOR ESTIMATE	b. CONTRACT VALUE	10. UNFILLED ORDERS OUTSTANDING
Personal Services	2.4/ 240 Hr	2.3/ 230 Hr	82.6/ 8260Hr	84.8/ 8480 hr	2.3/ 230Hr	2.3 230Hr	7.8 780Hr			
Retirement	.2	.2	6.6	6.9	.2	.2	1.6			
Material & Supplies	.0	.1	2.0	2.5	.1	.1	2.5			
Travel	.0	.1	2.5	2.7	.1	.1	2.3			
Computer	.0	.1	1.7	2.1	.1	.1	1.1			
Overhead	1.8	1.5	57.6	59.3	1.5	1.5	3.9			
Total	4.4	4.3	153.0	158.3	4.3	4.3	19.2			

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION MONTHLY CONTRACTOR FINANCIAL MANAGEMENT REPORT	Form Approved Budget Bureau No. 104-R0011	2. REPORT FOR MONTH ENDING AND NUMBER OF OPERATING DAYS March

TO:	FROM:	3. CONTRACT VALUE
NASA L&RC; Mr. George Lawrence Advanced Missions Mail Stop 323 Hampton, VA 23665	Mr. Peter G. Sassone EES/SED Georgia Tech	a. COSTS $ b. FEE $
1. DESCRIPTION OF CONTRACT — a. TYPE	b. CONTRACT NO. AND LATEST DEFINITIZED AMENDMENT NO. NASA-14351	4. FUND LIMITATION $ 172.4K $
c. SCOPE OF WORK Benefit Assessment of Pollution Monitoring Satellites	d. AUTH. CONTR. REP. (Signature) DATE	5. BILLING a. INVOICE AMTS BILLED $ 151,406.48 b. TOTAL PYTS REC'D $ 146,963.20

6. REPORTING CATEGORY	7. COSTS INCURRED/HOURS WORKED — DURING MONTH — ACTUAL $K/hr.	PLANNED $K/hr.	CUM. TO DATE — ACTUAL $K/hr.	PLANNED $K/hr.	8. ESTIMATED COSTS/HRS. TO COMPLETE — DETAIL — April $K/hr.	May $K/hr.	BALANCE OF CONTRACT $K/hr.	9. ESTIMATED FINAL COSTS/HOURS — CONTRACTOR ESTIMATE a.	CONTRACT VALUE b.	10. UNFILLED ORDERS OUTSTANDING
Personal Services	1.6/160	2.3/230	84.2/8400	87.1/8710	2.3/230	2.3/230	6.2			
Retirement	.2	.2	6.8	7.1	.2	.2	1.4			
Materials & Supplies	.0	.1	2.0	2.6	.1	.1	2.5			
Travel	.0	.1	2.5	2.8	.1	.1	2.3			
Computer	.0	.1	1.7	2.2	.1	.1	1.1			
Overhead	1.3	1.5	58.9	60.8	1.5	1.5	2.6			
Total	3.1	4.3	156.1	162.6	4.3	4.3	16.1			

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
MONTHLY CONTRACTOR FINANCIAL MANAGEMENT REPORT

Form Approved
Budget Bureau No. 104-R0011

2. REPORT FOR MONTH ENDING AND NUMBER OF OPERATING DAYS: APRIL [illegible]

SCOPE OF WORK
Benefit assessment of pollution monitoring Satellites

TO: NASA L & RC; Mr. George Lawrence
Advanced Missions Mail Stop 323
Hampton, VA 23665

FROM: Mr. Peter G. Sassone
EES/SED
Georgia Tech

3. CONTRACT VALUE
a. COSTS $
b. FEE $

1. DESCRIPTION OF CONTRACT
a. TYPE
b. CONTRACT NO. AND LATEST DEFINITIZED AMENDMENT NO.: NASA - 14351
c. SCOPE OF WORK

d. [illegible] (Signature) DATE

4. FUND LIMITATION: $ 172.4K $

5. BILLING
a. INVOICE AMTS BILLED: $154,486.62
b. TOTAL PYTS REC'D: $151,406.48

6. REPORTING CATEGORY	7. COSTS INCURRED/HOURS WORKED — DURING MONTH — ACTUAL $K a.	PLANNED $K b.	CUM. TO DATE — ACTUAL $K c.	PLANNED $K d.	8. ESTIMATED COSTS/HRS. TO COMPLETE — DETAIL — May $K a.	June $K b.	BALANCE OF CONTRACT $K c.	9. ESTIMATED FINAL COSTS/HOURS — CONTRACTOR ESTIMATE a.	CONTRACT VALUE b.	10. UNFILLED ORDERS OUTSTANDING
Personal Services	1.5/150	2.3/230	85.8/ 8580	89.4/ 8940	2.3/230	2.3/230	4.6/460			
Retirement	.2	.2	6.9	7.3	.2	.2	1.3			
Material & Supplies	.0	.1	2.0	2.7	.1	.1	2.4			
Travel	.2	.1	2.7	2.9	.1	.1	2.1			
Computer	.0	.1	1.7	2.3	.1	.1	1.0			
Overhead	1.2	1.5	60.0	62.3	1.5	1.5	1.4			
Total	3.1	4.3	159.1	166.9	4.3	4.3	12.8			

PAGE ______ OF ______ PAGES

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
MONTHLY CONTRACTOR FINANCIAL MANAGEMENT REPORT

Form Approved
Budget Bureau No. 104-R0011

2. REPORT FOR MONTH ENDING AND NUMBER OF OPERATING DAYS: May [illegible]

TO: NASA/LARC, Mr. George Lawrence
Advanced Missions Mail Stop 323
Hampton, VA 23665

FROM: Mr. Peter G. Sassone
EES/SEL
Georgia Tech

3. CONTRACT VALUE
a. COSTS $
b. FEE $

1. DESCRIPTION OF CONTRACT
a. TYPE
b. CONTRACT NO. AND LATEST DEFINITIZED AMENDMENT NO.: NASA-14351
c. SCOPE OF WORK: Benefit Assessment of Pollution Monitoring Satellites
d. AUTHD CONTR. REP. (Signature)
DATE

4. FUND LIMITATION: $ 172.4K $

5. BILLING
a. INVOICE AMTS BILLED: $ 157,569
b. TOTAL PYTS REC'D: $ 154,486.62

6. REPORTING CATEGORY	7. COSTS INCURRED/HOURS WORKED: DURING MONTH — ACTUAL a.	DURING MONTH — PLANNED b.	CUM. TO DATE — ACTUAL c.	CUM. TO DATE — PLANNED d.	8. ESTIMATED COSTS/HRS. TO COMPLETE: DETAIL — June $K a.	DETAIL — July $K b.	BALANCE OF CONTRACT c.	9. ESTIMATED FINAL COSTS/HOURS: CONTRACTOR ESTIMATE a.	CONTRACT VALUE b.	10. UNFILLED ORDERS OUTSTANDING
Personal Services	1.2/120	2.3/230	87.0/8700	88/8800	3.6/360	.1/10	3.4			
Retirement	.1	.2	7.1	7.2	.2	0	1.1			
Materials and Supplies	0	.1	2.0	2.0	.1	1.3	2.4			
Travel	0	.1	2.7	2.7	0	0	2.2			
Computer	0	.1	1.7	1.7	.1	.1	1.1			
Overhead	.9	1.5	61.0	62.0	2.8	.1	.5			
Total	2.3	4.3	161.6	163.7	6.8	1.5	10.8			

Baseline Plan Identification [illegible]

PAGE ______ OF ______ PAGES

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

MONTHLY CONTRACTOR FINANCIAL MANAGEMENT REPORT

Form Approved
Budget Bureau No. 104-R0011

2. REPORT FOR MONTH ENDING AND NUMBER OF OPERATING DAYS: June [illegible]

TO: NASA/LARC, Mr. George Lawrence
Advanced Missions Mail Stop 323
Hampton, VA 23665

FROM: Mr. Peter G. Sassone
EES/SEL
Georgia Tech

3. CONTRACT VALUE
a. COSTS $
b. FEE $

1. DESCRIPTION OF CONTRACT
a. TYPE
b. CONTRACT NO. AND LATEST DEFINITIZED AMENDMENT NO.: NASA-14351
c. SCOPE OF WORK: Benefit Assessment of Pollution Monitoring Satellites
d. AUTH. CONTR. REP. (Signature) / DATE

4. FUND LIMITATION: $ 172.4K $

5. BILLING
a. INVOICE AMTS BILLED: $158,826.93
b. TOTAL PYTS REC'D: $157,569.00

6. REPORTING CATEGORY	7. COSTS INCURRED/HOURS WORKED — DURING MONTH — ACTUAL a.	PLANNED b.	CUM. TO DATE — ACTUAL c.	PLANNED d.	8. ESTIMATED COSTS/HRS. TO COMPLETE — DETAIL — July a.	Aug b.	BALANCE OF CONTRACT c.	9. ESTIMATED FINAL COSTS/HOURS — CONTRACTOR ESTIMATE a.	CONTRACT VALUE b.	10. UNFILLED ORDERS OUTSTANDING
Personal Services	3.67/360	3.67/360	90.6	90.6	.1/10	.2/20	-.2			
Retirement	.2	.2	7.3	7.3	0	0	.9			
Materials and Supplies	.1	.1	2.1	2.1	1.3	.3	2.4			
Travel	0	0	2.7	2.7	0	0	2.2			
Computer	.1	.1	1.8	1.8	.1	0	1.0			
Overhead	2.8	2.8	63.7	63.7	.1	.1	-2.2			
Total	6.8	6.8	168.3	168.3	1.5	.6	4.0			

Baseline Plan Identification [illegible]

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
MONTHLY CONTRACTOR FINANCIAL MANAGEMENT REPORT

Form Approved
Budget Bureau No. 104-R0011

2. REPORT FOR MONTH ENDING AND NUMBER OF OPERATING DAYS: July [illegible]

TO: NASA/LARC, Mr. George Lawrence
Advanced Missions Mail Stop 323
Hampton, VA 23665

FROM: Mr. Peter G. Sassone
EES/SEL
Georgia Tech

3. CONTRACT VALUE
a. COSTS $
b. FEE $

1. DESCRIPTION OF CONTRACT
a. TYPE
b. CONTRACT NO. AND LATEST DEFINITIZED AMENDMENT NO.: NASA-14351
c. SCOPE OF WORK: Benefit Assessment of Pollution Monitoring Satellites
d. AUTH. CONTR. REP. (Signature)
DATE

4. FUND LIMITATION: $ 172.4K $

5. BILLING
a. INVOICE AMTS BILLED: $166,612.26
b. TOTAL PYTS REC'D: $ 159,826.93

6. REPORTING CATEGORY	7. COSTS INCURRED/HOURS WORKED — DURING MONTH — ACTUAL a.	DURING MONTH — PLANNED b.	CUM. TO DATE — ACTUAL c.	CUM. TO DATE — PLANNED d.	8. ESTIMATED COSTS/HRS. TO COMPLETE — DETAIL — August	DETAIL — Sept	BALANCE OF CONTRACT e.	9. ESTIMATED FINAL COSTS/HOURS — CONTRACTOR ESTIMATE a.	CONTRACT VALUE b.	10. UNFILLED ORDERS OUTSTANDING
Personal Services	.1	.1	90.7	90.7	.2/20	.2	-.3			
Retirement	0	0	7.4	7.4	0	0	.9			
Materials and Supplies	1.3	1.3	3.4	3.4	.3	0	.9			
Travel	0	0	2.7	2.7	0	0	2.2			
Computer	.1	.1	1.8	1.8	0	0	1.0			
Overhead	.1	.1	63.8	63.8	.1	.1	-2.3			
Total	1.5	1.5	169.8	169.8	.6	.3	2.4			

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
MONTHLY CONTRACTOR FINANCIAL MANAGEMENT REPORT

Form Approved
Budget Bureau No. 104-R0011

2. REPORT FOR MONTH ENDING AND NUMBER OF OPERATING DAYS: August 1979

TO: NASA/LARC, Mr. George Lawrence
Advanced Missions Mail Stop 323
Hampton, VA 23665

FROM: Mr. Peter G. Sassone
EES/SEL
Georgia Tech

3. CONTRACT VALUE: a. COSTS $ b. FEE $

1. DESCRIPTION OF CONTRACT
a. TYPE
b. CONTRACT NO. AND LATEST DEFINITIZED AMEND. MENT NO.: NASA-14351
c. SCOPE OF WORK: Benefit Assessment of Pollution Monitoring Satellites

4. FUND LIMITATION: $ 172.4K $

AUTH. CONTR. REP. (Signature) DATE 10/18/79

5. BILLING: a. INVOICE AMTS BILLED $ 168,072.07 b. TOTAL PYTS REC'D $159,826.93

6. REPORTING CATEGORY	7. COSTS INCURRED/HOURS WORKED: DURING MONTH Actual a.	Planned b.	CUM. TO DATE Actual c.	Planned d.	8. ESTIMATED COSTS/HRS. TO COMPLETE: DETAIL Sept a.	Oct b.	Balance of Contract c.	9. ESTIMATED FINAL COSTS/HOURS: Contractor Estimate a.	Contract Value b.	10. UNFILLED ORDERS OUTSTANDING
Personal Services	.2	.2	90.9	90.9	.2	.2	-.4			
Retirement	0	0	7.4	7.4	0	0	.9			
Materials and Supplies	.3	.3	3.7	3.7	0	1.0	.8			
Travel	0	0	2.7	2.7	0	0	2.2			
Computer	0	0	1.8	1.8	0	0	1.0			
Overhead	.1	.1	63.9	63.9	.1	.1	-2.4			
Total	.6	.6	170.4	170.4	.3	1.3	2.0			

A-1818

FINAL REPORT

BENEFIT ASSESSMENT OF POLLUTION MONITORING SATELLITES

By

Peter G. Sassone, Project Director
Frank E. Gramling
Fred E. Williams
R. David Wilkins
D. McCarty Brown
John B. Wood

Prepared for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
LANGLEY RESEARCH CENTER
Contract NAS1–14351

GEORGIA INSTITUTE OF TECHNOLOGY

Engineering Experiment Station
Atlanta, Georgia 30332

1979

BENEFIT ASSESSMENT OF POLLUTION MONITORING SATELLITES

by

Peter G. Sassone, Project Director
Frank E. Gramling, Fred E. Williams
R. David Wilkins, D. McCarty Brown,
John B. Wood

Georgia Institute of Technology
Engineering Experiment Station
Systems Engineering Division
Systems Technology Branch

Prepared for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
LANGLEY RESEARCH CENTER
Contract NAS1-14351

FOREWORD

The "Benefit Assessment of Pollution Monitoring Satellites" project under Contract NAS 1-14351 was conducted by the Engineering Experiment Station (EES) at Georgia Tech in conjunction with the School of Industrial Management (IM). The program was administered under Georgia Tech Project A-1818 by the Systems Engineering Division.

This report describes the work performed during the period February 1976 through December 1978. Mr. George Lawrence of NASA/Langley Research Center was the Program Manager.

The Georgia Tech Project Director was Dr. Peter G. Sassone. Mr. Frank Gramling and Mr. David Wilkins have served as Associate Project Directors. The project was conducted under the general supervision of Mr. Robert P. Zimmer, Chief of the Systems Engineering Division and Dr. Neil B. Hilsen, Head of the Systems Technology Branch. In addition to the project director, the project team was comprised of the key personnel listed below along with their principal area of contribution.

F. E. Gramling	Modeling and Simulation
R. D. Wilkins	Modeling and Simulation
F. E. Williams	Production Costing
J. B. Wood	Economic Evaluation
D. M. Brown	Modeling and Simulation

ABSTRACT

This report presents the results of a broadscale economic assessment of the potential benefits of stratospheric monitoring. Of particular importance is the role of monitoring in decision processes involving industrial pollution control and regulation. The primary results of the study are listed below:

--By considering a broad range of physical and economic effects, it is possible, on an order of magnitude basis, to estimate the benefits of improved stratospheric monitoring. A computer model has been utilized to simulate this sequence of causal relationships. The computer model was found to be a tractable method for evaluating the sensitivity of the benefits of improved monitoring to alternative parameter values in each link of the model.

--Benefits of monitoring ozone and aerosols were found to be inversely related to the actual (best presently known) trends in these stratospheric constituents. Depending on the actual trend, the present worth (over 50 years) of benefits of improved ozone monitoring ranges between 564 million dollars and 2039 million dollars. The benefits of adding improved aerosol monitoring capability to the ozone monitoring capability range from 24 million dollars to 79 million dollars.

--Benefits derived from improved understanding of atmospheric processes, not considered withn the scope of this study, may well overshadow the direct benefits considered in this research.

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ABBREVIATIONS

RHS	Right Hand Side
MEBS	Model of Environmental Benefits
EMS	Environmental Monitoring System
ADL	Arthur D. Little, Inc.
BDC	Bureau of Domestic Commerce
CBA	Cost Benefit Analysis
CIAP	Climatic Impact Assessment Program
CFM	Chlorofluoromethane
F-11	$CFCL_3$
F-12	CF_2CL_2
NB	Net Benefits
NPV	Net Present Value
UV-B	Erythemally effective ultraviolet radiation
WMO	World Meteorological Organization
OLS	Ordinary Least Squares
BACER	Biological And Climatic Effects Research Program (EPA)
HAPP	High Altitude Pollution Program (FAA-DOT)

SECTION I

OVERVIEW

1.1 Introduction

In recent years there has been increasing concern with the possibility that man's terrestrial economic activities of production, distribution, and consumption contribute pollutants to the environment in sufficient quantities to upset naturally existing chemical equilibria in the atmosphere. Such inadvertent anthropogenic phenomena have become associated with possible changes in climate (temperature, precipitation, and ultraviolet radiation) where long term consequences may be serious, if not disastrous. Temperature and precipitation changes can be expected directly to impact agriculture, forestry, and marine biology; and to indirectly affect virtually the full range of human activity. Changes in ultraviolet radiation can be expected to affect the incidence of skin cancer--greater radiation results in more skin cancer.

In the cause-effect chain linking economic activity to pollution to atmospheric chemistry to climate to social well-being, very little is known with certainty. Indeed, there is very substantial uncertainty at every step. A number of research programs, including CIAP, HAPP, BACER*, and efforts sponsored by the NAS, have been slowly resolving uncertainties in this area. Nonetheless, the condition remains that very substantial uncertainties persist.

It is in this context that the issue of monitoring the environment arises. Monitoring reduces uncertainty in the areas to which it is addressed. Atmospheric monitoring -- which is our concern in this report --reduces uncertainty

*Note the list of abreviations.

about the state and trends in the atmosphere, but presumably adds neither to the understanding of the relation of economic activity to pollution, nor the relation of climate to social wellbeing. A point to be borne in mind is that each link in the chain of causes and effects in the climate modification problem suggests types of, and areas for, monitoring. *Atmospheric monitoring adds to the understanding of only one link in that chain. However, that link appears to be the most difficult, and most important one to understand.*

A monitoring system can be based on the ground or at sea, aboard aircraft or satellites, or in any combination of these. A monitoring system has myriad technical specifications. The main concern in this report will be not with monitoring platforms nor with technical specification, but with the economic benefits--broadly construed--of monitoring. The implementation of a monitoring system requires scarce resources, such as scientific, engineering and managerial manpower; and such as electronic components and possibly booster rockets. Insofar as these resources have alternative uses, the issue of devoting them to a monitoring system rather than some other use is an economic issue. Generally, this report deals with the economics of environment monitoring systems.

1.2 Objective

The goal of research in this field is to improve government decision making in issues related to monitoring. Questions such as which constituents to monitor, what types of platforms, where to locate instruments, how much should be spent, and when to start and stop, arise with increasing frequency. The systematic application of economic analysis can improve the efficiency of resource allocation in both the technical sense of minimizing the cost of any given system and the social sense of providing society with the mix of monitoring systems it most desires.

Three objectives have guided this research program. The first objective is to develop a general procedure - a methodology - for economic evaluation of proposed environment monitoring systems (EMS's). The second objective is to demonstrate that the methodology is tractable--that the requisite models and submodels can actually be constructed with available information. The third objective is to use the models to derive actual dollar estimates of the benefits of a monitoring system designed to monitor stratospheric ozone and aerosols.

The motivation for considering a monitoring system for stratospheric ozone and aerosols is suggested by Figure 1.1. Current hypotheses suggest that high flying aircraft and terrestrial chlorofluoromethane (CFM) production can each influence climate through a number of possible consequence chains. Monitoring of ozone and aerosols can establish the reliability of the hypotheses, determine whether any danger exists now or in the future, and guide environmental policy making.

1.3 Scope

The scope of this research stops short of laboratory or *in situ* experi ments and data collection, and short of the analysis of chemical and atmospheric data. Rather, with regards to our need to model atmospheric chemistry and transport mechanisms, and to model certain cost and damage functions, we have freely made use of the results of other research efforts. The contribution of the work described here is to synthesize the results of many diverse efforts and to provide an economics superstructure for the decision process.

1.4 Approach

The diverse set of elements related to environmental monitoring have been modeled as a single complex system. Relevant subsystems in this scheme include the economic system, the atmospheric system, the terrestrial ecosystem, the

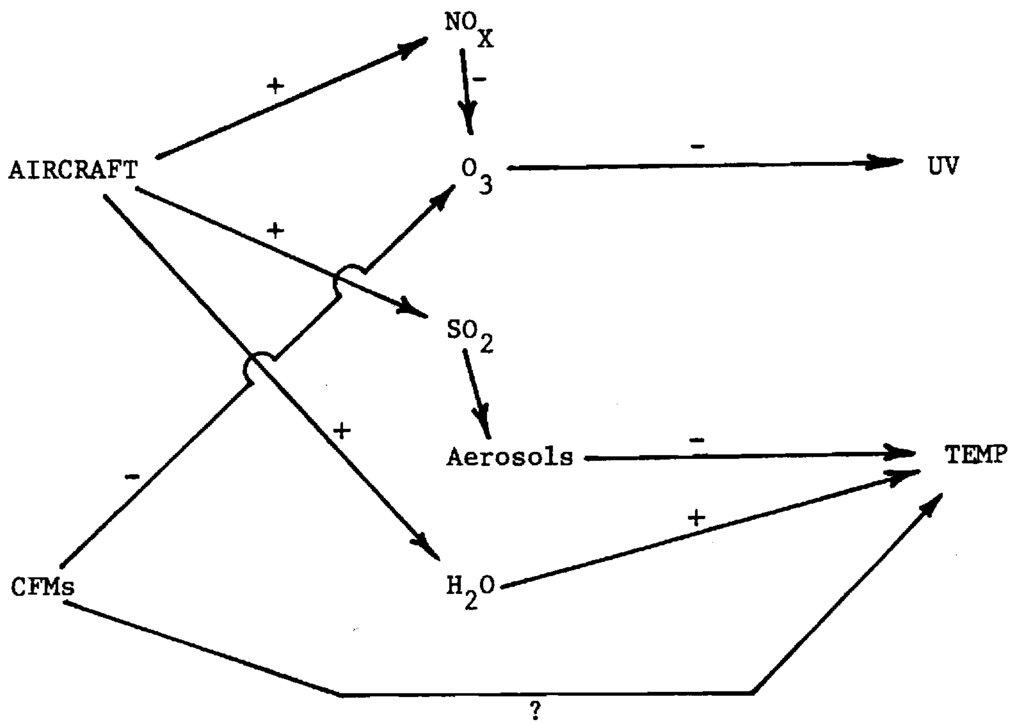


Figure 1.1 Cause-Effect Linkages in the Applications Model. (Algebraic Signs Indicate Direction of Effect, i.e., Sign of Partial Derivative)

policy making system, and of course, environment monitoring systems. Figure 1.2 illustrates the system in Block Diagram Form. This overall system can be loosely described as follows. A monitoring system with given performance capabilities is assumed to be implemented in the initial time period. A trend (% per decade increase or decrease) in some constituent monitored by that system is postulated. At some future point in time, which depends on both the performance specification of the monitoring system and the magnitude of that trend, the trend is detected. A specific policy to deal with that discovered trend is predicted to be chosen. The policy is implemented, and it results in certain near term costs, whose magnitudes differ from policy to policy. Examples of policies might be the banning of the use of CFMs as propellants, or the curtailing of commercial stratospheric flight. In the more distant future, benefits accrue as damage which would have otherwise occurred is averted. Examples of damage might be skin cancer or lower crop yields. The value of a monitoring system depends on the difference in policy decisions it makes. It is inappropriate to assume that no monitoring system would be implemented in the absence of the proposed system. Rather the proposed system must be compared with the alternative to find its real value. Thus, in computing costs and benefits, it is the difference in costs and benefits occurring under the proposed system vis a vis the alternate system which is of ultimate interest. Figure 1.3 illustrates the benefit calculation procedures. All of these calculations are driven by the postulated value of the trend. Of course, the true numerical value of the trend is unknown--it is the purpose of the monitoring system to determine it. Thus, the calculations must be carried out for a host of trend values, with the understanding that the calculated values are conditional. Finally, the monitoring system might monitor several constituents. Policies adopted in response to a trend in one constituent

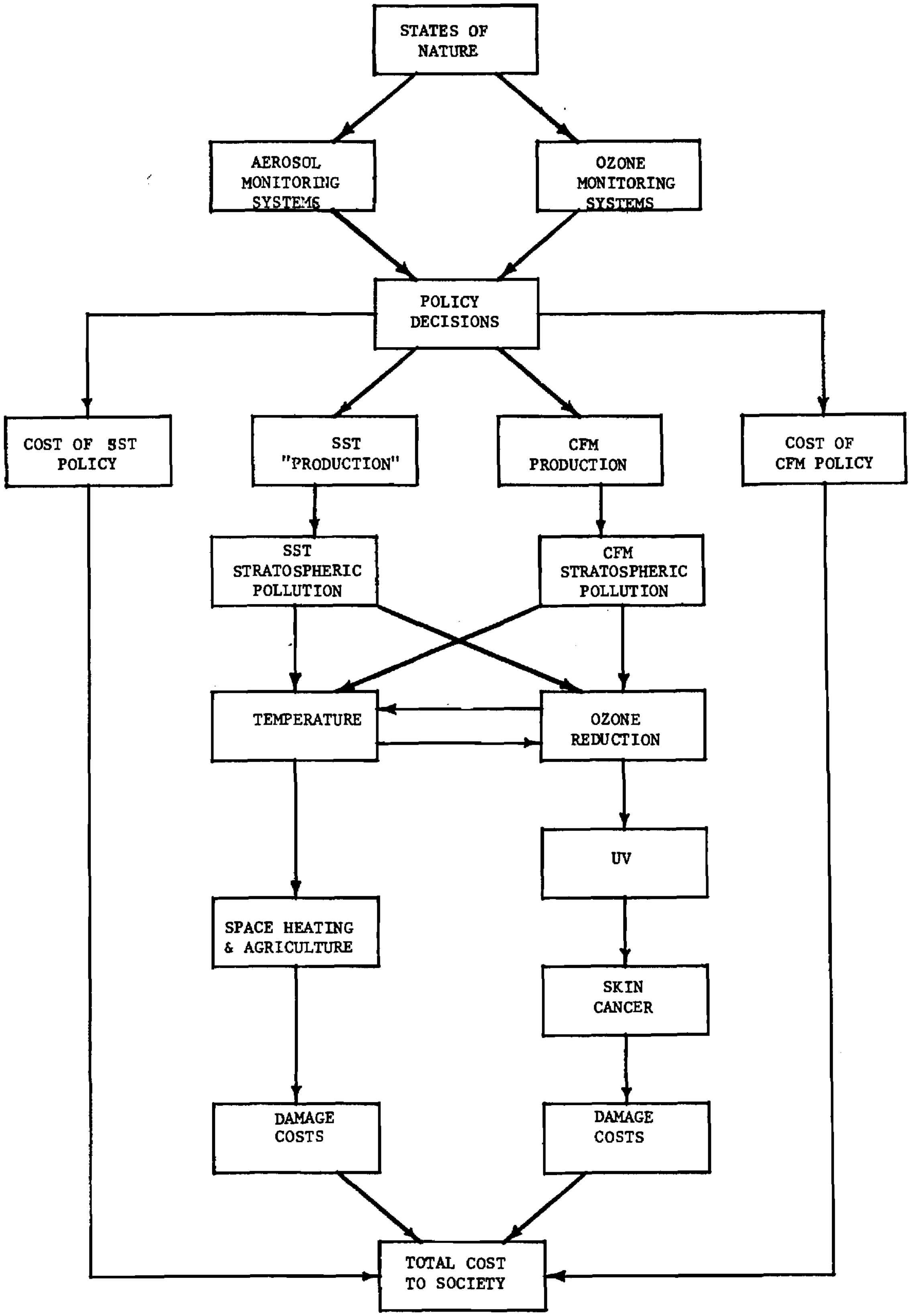


Figure 1.2 Detailed Breakdown of Linkages in the Model of Environmental Benefits (MEBS)

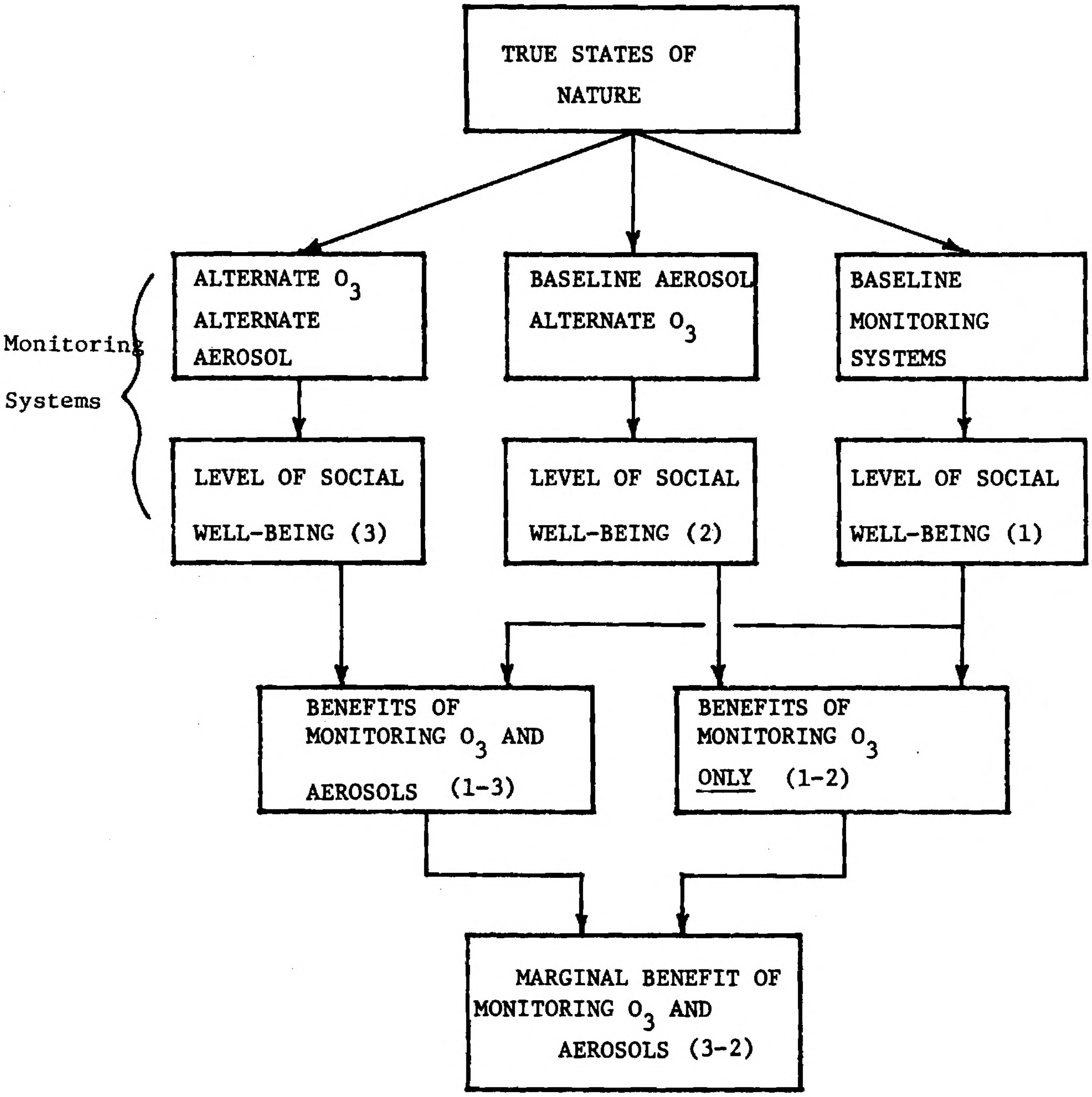


Figure 1.3 Procedure for Calculating Benefits of Improved Ozone Monitoring, Joint Benefits of Improved Ozone and Aerosol Monitoring, and Marginal Benefits of Monitoring Aerosols.

might alter the trend in another, thereby complicating the benefit assessments.

As mentioned above, this field is laden with uncertainties. Of necessity, these uncertainties must influence the reliability of our results. The philosophy underlying this work is simply that decisions about monitoring systems will be made, and decisions will probably be better if all available information is synthesized in a coherent framework, and is made available to decision makers. This, in no way, mitigates the presence of uncertainty, yet it does affirm the belief that some information is usually better than none.

1.5 Impact of Recent Regulations

The issue remains as to how these results are affected, or indeed whether they are pre-empted, by the recently enacted regulations banning the propellent uses of CFMs. Since this research effort was begun prior to the enactment -- even prior to the serious consideration -- of the CFM propellant ban, the models were not constructed with the ban as the baseline case. This means that in simulating the policy response to the projected trend detection of an EMS, the policy choice of banning propellant uses of CFMs was allowed to be chosen as a consequence of monitoring activity. Thus, insofar as banning propellant uses of CFMs is predicted to contribute to benefits, those benefits (or at least the quicker realization of those benefits) are ascribed by the model to the monitoring system. In fact, of course, since the implementation of the ban has predated any EMS which might be considered, no benefits induced by that ban can logically be ascribed to an EMS. Moreover, in using the model to evaluate the EMS given the prior existence of a CFM propellant ban, the benefits of the EMS are reduced substantially. The model indicates that under a broad range of postulated trends in O_3 destruction, banning propellant CFM use is the optimal policy and the sooner it is implemented, the better. Based on the model, it appears the optimal policy has been chosen, and in the absence of an advanced O_3 monitoring system. It should be mentioned, however, that had an advanced O_3 monitoring system been in place, the propellant ban might have been implemented even sooner. The models show that the present value of benefits as of 1976 of implementing the propellant ban in 1977 rahter than 1978 is approximately $5.3 billion, assuming an ozone depletion rate of 1%-3% per decade.

That the policy calculated as optimal by the model was in fact implemented is hardly surprising. After all, much of the same information undoubtedly forms the basis for both the model and the policy decision. What must be recognized is that some of the information may be wrong -- that <u>both</u> the model and the policy decision may be wrong. A monitoring system provides a check against the information derived from models. If the current information is wrong, the policy choice is likely wrong, and costs will be incurred needlessly. Carried to the extreme, it is untenable to argue that policy can be formulated from analysis of models, but without an adequate monitoring system. At some point, the information derived from the monitoring must, <u>ex ante</u> or <u>ex post</u>, sanction a policy choice.

The dynamics of atmospheric monitoring depend upon whether the monitoring process is just beginning and is in response to some specific problem, or whether the monitoring system is already in place and is prepared to detect a problem should it arise. In the former case, one can expect that a risk minimizing policy might be implemented before the monitoring system is put in place, because the development time for the system may be substantial (not to mention the time to accumulate observations). In this case, the monitoring system serves as a check on the previously implemented policy. It may show the policy to be correct, or too weak, or too strong. The policy can be adjusted if necessary. In this case, the value of the monitoring system lies in its ability to properly adjust policy, not to induce it.

The monitoring systems in place before problems are known to exist obviously detect the problem before it would be detected otherwise, and the corrective policy may be implemented more quickly. This can be thought of as the usual, or more typical, case in the sense that a monitoring system spends most of its life in the "standby" state. In this research, the value of a system operating in this "standby" state has been analyzed. There is an understandable lack of any knowledge of an unknown problem that the system might detect in the future. Since an unknown problem could potentially drive the calculation of benefits, the system has been simulated to conclusively detect the CFM and aircraft problems sooner than would otherwise have occured. Thus, the model calculates the value of an EMS in the "standby" state which "happens" to detect the CFM and aircraft problems. If one accepts that there may be other problems in the future whose magnitudes are similar to the CFM/aircraft problems, then the current study can be considered a suggestive "case study," which indicates that a standby O_3 and aerosol monitoring system can be economically justifiable.

In sum, the perspective of the quantitative results is this: Suppose that the time is 1976 and we have a choice of implementing an advanced stratospheric ozone and aerosol monitoring system, or simply retaining the extant system. Further, there is a suspicion that CFMs and aircraft may be creating problems, but no policy will be implemented until "hard" evidence--detection of statistically significant and (highly probable) anthropegenic ozone and aerosol trends--is found. Then, for given (but unknown as of 1976) actual trends in stratospheric ozone and aerosols, the question becomes, what is the economic value of implementing the advanced monitoring system? This is the basic question to which our results apply.

1.6 Results

The primary results are listed below. Caveats and assumptions associated with the results are documented in the following sections of the report.

-- By considering a broad range of physical and economic effects, it is possible, on an order of magnitude basis, to estimate the benefits of improved stratospheric monitoring. A computer model has been utilized to simulate this sequence of causal relationships. The computer model was found to be a tractable method for evaluating the sensitivity of the benefits of improved monitoring to alternative parameter values in each link of the model.

-- Benefits of monitoring ozone and aerosols were found to be inversely related to the actual (best presently known) trends in these stratospheric constituents. Table 1.1 and Figure 1.4 illustrate the relationship between the trends and economic benefits. Depending on the actual trend, the present worth (over 50 years) of benefits of improved ozone monitoring ranges between 564 million dollars and 2039 million dollars. The benefits of adding improved aerosol monitoring capability to the ozone monitoring capability range from 24 million dollars to 79 million dollars.

-- Benefits derived from improved understanding of atmospheric processes, not considered within the scope of this study, may well overshadow the direct benefits considered in this research.

TABLE 1.1. BENEFITS OF ALTERNATE MONITORING SYSTEMS -BASE CASE

AEROSOL TREND (INCREACE %/DECADE)	OZONE TREND (%/DECADE REDUCTION) 1	3	5	7	9
1	2039. 2118. 79.	1131. 1211. 79.	564. 643. 79.	564. 643. 79.	564. 643. 79.
3	2039. 2085. 47.	1131. 1178. 47.	564. 610. 47.	564. 610. 47.	564. 610. 47.
5	2039. 2062. 24.	1131. 1155. 24.	564. 588. 24.	564. 588. 24.	564. 588. 24.
7	2039. 2062. 24.	1131. 1155. 24.	564. 588. 24.	564. 588. 24.	564. 588. 24.
9	2039. 2062. 24.	1131. 1155. 24.	564. 588. 24.	564. 588. 24.	564. 588. 24.

* Legend

X_1 \ X_2	
A	
B	C

X_1 = Trend in Aerosol Increase (%/decade)

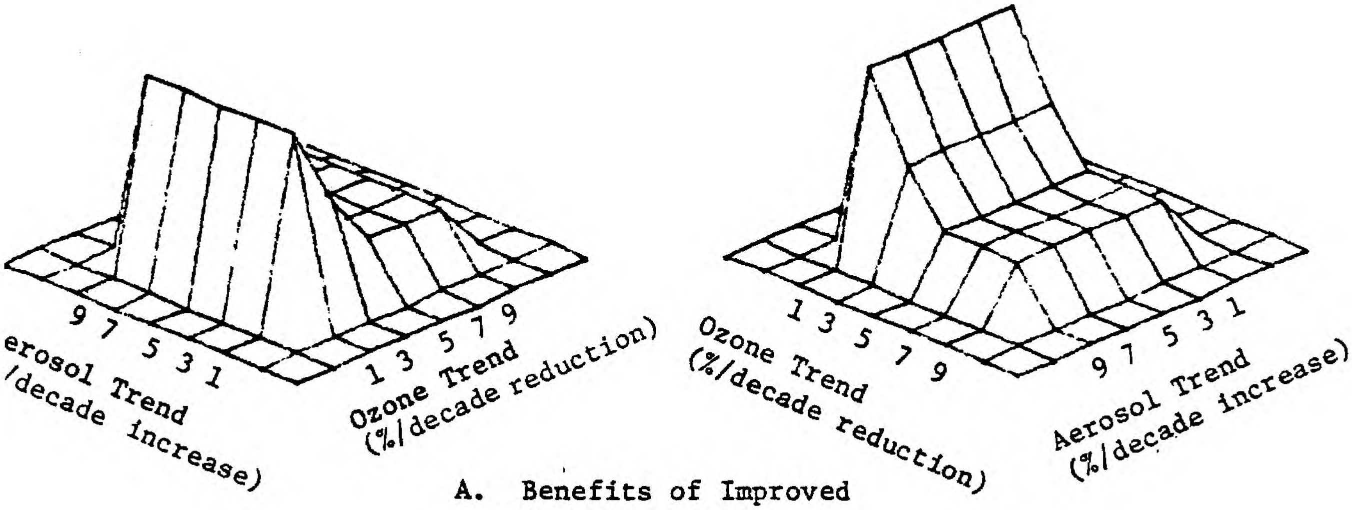
X_2 = Trend in Ozone Reduction (%/decade)

A = Benefits of an Alternate Ozone Monitoring System

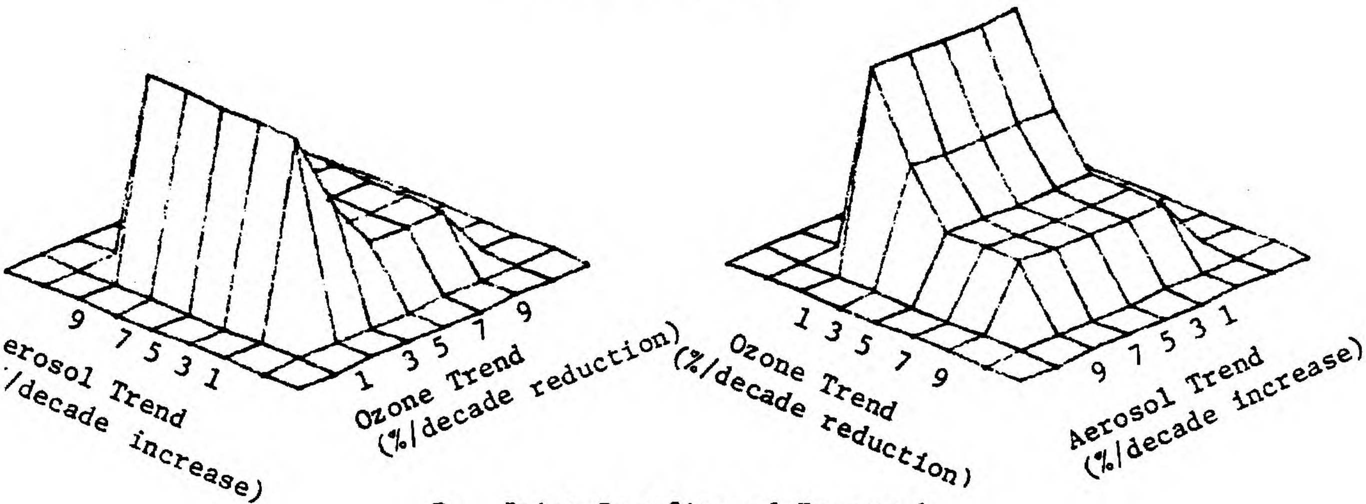
B = Benefits of an Alternate Ozone and Aerosol Monitoring System

C = Marginal Benefits of an Alternate Aerosol Monitoring System (= B-A)

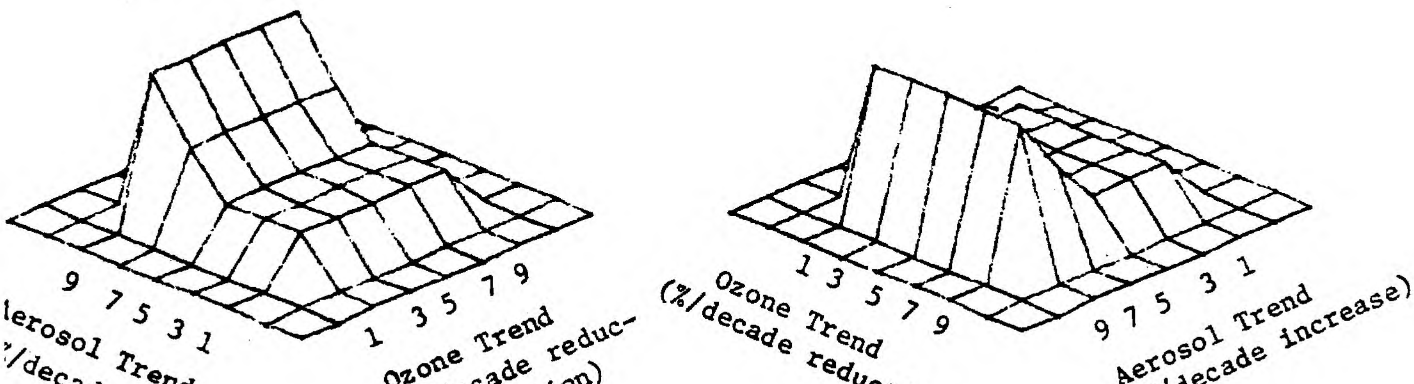
($ Million)



A. Benefits of Improved
Ozone Monitoring



B. Joint Benefits of Improved
Ozone and Aerosol Monitoring



C. Marginal Benefits of
Improved Aerosol Monitoring

Figure 1.4. Benefits, Joint Benefits and Marginal
Benefits of Additional Monitoring

SECTION II

THE ECONOMICS OF MONITORING THE ENVIRONMENT: METHODOLOGY

2.1 Introduction

The monitoring of atmospheric constituents is a relatively new undertaking. Insofar as there are myriad choices about target species, methods, scale activity, timing, etc. -- all of which are issues of resource allocation -- the discipline of economics should have useful contributions to make toward improving decision making as it relates to environmental monitoring.

This section of the report describes the development of an economics of environment monitoring: a framework for analyzing environment monitoring decisions. The goal is to develop a methodology which can ultmately be implemented to estimate the economic benefits of specific environment monitoring systems, and to aid in performing engineering/economic tradeoffs in designing such systems. This section develops that methodology. The following section describes its implementation.

This section first places atmospheric modeling in perspective by showing, through the development of an econometric model, that monitoring the entire sequence of linkages in the systems model is necessary for complete understanding, prediction, and control of anthropogenic atmospheric trends. It is also shown what assumptions are necessary to derive the simple trend model as the appropriate target for investigation. Next, it is shown how the time-to-detection curves can be derived from the mathematical and statistical properties of the estimated trend equation. The minimum detectable trend is seen to depend on the natural variability of the concentration of the subject element in the atmosphere, on the accuracy of the monitoring system, and on the number of observations the system can record. This last variable depends, in turn, on the system's rate of accumulating observations, and on the length of time the system is in service. After a brief illustration of how the model developed thus far can be used to perform engineering/economic trade-off analyses, the policy choice model is introduced.

The model is built on the assumption that the same policy is ultimately chosen with both the baseline and proposed systems. The difference is that the policy is implemented sooner with the proposed system. This formulation permits the economic value of a monitoring system to be expressed as a function of both the policy it induces and the delay averted in policy implementation. It might be noted that while the methodological guide assumes the same policy is chosen in either case, that restriction is later relaxed in the actual application.

Finally, using Net Present Value (NPV) as the measure of the value of the proposed monitoring system, an explicit form for NPV is determined, and predictions regarding the sensitivity of NPV to the various parameters is derived. It is shown that increases in system accuracy and in rate of observation can be expected to increase NPV, as can larger natural variability of the concentration of an atmospheric constituent. Tending to reduce the proposed system's NPV are better baseline system accuracy and and rates of observation, as well as larger discount rates used in the NPV calculation. The effect of a larger true trend, however, can either increase or decrease NPV, depending on the specific circumstances. Table 2.1 summarizes the notation used in the models in the following sections.

2.2 Monitoring Models

In this subsection a very simple model of the monitoring process is devel-

Table 2.1 Summary of Notation

Y_t	Observed concentration of Y at time t, observation generated by monitoring system.
$\tilde{Y}_t$	Actual concentration of Y at time t.
$\tilde{Y}_{Nt}$	Actual concentration of Y at time t due to natural forces.
$\tilde{Y}_{At}$	Actual concentration of Y at time t due to anthropogenic sources.
P_{it}	Emission of the i^{th} pollutant (affecting the concentration of Y) at time t.
X_{ikt}	The quantity of the k^{th} good produced at time t with which P_i is associated.
W_t	Index of Social Wellbeing at time t.
U_t^M, U_t^N	Disturbance terms, independent of each other, each normally distributed, and each serially uncorrelated.

oped which illustrates some of the key issues. One of the goals of an environmental monitoring system is to corroborate the causal relationship between terrestrial activity (typically the economic activities of production, distribution and consumption) and ambient pollution concentrations. Once the causal relationships are known, the offending activities can be controlled in an efficient manner, and standards for ambiant pollution concentrations achieved at minimal costs.

A one dimensional world is assumed in which only a single observation can be made at one time. In the real world, of course, many spacially separate observations can be taken at once. Our assumption is tantamount to having an implicit aggregating scheme which reduces all cotemporal observations to a single summary statistic (such as an average), which is then used in the model. Indeed, a series of mean global or regional averages is often the raw data for pollution trend analyses. Our primary interest in this simple model is in a specific atmospheric constituent. The constituent may be naturally present in the atmosphere, or it may be present due solely to anthropogenic causes as are CFM's. In general this concentration may be due to both natural and anthropogenic forces.

The observation recorded by the monitoring system is assumed to be the true concentration plus the independent error term which is assumed to be normally distributed. The true concentration can be considered the sum of two terms: one due to natural forces; the other due to anthropogenic forces. The natural concentration may follow complex daily, seasonal, or annual and/or multi-year cycles. These cycles are assumed to be known from prior observations in a period characterized by the absence of anthropogenic perturbations. The true natural concentration then, is the sum of an explained term -the known cyclically varying concentration - plus an independent error term.

The reason for concern about anthropogenic environmental changes is, of course, the suspicion that any perturbations of natural balances of the ecosystem can be deleterious to man. A common theme in the literature is that there is likely to be a substantial time lag between the pollution emission and the ultimate social impact of its physical consequence. Thus, waiting for impacts to occur, and then reacting to their causes is not seen as a viable strategy. Once the initial impacts are felt, possibly several more decades of increasing impacts may be suffered even if the causes are stopped at once. The nature of the time lag is that many years of impacts are irreversibly built into the system at any one time. Ultimately, social well being at any time depends on the history of ambient pollution concentrations.

In recent years, much effort has been expended investigating the empirical form of relations describing the impact of pollution on ozone and climate. For example, the Climatic Impact Assessment Program attempted to determine the impact of the SST by linking the projected pollution emissions to potential climate change to the economic effects of such a change. The types of economic costs considered included impacts on agriculture, marine life, human health, aesthetics, and physical and urban resources.

If the impacts of pollution on the economy were known or could be readily estimated, environmental management decisions could be made with complete information and the most efficient economic policies adopted. For example, if the environment is found to be approaching a non-zero equilibrium value for a pollutant, the cost of various levels of corrective action could be weighed one against the other and against the "Do Nothing" alternative, and an optimal decision achieved. Complete knowledge of parameter values and functional forms is clearly the ideal state of affairs.

The role of a monitoring system is to collect data from which information can be inferred. In the context of our model, the data are observations on the various atmospheric constituents, levels of production and consumption, and levels of pollution damage. Thus a monitoring system whose goal is the optimization (or even improvement) of environmental management decisions is not one monitoring system, but very many. Comprehensive monitoring systems which provide data for estimation of this information are not now available and are not likely to be available in the near future. Instead, there are disparate data collection efforts run by various private and public agencies, for reasons not necessarily related to environmental quality. One might easily speculate that the lack of comprehensive monitoring systems is due to the lack of a demonstrated need. Coupled with this is the confidence that should a non-zero, non-natural trend in an atmospheric constituent be detected, enough would be known or could be quickly be learned about the underlying causes that the trend could be reversed, albeit through inefficient policies, before serious damages are experienced. The recent ozone depletion issue, for example, is being attacked with policies based on a small amount of data coupled with educated guesses, in a state of substantial uncertainty about the true transport-reaction properties of chlorofluoromethanes.

One could easily argue that because of the great cost of establishing and operating a comprehensive monitoring system for any atmospheric constituent, and because of the large number of atmospheric constituents which are potentially of interest, the establishment of comprehensive systems is neither a desirable, nor even politically feasible strategy. The economic desirability of such systems is an empirical issue, but insufficient data are now available to resolve it. In any case comprehensive monitoring systems are not within the feasible set, and this report focuses on the realities which are developing.

It appears, at least for the near future, that environmental monitoring developments will be directed mainly in the realm of technology and hardware for the monitoring of atmospheric constituents. In justification it should be pointed out that technology seems to be the main obstacle in developing a possible future comprehensive monitoring system, and until the comprehensive system exists, the ability to monitor atmospheric constituents is the most useful component of that ultimate system to have on hand. The use of the limited system would be to detect unexplained and presumably anthropogenic trends in critical species. When such a trend is detected, the alarm goes out, bits and pieces of the rest of the comprehensive system are assembled and (admittedly inefficient) stop gap policies are developed and implemented. Then, the need having been established, the comprehensive monitoring system for that constituent can be developed over time. Ultimately, but not immediately, efficient policies might be expected to prevail.

Monitoring sensitive atmospheric constituents does provide an "early-warning" system. Detection of a trend of one atmospheric species does not, however, necessarily confirm theories predicting the change.

2.3 Trend Detection

Given that the role of the monitoring system is to detect the existence of any anthropogenic trend in Y, an atmospheric constituent, we must now inquire as to how well a specified system can accomplish that task. To reiterate our point of view, we assume the natural seasonal patterns of Y are known from past observations on an unperturbed environment. Therefore, each current observation on Y, at time t, is the sum of:

1) the known seasonal variation, f(t)

2) any anthropogenic contribution to Y concentration, Y_{At}

3) the random monitoring system error, U_t^M

4) and the random unexplained component of the natural concentration, U_t^N.

The key issue in the evaluation of any monitoring system is how quickly it can detect any given trend, and with what degree of confidence. The characteristics of the monitoring system germane to the issue are its rate of observation (number of observations per time period), and the nature of the monitoring system error term. By assumption, the error term U_t^M is normally distributed with mean zero and variance σ_M^2. It is the variance, then, which describes the "accuracy" of the system. The smaller the variance, the closer to the true concentration each reported observation is likely to be.

In using the monitoring system data to estimate the parameters of a prediction model, we would adopt as the null hypothesis that the trend, B_1, is 0. The alternate hypothesis would be, of course, that B_1 is not 0. For any true non-zero B_1, how long would it take to be detected? Figure 2.1 illustrates the meaning of the question. Clearly, we would not reject the null hypothesis only if the estimated trend ($\hat{B}_1$) differed slightly from 0. After all, the random process (the U_t's) may not average out to 0 in any given sample. Thus, there would be some range around 0 that, should the estimated trend fall into it, it could be concluded that the observations are consistent with the null hypothesis, and that hypothesis would not be rejected. By chance, the estimated trend could fall outside the range even if the trend were truly 0. This would cause rejection of the true hypothesis - a Type I or Alpha error. This error can be controlled by adjusting the size of the range of trend values which we deem

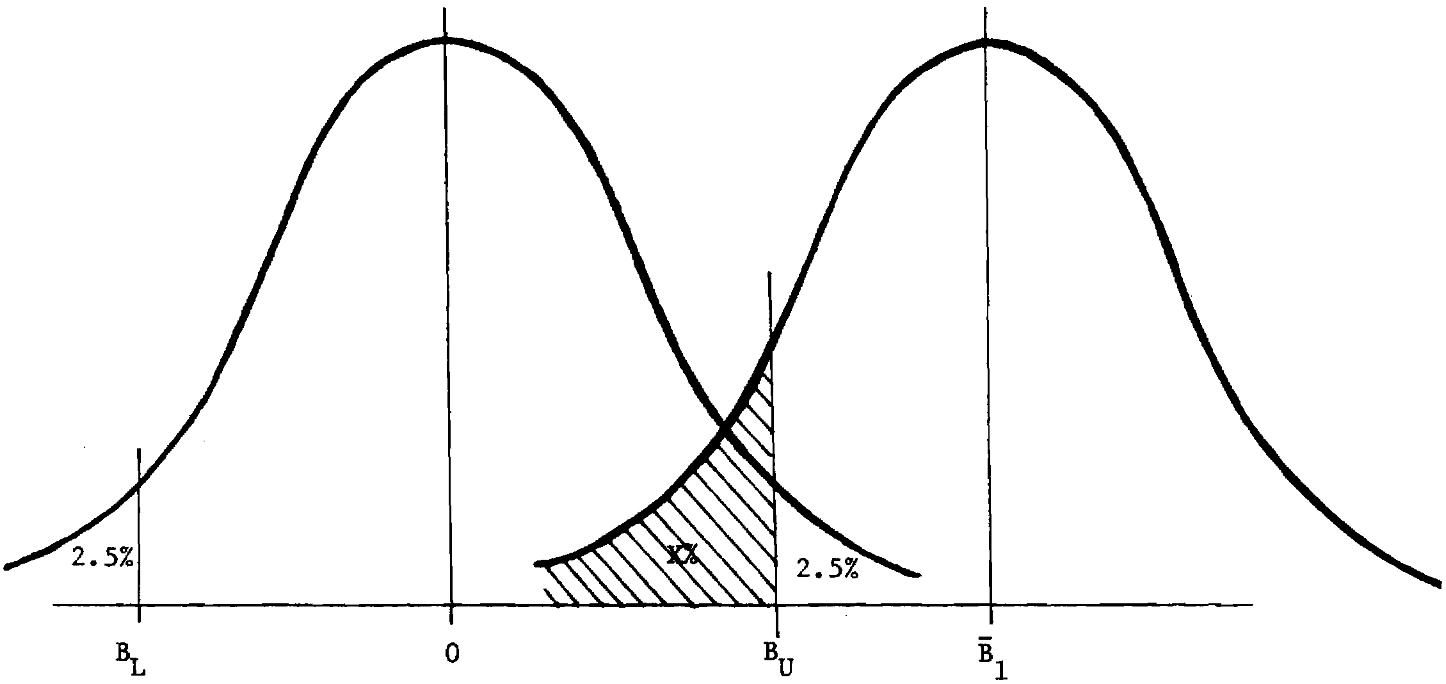


Figure 2.1 Hypothesis Testing on Trends in Environmental Constituents.

consistent with a 0 trend. The larger the range, the smaller the chance of committing this type of error. Typically, the acceptable chance of committing a Type I error might be set at 5%. In Figure 2.1, the acceptable range for accepting a 0 trend is for the estimate of B_1, $\hat{B}_1$, to fall between B_L and B_U (given we accept a 5% chance of a Type I error). But now suppose that the true trend is $\bar{B}_1$. Again, because of the random disturbance term, the estimated trend will likely not be exactly B_1. There would be a range around $\bar{B}_1$ into which $\hat{B}_1$ should fall. If $\bar{B}_1$ is close to 0, there is the possibility that the estimated trend, even if $\bar{B}_1$ is true, falls in the B_L to B_U range. This is the chance of accepting a false hypothesis - that the trend is 0 -- when it is truly $\bar{B}_1$, and is indicated by the shaded area in Figure 2.1. Accepting a false hypothesis is known as a Type II, or Beta error. If the shaded area is X% of the area under the curve, we can say that we have a (100-X)% chance of detecting a trend of B_1 against a null hypothesis of 0 trend tested at a .05 significance level with a two tailed test. In general, we would like X as small as possible. X can be reduced by simply shifting B_U to the left. However, this results in a corresponding increase in the chance of a Type I error which, if we wish to maintain the chance of that error at 5%, is unacceptable. X can also be reduced by increasing the number of observations on which the trend estimate is based. This, of course, does not cause a corresponding increase in the probability of a Type I error. The larger the number of observations, the tighter the bell curves fit around 0 and B_1. The idea would be to increase the number of observations until some B_U can be found so that 2.5% of the area under the curve centered at 0 lies to the right of that B_U, and just some minimal acceptable amount, say 5%, of the area under the curve centered at B_1 lies to the left of B_U. Using these ideas, we recognize the existence of a relationship of the form:

$$\bar{B}_1 = F(n, \sigma_u^2, H_0, \alpha, B \tag{1}$$

where n is the number of observations, σ_u^2 is the variance of the disturbance term, H_0 the trend value under the null hypothesis, α is the chance of a Type I error, and B the chance of a Type II error. The interpretation of (1) is that $\bar{B}_1$ is the smallest trend that can be expected to be detected with 100(1-B)% confidence with n observations against a null hypothesis trend of H_0 tested with a 100 % significance level, given the variance of the error term is σ_u^2.

Equation (1) can be parameterized so that an explicit form, for some given values of H_0, and B can be constructed. Let this new form be:

$$\bar{B}_1 = F(n, \hat{\sigma}_u | H_0 = 0, \alpha = .05, B = .05) \tag{2}$$

where $\hat{\sigma}_u$ is the estimate of σ_u from the observations. That is, (2) is to be derived using the properties of the OLS estimates of the prediction model.

It can be shown (Appendix D) that:

$$\bar{B}_1 = \frac{\hat{\sigma}_u}{\sqrt{\Sigma (t-\bar{t})^2}} \left[t_c^{.025}(n-2) + t_c^{.05}(n-2) \right] \tag{3}$$

Equation (3) appears to correspond to the relations reported by Pittock [7]and, - Hill [18] for ozone monitoring. It is easily verified that:

$$\frac{\partial \bar{B}_1}{\partial n} < 0, \ \frac{\partial}{\partial n} \frac{\partial \bar{B}_1}{\partial n} > 0 \tag{4}$$

and

$$\frac{\partial \bar{B}_1}{\partial \hat{\sigma}_u} > 0 \, , \frac{\partial}{\partial \hat{\sigma}_u} \frac{\partial \bar{B}_1}{\partial \hat{\sigma}_u} = 0. \tag{5}$$

Figure 2.2 depicts the general shape of (3). The greater the number of observations and/or the smaller the estimate of the standard deviation of the disturbance term, the smaller the trend which can be detected at the specified levels of significance. Put another way, for given $\hat{\sigma}_u$, it takes a greater number of observations to detect a smaller trend. *In general, there is a trade-off between gaining more observations through more monitoring "stations" over less chronological time and through fewer monitoring stations over more chronological time. The former entails greater investment cost but poses less risk of letting a deleterious environmental trend go undetected.* We will return to the point below.

Consider again the disturbance term U_t. It is the sum of two assumably unrelated errors, namely, the natural unexplained disturbance U_t^N and the monitoring system detection error U_t^M. Since both components of U_t are assumed normally distributed, then so U_t:

$$U_t \sim N(0, \sigma_M^2 + \sigma_N^2). \tag{6}$$

It is convenient to think of the variance of the monitoring system error term as

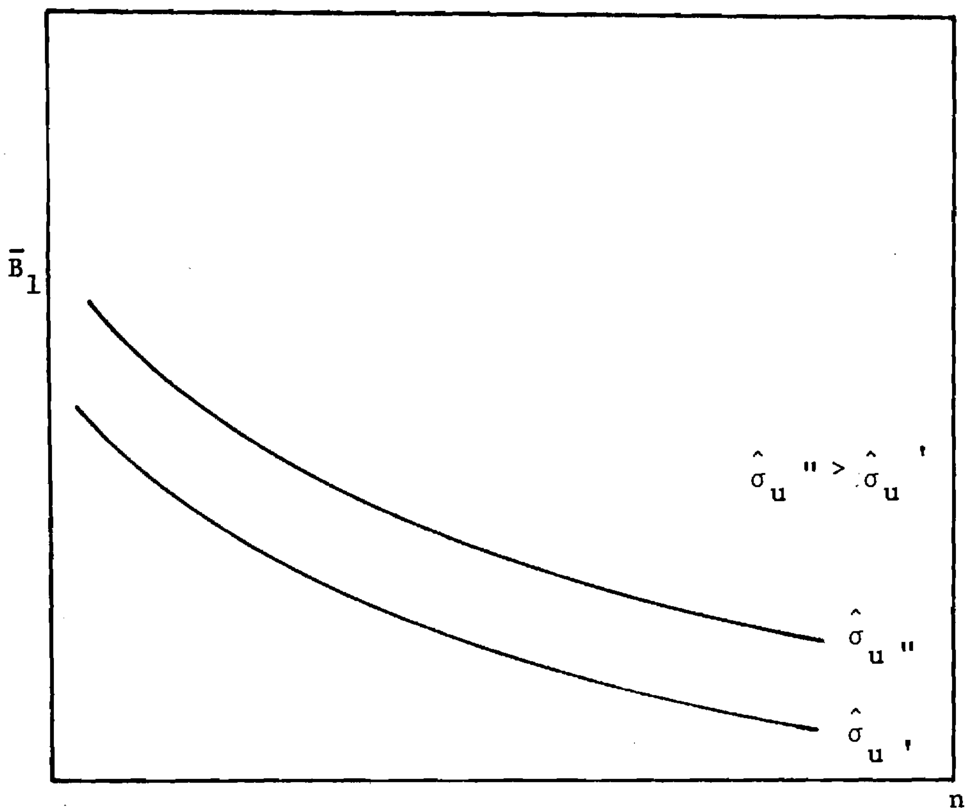


Figure 2.2 General Relation Among $\overline{B}_1$, n, and $\hat{\sigma}_u$.

a percentage of the natural variance. Define:

$$\rho = \frac{\sigma_M^2}{\sigma_N^2} ; \qquad (7)$$

from this it follows

$$\sigma_u = \sigma_N \sqrt{1+\rho} \quad . \qquad (8)$$

Substituting into (6) yields:

$$\bar{B}_1 = \frac{\bar{\sigma}_N \sqrt{1 + \hat{\rho}}}{\sqrt{\Sigma (t-\bar{t}^{2})}} [t_C^{.025} (N-2) + t_C^{.05} (N-2)], \qquad (9)$$

assuming $\bar{\sigma}_n$, the value of σ_n, is known from previous experimentation, and

$$\hat{\rho} = \frac{\hat{\sigma}_M^2}{\bar{\sigma}_N^2} \text{ where } \hat{\sigma}_M^2 = \hat{\sigma}_U^2 - \bar{\sigma}_N^2 .$$

2.4. Cost-Effectiveness Analysis of Environment Monitoring Systems

As mentioned above, the model of monitoring systems performance developed above can be used to perform trade-off, or cost-effectiveness, analyses among alternative methods of achieving given trend detection capability. The purpose here is to sketch briefly the construction of such a model.

In general, the costs of an environment monitoring system will consist of development, procurement, installation, operation, and maintenance costs. These costs, in turn, depend on

- ρ the ratio of the monitoring system error variance to the variance the natural disturbance term, i.e., $\rho = \sigma_M^2/\sigma_N^2$ as in (10).
- I the number of monitoring "stations" or instruments.
- s the rate of instrument observation, i.e., number of observations per instrument per year

t the maximum number of years allowed for the monitoring system to detect the trend.

Typically, there is some maximum number of observations per year which are usefully effected. Observations beyond the number add no new information*. Let T represent this maximum number of annual observations. The cost-effectiveness problem can be stated as:

$$\text{MINIMIZE Cost } (\rho, I, s, \bar{t}) \tag{10}$$

Subject to:

$$\bar{\bar{B}}_1 = \frac{\bar{\sigma}_N \sqrt{1+\rho}}{\sqrt{\Sigma t^2}} \left[t_c^{.025}(n-2) + t_c^{.05}(n-2)\right] \tag{11}$$

$$t = \bar{t} \tag{12}$$

$$n = \bar{t} \cdot I \cdot s \tag{13}$$

$$T \geq I \cdot s \tag{14}$$

$$\rho, I, s, \bar{t} \geq 0 \tag{15}$$

Expression (10) is the objective function. (11) and (12) are constraints defining the requisite performance of the monitoring system - a trend as small as $\bar{\bar{B}}_1$, must be detectable within time period $\bar{t}$. (13) is merely a definition. (14) constrains the number of annual observations to no more than the maximum useful observations. (15) simply states that the policy variables must be non-negative. Note that only the explicit form of (10), and specified values for $\bar{\bar{B}}_1$, $\bar{y}$, T, are needed for implementation of the model.

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*For example, in the case of ozone it is thought that approximately 120 independent observations per year (properly spacially and temporally distributed) exhaust all useful information [7].

2.5 A Policy Choice Model

Ultimately, the social value of an environment monitoring system depends on what difference that system makes, which in turn depends on the policy choices which would be made with and without the monitoring system in question. "Policy choices" refer to government actions like banning the use of fluorocarbons as spray can propellents, or banning stratospheric (mainly SST) flight; and, in general, banning, controlling, limiting, or mandating modification of any product or production process.

The a priori determination of the value of an EMS is necessarily based on predictions of policy choices which will be adopted with and without the subject EMS, and is based on the conditionally forecasted environmental trends which the monitoring system is predicted to detect. Regarding the former basis, it is obvious that the most sophisticated monitoring system is worth little or nothing if the information gained from that EMS is not made available to policy makers or not used by them in formulating policy. If the policy makers' choices are essentially independent of the EMS information, there is no reason to implement that EMS -- it would have no social value*. Regarding the latter basis, some reflection will suggest that the social value realized from an EMS depends, but in no especially clear cut way, on the true underlying environmental trend being sought out by the EMS. If the true trend were zero, and if policy makers

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*One might argue that knowledge for its own sake has social value. Even if policy makers do not respond to the information, science would progress using an EMS would not (presumably) alter the choices made by policy makers, for the EMS that information. This line of thought leads directly to debating the social value of science, and we could not hope to resolve such an issue here.

proceeded in the absence of an EMS as though the trend were zero, the presence of would simply confirm the zero trend which had been accepted anyway.** If there is truly a "small" trend, the value of an EMS can be great if one assumes that trend would be otherwise undetected for a long period of time and the cumulative effects of the environmental disturbance are substantial. The value can be small in that case if even long term cumulative effects are small. If there is a large trend, the value of an EMS can be large if substantial damage would be suffered because of the delay in detecting the trend, or the value of the EMS could be small if the trend would be detected quickly anyway because of its significant magnitude. In sum, the value of an EMS can reasonably be supposed to depend on the true state of nature (true trend), but whether that value is an increasing or decreasing function of trend is an empirical issue.

Besides depending on the true trend, the value of an EMS depends on the difference in policy which it induces. Suppose consideration is given to the implementation of a specific EMS, called System A; and the alternative course of action is simply to maintain whatever present system exists, call that system System B. Assume that both Systems A and B eventually detect the true trend, and that policies are adopted based on those findings. Assume System A is the more advanced system (lower ρ), so its time to detection is shorter. To simplify matters substantially, the assumption is made that the same policy is implemented under both A and B, except it is implemented sooner in the case of A. Also, assume that the costs and benefits of the policy depend only on the elapsed time from policy initiation, not also on calendar time. Table 2.2, as an example

**Let us suppress the perverse case wherein the EMS gives faulty information, and indicates a trend where none is truly present.

TABLE 2.2 Illustration of Policy Choice Model

Calender Time	0	1	2	3	4	5	6	7	8	9	10 ....
System A	C_A	-	-	V_1	V_2	V_3	V_4	V_5	V_6	V_7	V_8 ....
System B	C_B	-	-	-	-	-	-	V_1	V_2	V_3	V_4 ....

Vi = Value to society, year i

C_A = Investment cost, System A

C_B = Investment cost, System B

representation of this policy choice model, depicts the case where the time to detection - point of policy implementation - for System A is 3 years and for System B is 7 years. V_i represents the value to society (costs or benefits) i years after policy initiation. C_A and C_B represent the investment costs in Systems A and B respectively. In order to generalize the discussion, let t_A represent the calandar time when the policy is implemented under System A, and t_B likewise for System B. Letting r represent the discount rate, and assuming the true trend is B, the Net Present Value of the decision to implement System A rather than System B is the present value of the annual differences in the investment costs and V_i 's, i.e.,

$$NPV_{A/B} = (C_A - C_B) + \left[\frac{(1+r)^{t_B - t_A} - 1}{(1+r)^{t_B - 1}} \right] \cdot PV \qquad (16)$$

PV is the present value of the effects of the environmental policy as viewed from the time of its initiation, i.e.,

$$PV = \frac{V_1}{(1+r)^1} + \frac{V_2}{(1+r)^2} + \ldots \qquad (17)$$

The bracketed term in (16) can simply be viewed as a weighting factor which accounts for both the time elapsing between the present and the point of A's implementation and the time saved by implementing A over B. (16) is developed in Appendix D. Note that if $t_B = t_A$, i.e., if the time to trend detection and hence time of policy implementation is the same under both Systems A and B, $NPV_{A/B} = C_A - C_B$. That is, the only value of System A (over B) is the difference in costs, which are likely to be negative. Note also that as t_B gets large and t_A small, $NPV_{A/B}$ approaches $C_A - C_B + PV$. But in general, the value of System A is the value of its improvements over System B, not its value over no EMS at all. As will be seen in the following section, (16) can be used as the basis for deriving a useful explicit expression for the value of an EMS.

2.6 The Value of an Environment Monitoring System

Consider now the time path of the V_i's. A policy implemented in response to information on the existence of a presumably anthropogenically induced environmental trend will, in general, effect some changes in the processes or products of the production sector of the economy. As examples, one might think of a policy banning or curtailing the use of CFMs in the production of foams or a policy banning the use of CFMs in consumer spray can products. The former is an example of a policy affecting a production process, the latter an example of a policy affecting a final product. These changes necessarily impose costs on the economy -- costs of changing existing production processes and/or costs of consuming inferior products. With time these costs diminish as the production changeover is completed and/or as the modified consumer products are improved up to their previous level of quality and consumer acceptance. Eventually, the policy results in benefits as damages which would have resulted from the unchecked environmental trend are averted. Just as we can assume the damages would ultimately achieve an equilibrium level, so the benefits (of damage averted) can be assumed to ultimately achieve an equilibrium level. Figure 2.3 depicts the assumed path in the V_i's. For convenience, the path is modeled as a function of the form:

$$V = k_0 - k_1 e^{-k_2 t} \; ; \quad k_0, \, k_1, \, k_2 > 0 \, . \qquad (18)$$

The initial cost of the policy is $k_0 - k_1$, the ultimate equilibrium (asymptotic) benefit is k_0, and benefits and costs net to zero at time $t = \dfrac{\ell n k_1 - \ell n k_0}{k_2}$.

Using the result established in (16), the value of one EMS over another depends

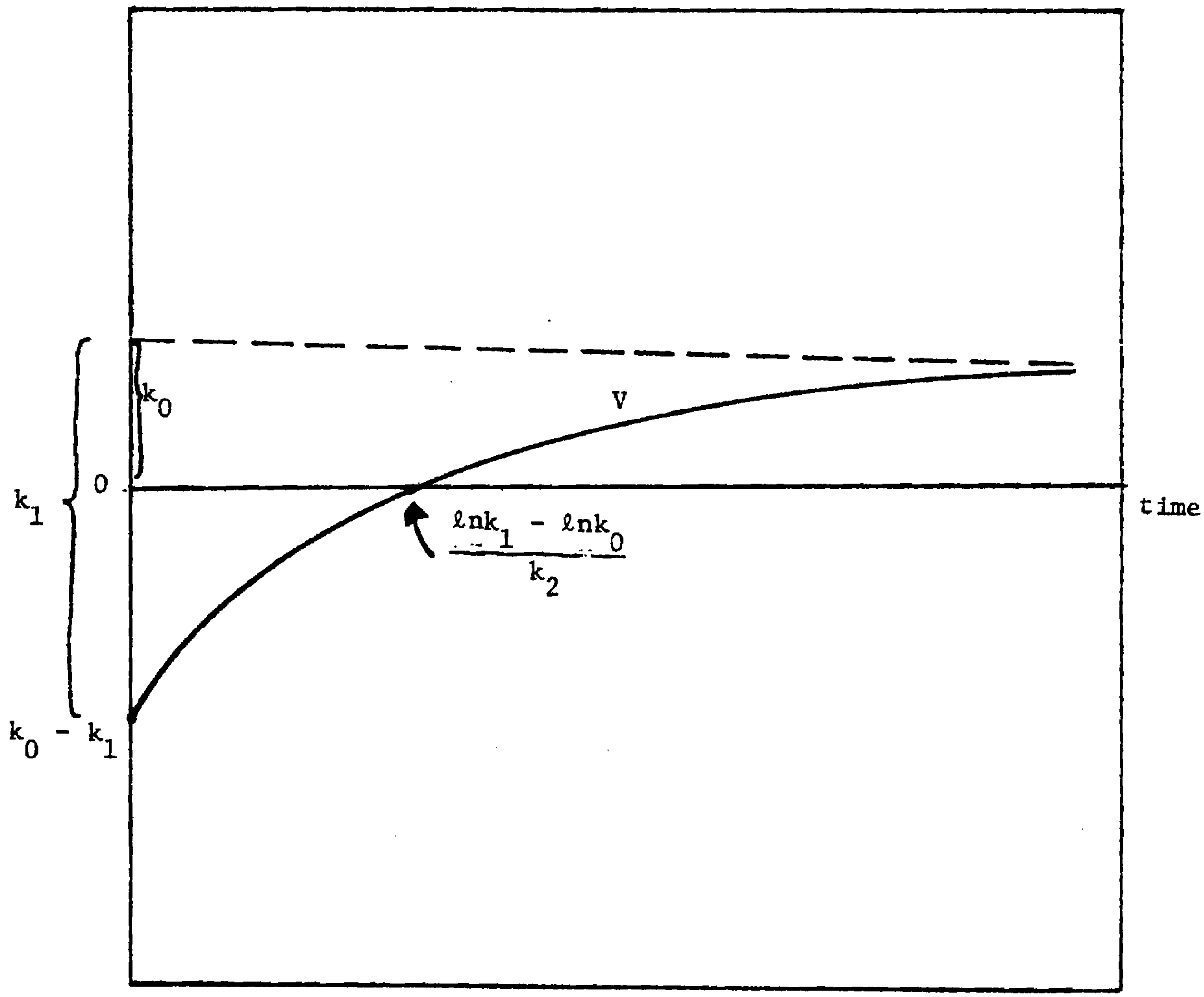

Figure 2.3 The Path of Annual Net Benefits for an Environmental Policy.

on PV. PV is defined in discrete form in (17). However, given the continuous form of V in (18), it is more convenient to express NPV as

$$NPV_{A/B} = (C_A - C_B) + \left[\frac{(1+r)^{t_B - t_A} - 1)}{(1+r)^{t_B - 1}}\right] \cdot \left[\frac{k_0 k_2 + rk_0 - rk_1}{r^2 + rk_2}\right] \tag{19}$$

The most interesting part of (19) is $t_B - t_A$, which depends on $\bar{B}_1, \rho_A, \rho_B, \bar{\sigma}_N$, (the last two terms are the annual number of observations for each EMS).

Given some proposed EMS, designated as System A; and given an extant (perhaps crude) EMS, designated as System B; the principal concerns are to construct a good estimate of the NPV of System A, and to examine the sensitivity of that estimate to changes (or errors) in the underlying parameter values. Of course, an estimate of NPV must be based on the data, and cannot be inferred from the model. However, the model can be used to predict and explain the sensitivity of NPV to underlying parameters. Specifically, this concern is with the influence on NPV of:

- the actual environmental trend, $\bar{B}_1$
- the standard deviation of the natural disturbance term, $\bar{\sigma}_N$
- the accuracy of the observations of the proposed monitoring system as measured by $\hat{\rho} = \hat{\sigma}^2_M / \hat{\sigma}^2_N$
- the rate of observation of the proposed EMS, $I_A \cdot s_A$
- the discount rate used in the NPV calculation, r.

The investigation is carried out by examining the partial derivatives of (19). Since the calculations are tedious, only the results are presented. The first result is that the direction of the effect of $\bar{B}_1$ on NPV cannot be determined from the model. (This relation was discussed in the previous section.) The issue is strictly empirical, involving the particular parameter values. However, jumping ahead to the empirical results of the next section for a moment, the findings there are that NPV declines with greater $\overline{B}_1$ for the cases of both stratospheric ozone and aerosols. The reasoning is that even a crude EMS would rapidly detect large trends, but only a sophisticated EMS can quickly detect small trends. In addition, it appears the greater rate of damage (albeit for a shorter period) under the large trend is not so important to the NPV as is the longer period of lower damages. In the empirical models, it is a complex sequence of lagged cause-effect relations which contribute to this result.

The influence of $\overline{\sigma}_N$ on NPV depends on the rates and accuracies of observations of the two systems being compared, and on the discount rate. The sign depends on, and is the same as, the sign of:

$$\left[\frac{(1+\hat{\rho}_A)^{1/3}}{I_A \cdot s_A} - \frac{\dfrac{(1+\hat{\rho}_B)^{1/3}}{I_B \cdot s_B}}{(1+r)^{t_B - t_A}} \right] \tag{20}$$

If $I_A \cdot s_A$ is greater than $I_B \cdot s_A$, and if $\hat{\rho}_A < \rho_B$ (both of which may be expected), then as long as $(1+r)^{tB - tA}$ is not too large, the bracketed term is negative and the entire expression (23) is positive. Generally, then, we expect the NPV of System A to be larger, the larger the standard deviation of the natural disturbance term.

$\hat{\rho}_A$ is a measure of the accuracy of EMS measurements. The smaller $\hat{\rho}_A$, the more accurate the measurements. (See (7)). As would be expected, NPV is inversely related to $\hat{\rho}_A$: the smaller $\hat{\rho}_A$, the larger NPV.

$I_A \cdot s_A$ is the number of observations per year made by System A. Not unexpectedly the model's prediction is that larger $I_A \cdot s_A$ results in larger NPV.

The discount rate (more precisely, one plus the discount rate) is the rate at which future and present costs or benefits are traded off. For example, if the discount rate were $r = .10$, then a benefit (or cost) of $110 next year would be equivalent to a benefit (or cost) of $100 this year. The parameter r appears in both bracketed terms in (19). It happens that an increase in r will always decrease the first bracketed term, but the effect of a change in r on the second bracket depends on the value of r. At low values of r, an increase in r will decrease the value of the second bracket, but at high values of r, an increase in r will increase the value of that bracket. The overall effect of the two bracketed terms is that NPV initially decreases with increases in r, but eventually tends to increase as r continues to increase. However, the eventual tendency to increase is not so strong as the initial tendency to decrease, and the tendency to decrease occurs over a fairly large range.

In sum, the model suggests that the value of a proposed EMS, <u>in lieu</u> of an extant EMS, depends on $B_1, \bar{\sigma}_N, \rho_A, I_A, s_A$, and r; as well as on $\hat{\rho}_B$, I_B, s_B, C_A and C_B. Table 2.3 summarizes the expected direction of impact of these parameters on the value (as measured by the Net Present Value) of a proposed EMS called System A, when another EMS called System B, is already in place, and where System A is assumed to be the more sophisticated system.

2.7 Application to Monitoring Stratospheric Ozone and Aerosols

The model described in the preceding sections has been applied to the problem of estimating the benefits of an EMS designed to monitor both stratospheric ozone and aerosols. Since the value of benefits (actually present value of benefits), and not NPV is estimated, the results must be interpreted as the maximum (present value of) costs which can be incurred yet still retain non-negative NPV. The reason for this approach is that the EMS under consideration is strictly a postulated system, defined by its performance specifications, and no reliable cost estimates are available.

Table 2.3 Predicted Sensitivity of Net Present Value of System A to Variance Parameters

$\partial NPV/\partial(1) > 0$	$\partial NPV/\partial(2) < 0$	$\partial NPV/\partial(3) \lesseqgtr 0$
1	2	3
$\hat{\rho}_B$	$\hat{\rho}_A$	$\bar{B}_1$
C_B	C_A	
$I_A \cdot s_A$	$I_B \cdot s_B$	
$\bar{\sigma}_N$	r	

In carrying out an application of the model, a number of issues which may be subsumed, suppressed, or otherwise sidestepped on the theoretical plane now must be faced squarely. Thus, on balance, the modified and extended model used to carry through actual calculations turns out to be considerably more complex than the foregoing model which subsumes it. In practice, the NPV model becomes a simulation model, which steps through time year by year simulating monitoring, detection, policy choice, policy implementation, and policy costs and benefits for many scenarios.

Underlying the application is the assumption that the equation:

$$Y_t - f(t) = B_0 - B_1 t + U_t \tag{21}$$

is to be estimated. As mentioned earlier, estimates of (19) - the "time to detection" curve - have appeared in the monitoring literature. These curves are presented with time, rather than number of observations, on the horizontal axis. The curve developed by Hill-Sheldon [18] for the extant ozone monitoring system is reproduced in Figure 2.5. That extant system is the ground based network of approximately 120 Dobson spectrophotometers. The alternate system --defined by its performance specifications -is postulated as a monitoring system with half the time to detection compared to the extant system.

Implicit here is that it is possible to design and implement such a system. This depends on $I_A \cdot s_A, I_B \cdot s_B, \hat{\rho}_A$, and $\hat{\rho}_B$. It can be shown:

$$\frac{t_A}{t_B} = \frac{I_B \cdot s_B}{I_A \cdot s_A} \left(\frac{1 + \rho_A}{1 + \rho_B} \right)^{1/3} \tag{22}$$

t_A/t_B can always achieve the ratio 1/2, it would appear, by doubling the observation rate $I_A \cdot s_A$ of the proposed system over that of the extant system. This does not consider the constraint (14), which indicates there is a finite maximum number of available observations. Clearly, so long as the extant system captures less than half that maximum, there is no problem. Otherwise, the difference must be made up by a sufficient decrease in $\hat{\rho}_A$ as compared with $\hat{\rho}_B$. In the extreme, if the extant system is already achieving the maximum available observations, the total improvement must be in accuracy. This implies:

$$1/2 \geq \left(\frac{1 + \beta_A}{1 + \beta_B}\right)^{1/3}$$

since, at best $\hat{\rho}_A$ can approach 0, it follows:

$$1/8\ \beta_B - 7/8 \geq \beta_A \geq 0$$

and therefore :

$$\beta_B \geq 7 \quad . \tag{23}$$

This means that halving the time to detection through improvements in EMS accuracy can be done only if the extant system's error term variance is at least seven times greater than the variance of the natural disturbance. Throughout our analysis, we assume that implementation of an EMS which reduces by half the time to detection is feasible.

A descriptive model predicting policy choices under different information states (different monitoring systems, different underlying trends, and different calendar times of detection) poses severe development problems. Our approach is to simulate a descriptive approach with a normative one. A list of potential policies is constructed, and in each situation the optimal policy is selected. The optimal policy is chosen by simulating the effects of each policy given the initial conditions specific to the scenario under consideration, and the policy resulting in greatest social net benefit (least social net cost) is chosen.

The list of possible policies in response to the detection of an ozone trend is listed in Table 2.4, and the corresponding list for an aerosol trend is presented in Table 2.5. Rather than a once-and-for-all policy choice as implied by the abstract model, the simulation model allows a sequence of policy choices, each in response to the current trend which is, quite naturally, affected by previous policy choices. Thus, the policy choice issue is ultimately modeled as a dynamic optimization problem over discrete policy choices. While some heuristics are involved in the calculations, the solution method is essentially complete enumeration.

An interesting issue arises when a trend is initially detected in only one stratospheric constituent, but the policy chosen in response to that trend affects the other constituent as well. In this application, it was discovered that if trends in both ozone and aerosols are postulated, and if the ozone trend is detected first, the policy response to that trend might mitigate the aerosol trend as well. This tends to decrease the marginal value of the aerosol EMS.

The simulation model is constructed as a series of modular submodels, where the output of one submodel becomes the input to another. This modular form permits easy update when revised parameter values, or revised models become available. The estimation of the benefits of a specific EMS follows the "with/without" procedures of estimating the benefits to society both with and without the proposed EMS, and the difference in benefits is taken as the benefits of the proposed EMS.

Table 2.4 Ozone Related Policies

CFM Related*

No.	Description
1	No. Regulation
2	Ban Propellant Uses of F-11 and F-12
3	Ban All Uses of F-11 and F-12

SST Related

No.	Description
1	No Regulation
2	Reduce Projected SST Operations by 1/2
3	Reduce Projected SST Operations by 1/2 and Desulfurize Fuel
4	Ban All SST Operations

* A three year implementation period is assumed.

Table 2.5 Aerosol Related Policies

No.	Description
1	No Regulation
2	Reduce Projected SST Operations by 1/2
3	Desulfurize SST Fuel
4	Reduce Projected SST Operations by 1/2 and Desulfurize Fuel
5	Ban All SST Operations

SECTION III

THE ECONOMICS OF MONITORING THE ENVIRONMENT: APPLICATION TO STRATOSPHERIC OZONE AND AEROSOLS

3.1 Applications Model

3.1.1 The Nature of Benefits and Benefit Assessment

This section develops and describes the Applications Model used to evaluate environment monitoring systems. While structured for computer implementation, the Model is based on the general theory presented in Section II.

The general problem being addressed is the way one determines whether, or to what extent, a satellite-based system for monitoring the environment ought to be implemented by government. In other words, how can it be determined whether the benefits of such a system outweigh the costs? The problem is nontrivial because the very different nature of the costs and benefits make comparisons difficult to carry out. The costs of a satellite monitoring system are, at least conceptually, easily defined and quantified. They would include R&D, hardware, and launch costs, for example. It is the benefits which present problems. Benefits do not accrue in an obvious and straightforward manner. Indeed, while real, they may be largely imperceptable to the casual observer. The benefits of a monitoring system are all the costs avoided if that system is implemented. Implied is the direct comparison of two scenarios: the sequence of events if the system is implemented and the sequence of events if the system is not implemented. The benefits arise from the (positive) difference in the scenarios.

There are numerous substances which are candidates for monitoring. This study focuses on stratospheric ozone and aerosols. This choice was, of course, mainly influenced by the recent speculation that the earth's ozone layer may be undergoing gradual destruction due to the catalytic effects of fluorocarbons and NO_x's. Other studies suggest SST engine effluents, may, in the future, contribute to ozone destruction. Both fluorocarbons and SST effluents have been hypothesized to change global average temperature.

In assessing the benefits of alternate systems for monitoring the stratosphere, three concepts must be defined: benefit, benefit assessment, and benefits of monitoring. For our purposes, benefit is value to members of society, through time, of undertaking some project over not undertaking it. Thus, benefits derive from the difference between scenarios - differences impacting the members of society. Then, benefit assessment is the determination, in a theoretically sound, consistent, and reasonably quantitative manner, of the magnitude of benefits. The benefits of monitoring are the values to members of society of undertaking a monitoring program over not undertaking it. The values follow from the impact the monitoring system has on the welfare of society. The impact springs from the influence of monitoring on policies. In the case of monitoring systems, value can often be quantified as cost savings. Of course, the benefits of an alternate monitoring system are the values to members of society of implementing that alternate, rather than the baseline system.

3.1.2 The Benefit Assessment Model

That an alternate monitoring system will have some effect on social well-being can be readily accepted. The question is, how much of what types of effects? To answer this question, and thereby perform the benefit assessment, the causality process which translates changes in monitoring to changes in the welfare of society must be understood. Once the process is understood, the relevant impacts may be traced out, quantified and valued. Figure 3.1 illustrates the initially unknown causality process as the necessary link between the

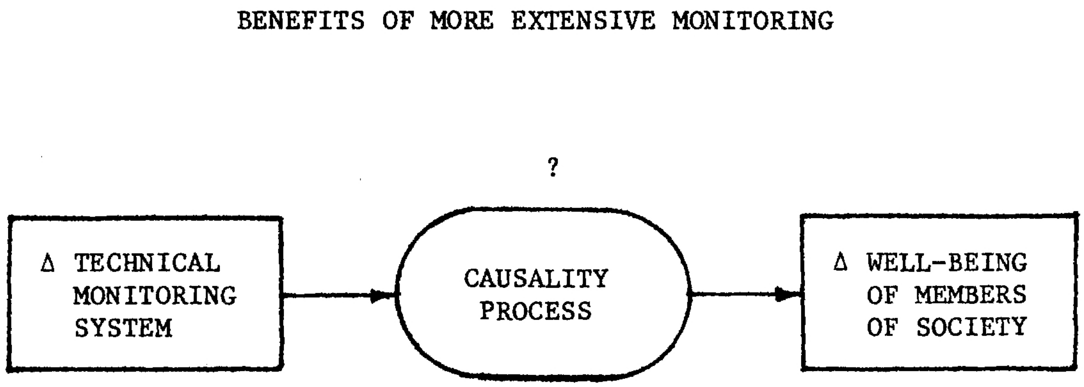

Figure 3.1 The Importance of the Causality Process

technical monitoring system and its economic value.

Figure 3.2 illustrates the results of investigating and analyzing the causality process. (See Appendix I - Review of Literature). The figure shows general causal relations. Monitoring produces data from which information is inferred. The information affects which policies are implemented. For the aerosol or ozone monitoring, all potential policies involve the possible intervention in production processes. Two possible causes of man-induced stratospheric ozone destruction are the catalytic effects of fluorocarbons and the NO_x in the exhaust of aircraft flying in the stratosphere. Policies of interest include banning or controlling fluorocarbon production and/or banning or controlling stratospheric flight.* The alteration of production processes has two effects. First, social well-being is directly influenced by the change in consumption opportunities brought about by bans on the use of some inputs. At the very least, less preferable substitutes must be consumed and at worst, a lack of substitutes causes needs to go totally unsatisfied. Second, the change in the production processes causes less pollutants (fluorocarbons and/or NO_x) to be emitted. Thus, there is an environmental effect whose consequences may be felt over quite a number of years. In this case, the environmental effect is a decrease in the amount of ozone destroyed or decrease in the change in global average temperature. Ozone changes have two potential effects: on ultraviolet radiation and on global temperature. The ozone layer shields the earth from ultraviolet radiation, radiation associated with the incidence of skin cancer --

* Fluorocarbons are used as spray can propellants, in refrigerants, and in the production of some foam products. Their usefulness derives from their remarkable molecular stability. Ironically, this same stability is the cause for environmental concern. The stratospheric flight of interest is flight by future SST's.

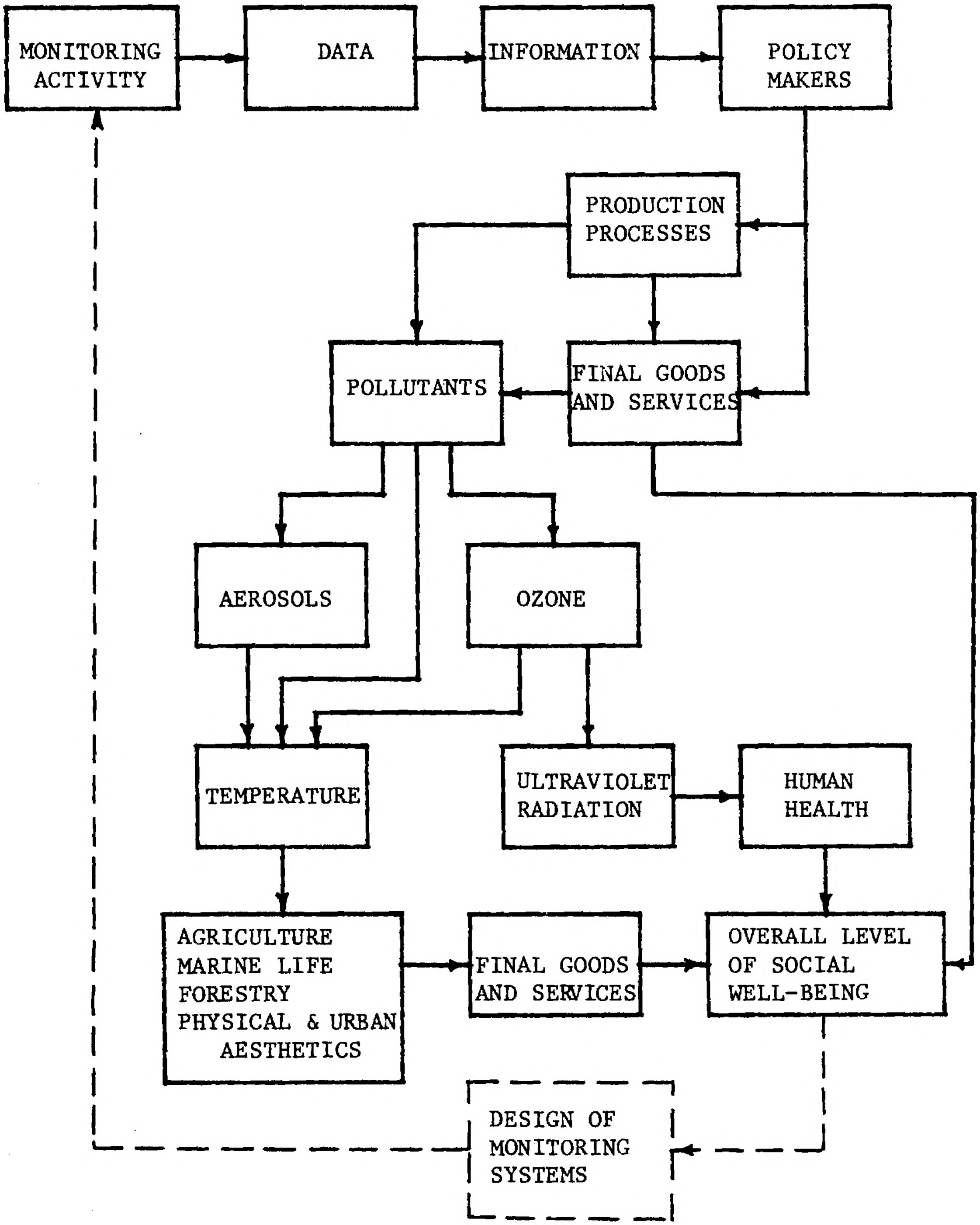

Figure 3.2 The Monitoring Causality Process

the human health effect depicted in the figure. Temperature changes have potential effects on agriculture, marine life, forestry, physical and urban resources, and aesthetics.** These effects impact final goods and services consumed by society. Thus, the overall level of social well-being is affected by the final goods and services impacted by the consequences of temperature changes, and by health effects.

The dotted line in Figure 3.2 illustrates how the impact on social welfare of monitoring can be used to influence the level of monitoring chosen.

The conceptual system approach to benefit assessment of monitoring can be operationalized by determining the causality processes involved and modeling those processes by a series of submodels, or links. This modular approach has many benefits, among which are ease of development and ease of updating. The sum of all the submodels is labeled the Benefit Assessment Model. The model lends itself to computerization, and therefore is capable of generating the many points necessary to produce graphical, rather than matrix, results. Needless to say, a computerized model is much more readily subjected to extensive sensitivity analyses.

3.2 Use of The Computer Model

Figure 3.3 presents the inter-relationships between linkages of the Model of Environmental Benefits of Satellites (MEBS) and Table 3.1 gives a listing of inputs and outputs for the eight major linkages of the MEBS. These linkages model the cause-effect relationships between trends in stratospheric ozone and aerosols and the resulting biological damage costs and costs due to goods and

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** These are the categories created by the Climate Impact Assessment Program. U.S. D.O.T. research program which investigated the environmental impact of the SST.

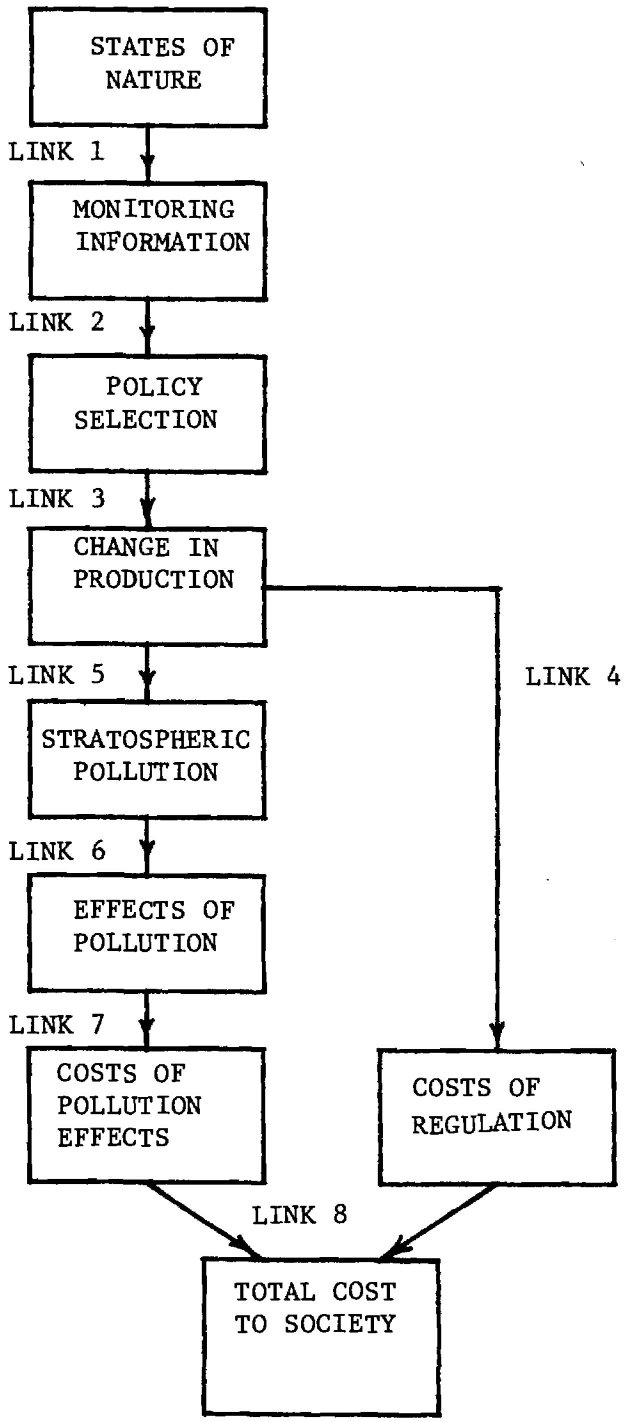


Figure 3.3 Major Links in the Benefit Assessment Model

TABLE 3.1 Description of Linkage Models

Link No.	Input	Output
1	States of Nature	Monitoring Information
2	Monitoring Information	Policy Selection
3	Policy Selection	Change in Production
4	Policy Selection	Costs Due to Policies
5	Change in Production	Change in Stratospheric pollution
6	Change in Stratospheric Pollution	Stratospheric Pollution Effects
7	Stratospheric Pollution Effects	Cost of Pollution
8	Cost of Regulation and Pollution	Total Cost to Society

services foregone. The overall procedure for use of the model as outlined in Section 3.1 is discussed in more detail here and the overall procedure for computing total costs is also described.

Inputs to link 1 are monitoring system characteristics. Some characteristics are number of locations sampled, frequency of observation, and the accuracy of each observation. Characteristics of the monitoring system are then translated into a representation of monitoring system capability, (a curve representing the time required to detect a given trend in reduction of stratospheric ozone). This monitoring system capability along with assumed trends in ozone reduction and aerosol loading are used to determine the time required by the monitoring system to detect each of the assumed trends. Selection of the appropriate regulatory policy, given that either or both trends have been detected, depends on inputs to policy makers as to the level of trend and evaluations of the possible consequences of erroneous decisions. The present approach to policy selection is to run the model for a trial period for all policies applicable to the trend, noting the total economic costs. The policy which results in minimum total cost to society is selected.

Once a given policy is selected, bans or restrictions on stratospheric flight and chlorofluoromethane (CFMs) production are implemented. This determines the quantities of pollutants produced, and it results in economic cost due to production changes and foregone goods. Changes in level of ozone and changes in temperature as a result of changes in levels of pollutants injected into the stratosphere are then determined. Changes in level of ozone or aerosols influence economic costs in two ways: (1) through effecting changes in surface ultraviolet radiation and therefore increases in the incidence of skin cancer in humans and (2) through changes in surface climate and therefore affecting crop yields, space heating requirements, etc. The economic costs due to biological damage and due to production changes and foregone goods are converted into a single number using the Net Present Value criterion. This procedure is then repeated for other assumed levels in ozone and aerosol trend.

Once an evaluation has been made for a number of assumed ozone trends for the baseline monitoring system, the same procedure is followed for evaluating the performance of the alternative ozone monitoring system. The difference between the total economic costs of the baseline and alternative ozone monitoring system for each assumed trend in stratospheric ozone is then the value of additional monitoring conditional on the trend. Next, the model is run using the alternate aerosol monitoring system as well as the alternate ozone monitoring system. The difference in costs (for each level of the trends) between the baseline case and the alternate-ozone, alternate-aerosol case represents the joint benefit of improved monitoring of both ozone and aerosols. The difference between this joint benefit and the benefits of improved ozone monitoring only represents the marginal benefits of improved monitoring of aerosols, given that an improved ozone monitoring is also used. Figure 3.4 illustrates the process.

The approach to modeling economic costs due to stratospheric pollution is to segment the link between monitoring activity and economic costs into a number of linkages and to model each particular linkage using work by experts in the given areas. Each link is independent of any other link and interacts with other links only through its inputs and outputs. This modular approach facilitates programming of individual links and provides for ease of model updates. A significant amount of research is currently under way concerning stratospheric pollution, and the modular approach will aid in future program updates.

The modeling approach for characterizing each linkage is to 1) survey

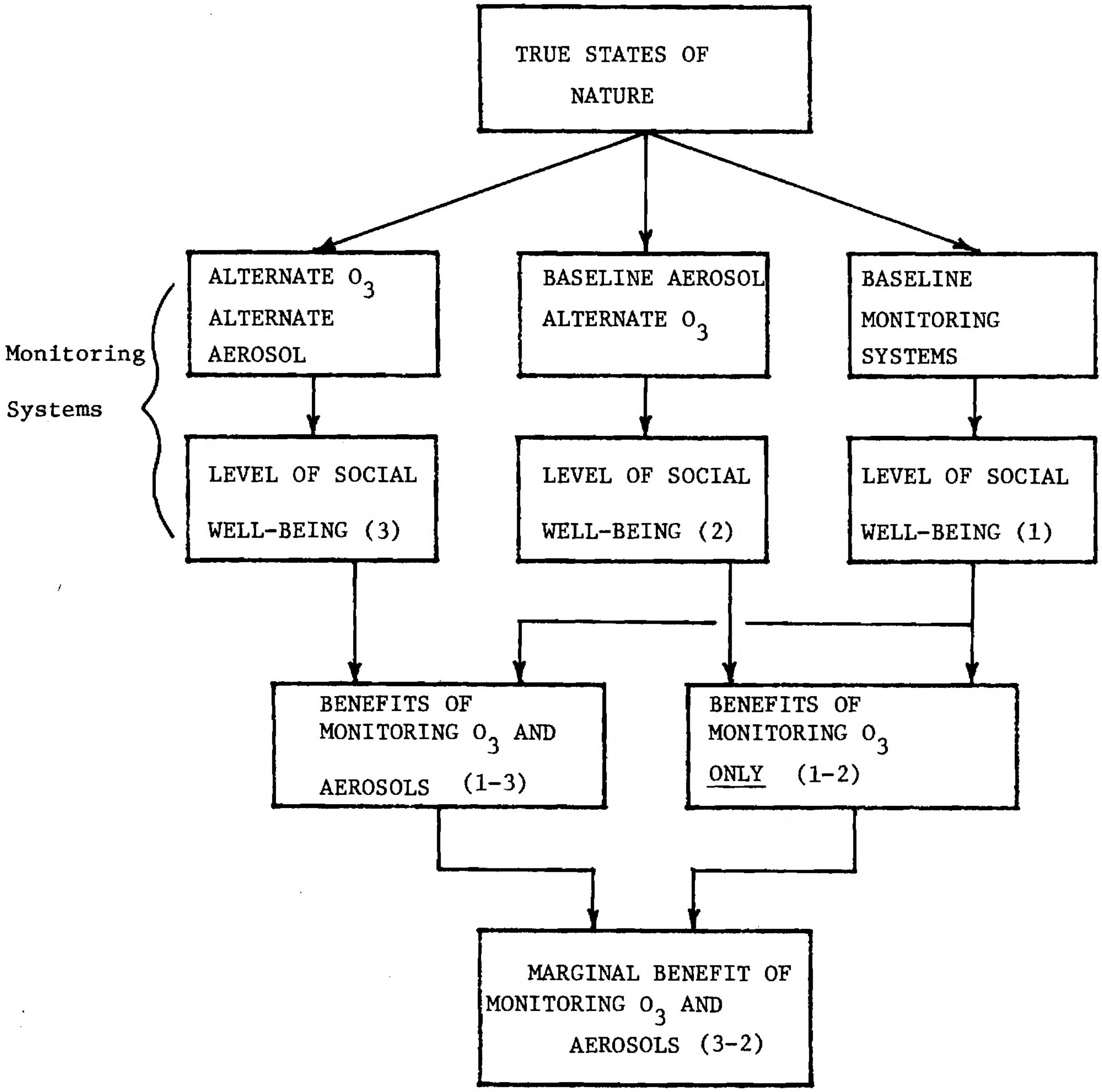


Figure 3.4 Procedure for Calculating Benefits of Improved Ozone Monitoring, Joint Benefits of Improved Ozone and Aerosol Monitoring, and Marginal Benefits of Monitoring Aerosols.

current literature related to the specific problem, 2) isolate relevant literature, 3) formulate reasonable assumptions, 4) formulate the empirical relationships between inputs and outputs, 5) quantify the cause-effect relationship relating outputs to inputs, and 6) document the assumptions. This modeling approach was carried out for each link. Each link was then computerized and integrated into the overall model.

Figure 3.5 illustrates the detailed breakdown of the linkage models. Table 3.1 summarizes the inputs and outputs. Appendix B describes these linkage models in detail.

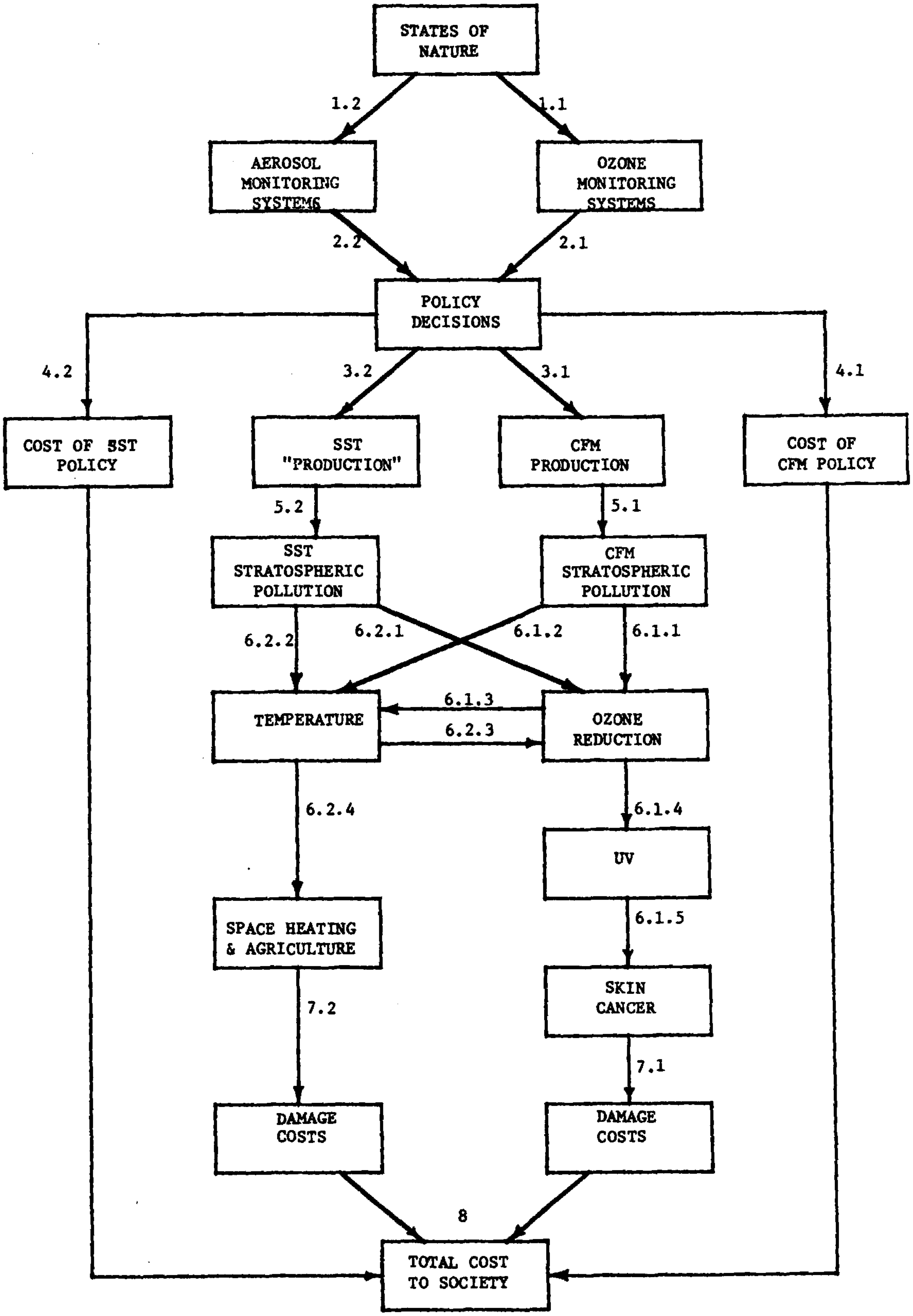


Figure 3.5 Detailed Breakdown of Linkages in the Model of Environmental Benefits (MEBS)

SECTION IV

RESULTS

4.1 The Basic Results

The model, as described in Appendix C and previous sections, was implemented via computer program. In this section, results of runs of the model are illustrated.

Table 4.1 indicates the results generated using the computer model. The entry in the upper left corner of each cell indicates the value of monitoring ozone alone. The entry in the lower left is the value of monitoring both ozone and aerosols. The entry on the right is the difference between the entries on the left, is the marginal value of monitoring aerosols, given the monitoring of ozone.

Note from the table that the benefits of the alternate ozone monitoring system are independent of the aerosol trend. Although it is not clear that this is necessarily the case, it is certainly a reasonable outcome. Figure 4.1 indicates the general nature of the results graphically. The cost to society for each of the trend levels varied considerably, but the benefits of monitoring come out the same. For trends over 5 percent per decade, the benefits level off. Again, this is not an obvious outcome, but it seems a reasonable one. For large levels of trend, the magnitude of the difference in capability between baseline and postulated alternate systems becomes negligible. For instance, even though the postulated alternate monitoring system detects a trend in one-half of the time required by the baseline system, for the larger trends this difference may be only one or two years.

For both alternate ozone and alternate aerosol monitoring systems similar

TABLE 4.1. BENEFITS OF ALTERNATE MONITORING SYSTEMS
-BASE CASE

OZONE TREND (%/DECADE REDUCTION)

		1		3		5		7		9	
	1	2039.		1131.		564.		564.		564.	
		2118.	79.	1211.	79.	643.	79.	643.	79.	643.	79.
AEROSOL	3	2039.		1131.		564.		564.		564.	
TREND		2085.	47.	1178.	47.	610.	47.	610.	47.	610.	47.
(INCREACE	5	2039.		1131.		564.		564.		564.	
%/DECADE)		2062.	24.	1155.	24.	588.	24.	588.	24.	588.	24.
	7	2039.		1131.		564.		564.		564.	
		2062.	24.	1155.	24.	588.	24.	588.	24.	588.	24.
	9	2039.		1131.		564.		564.		564.	
		2062.	24.	1155.	24.	588.	24.	588.	24.	588.	24.

* Legend

	X_2	
X_1	A	
	B	C

X_1 = Trend in Aerosol Increase (%/decade)

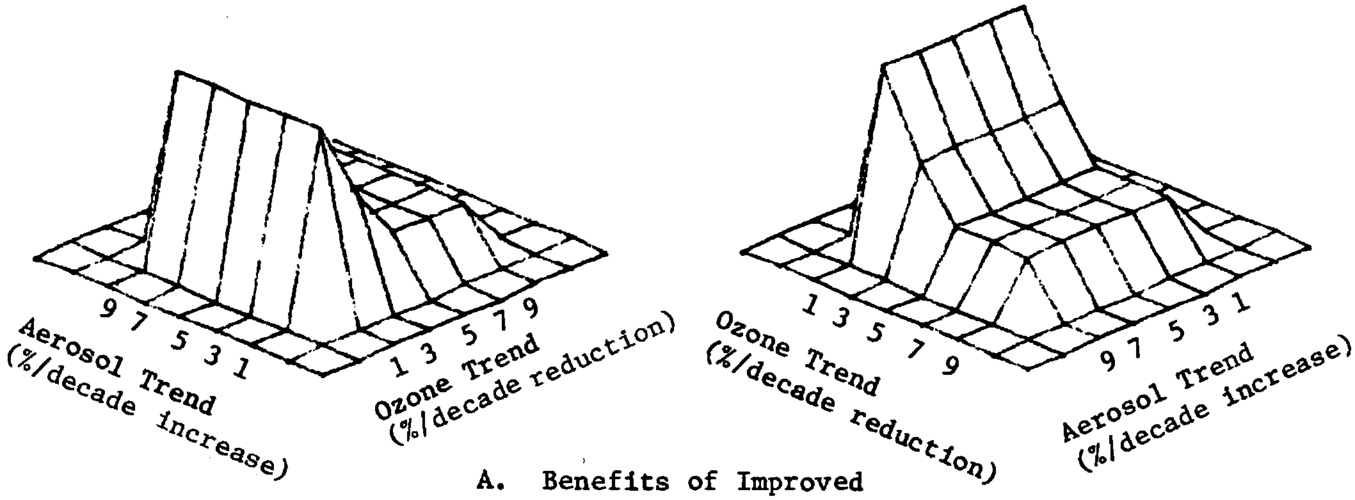
X_2 = Trend in Ozone Reduction (%/decade)

A = Benefits of an Alternate Ozone Monitoring System

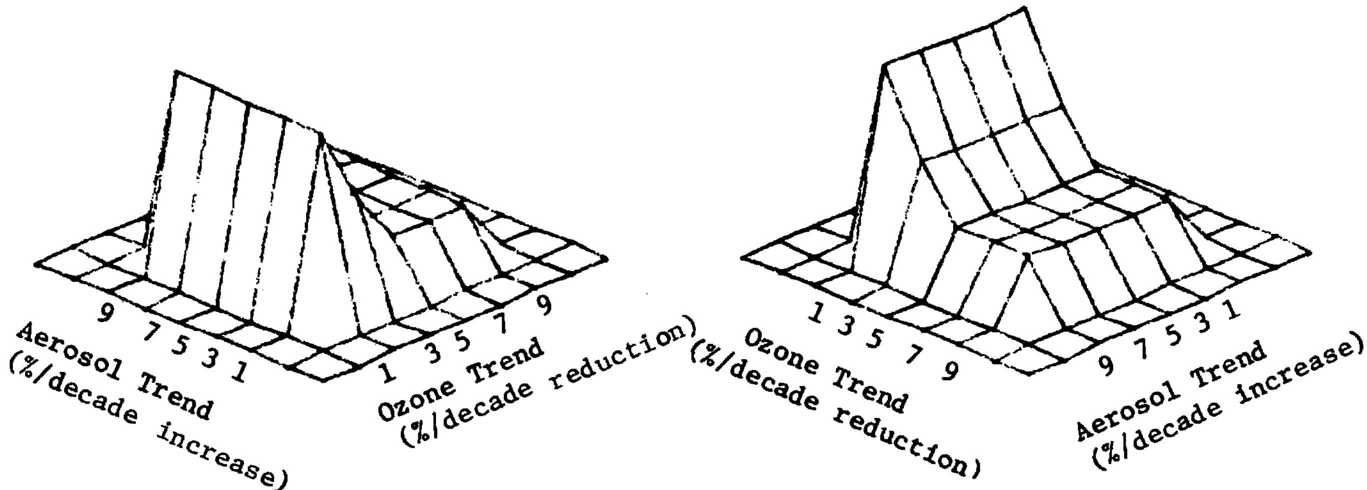
B = Benefits of an Alternate Ozone and Aerosol Monitoring System

C = Marginal Benefits of an Alternate Aerosol Monitoring System (= B-A)

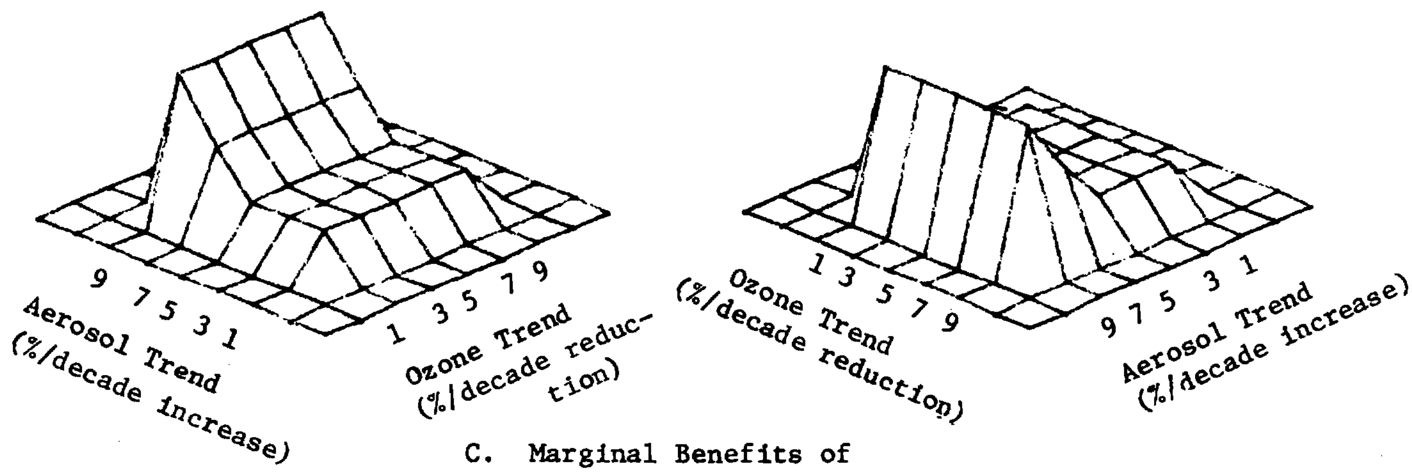
($ Million)



A. Benefits of Improved Ozone Monitoring



B. Joint Benefits of Improved Ozone and Aerosol Monitoring



C. Marginal Benefits of Improved Aerosol Monitoring

Figure 4.1 Benefits, Joint Benefits and Marginal Benefits of Additional Monitoring behavior is observed. In this case benefits to society depend on the level of both trends. The highest benefit resulted at the lowest levels of trend. The benefits taper off much more quickly for increasing ozone level (reduction) than for increasing aerosol trend.

The marginal benefits of improved monitoring of aerosols (over improved monitoring of only ozone) are illustrated in Figure 4.1C. These benefits are dependent only on the level of aerosol trend. This result also is intuitively reasonable, but not obvious. It is obvious that the aerosol trend affects the marginal benefits of improved monitoring of aerosols, but it is not obvious that the ozone trend should not. Note also that the marginal benefits are constant over the range of ozone trends even though the "ozone benefits" and "joint benefits" vary. They vary uniformly, giving constant marginal benefits, for each unit of aerosol trend.

The parameter values used are those documented in Appendix C as the base or nominal case. There is great uncertainty in the scientific community as to the values of many of these parameters. In other areas, there is controversy as to the basic nature of the models, as well as to the parameter values. Forecasts of future population, CFM production, and SST fleets are required. It is anticipated that ongoing research may significantly change some of these estimates and forecasts. Thus, it is important to investigate the model results when subjected to changes in critical parameters. The following sections examine some of these results.

4.2 Sensitivity Analysis

The procedure used to test the sensitivity of the results to variations in parameter values is to change the values, one at a time, and note the effects on the results. A simplistic approach is used, varying the parameter to its maximum and minimum values (or at least large and small values within the possible range), to see the range of results which may occur. Most of these runs display the same general characteristics as described for the base case, except scaled in magnitude.

4.2.1 The Pittock Curve

Table 4.2 gives the results using the Pittock baseline monitoring system curve. The alternate monitoring system is postulated to require one half of the time required by the baseline system to detect any given trend. With the "Pittock" curve, there is more absolute difference between the baseline and alternate system, even though the relative difference is the same as in the base, or "Hill" case. For this reason, the benefits of additional ozone monitoring, the joint benefits of additional ozone and aerosol monitoring, and the marginal benefits of additional aerosol monitoring are all larger than in the base case.

4.2.2 Discount Rate

Tables 4.3 and 4.4 give the results using various discount rates. Increasing the discount rate decreases the benefits of improved monitoring (Table 4.6). Decreasing the discount rate increases the benefits (Table 4.7). This result was expected because increasing the discount rate decreases the "weight" of future costs relative to present costs. Since most of the costs of regulation come early in the run, while the "benefits" (i.e. reduced cost) come after several decades, the benefits are quite sensitive to discount rate.

4.2.3 Time Horizon

The time horizon is the period of time over which the simulation is run. For the base case, 50 years is used. Table 4.5 and 4.6 indicate the results when this is varied. The longer time horizon results in larger benefits of additional ozone monitoring, and larger benefits of additional ozone and aerosol moni-

Table 4.2 BENEFITS OF ALTERNATE MONITORING SYSTEMS USING THE PITTOCK MONITORING SYSTEM CURVES

OZONE TREND (%/DECADE REDUCTION)

AEROSOL TREND (INCREACE %/DECADE)	1	3	5	7	9
1	3424. 3565. 142.	2039. 2180. 142.	1679. 1821. 142.	1136. 1277. 142.	1131. 1273. 142.
3	3424. 3503. 79.	2039. 2118. 79.	1679. 1759. 79.	1136. 1215. 79.	1131. 1211. 79.
5	3424. 3489. 66.	2039. 2104. 66.	1679. 1745. 66.	1136. 1201. 66.	1131. 1197. 66.
7	3424. 3468. 45.	2039. 2083. 45.	1679. 1724. 45.	1136. 1180. 45.	1131. 1176. 45.
9	3424. 3470. 47.	2039. 2085. 47.	1679. 1726. 47.	1136. 1182. 47.	1131. 1178. 47.

* Legend

X_1 \ X_2	
A	
B	C

X_1 = Trend in Aerosol Increase (%/decade)

X_2 = Trend in Ozone Reduction (%/decade)

A = Benefits of an Alternate Ozone Monitoring System

B = Benefits of an Alternate Ozone and Aerosol Monitoring System

C = Marginal Benefits of an Alternate Aerosol Monitoring System (= B-A)

($ Million)

TABLE 4.3 BENEFITS OF ALTERNATE MONITORING SYSTEMS
USING DISCOUNT RATES OF 7 PERCENT

		OZONE TREND (%/DECADE REDUCTION)									
		1		3		5		7		9	
AEROSOL TREND (INCREACE %/DECADE)	1	1259.		747.		376.		376.		376.	
		1325.	66.	814.	66.	442.	66.	442.	66.	442.	66.
	3	1259.		747.		376.		376.		376.	
		1300.	41.	789.	41.	417.	41.	417.	41.	417.	41.
	5	1259.		747.		376.		376.		376.	
		1280.	21.	768.	21.	397.	21.	397.	21.	397.	21.
	7	1259.		747.		376.		376.		376.	
		1280.	21.	768.	21.	397.	21.	397.	21.	397.	21.
	9	1259.		747.		376.		376.		376.	
		1280.	21.	768.	21.	397.	21.	397.	21.	397.	21.

* Legend

X_1 \ X_2		
	A	
	B	C

X_1 = Trend in Aerosol Increase (%/decade)

X_2 = Trend in Ozone Reduction (%/decade)

A = Benefits of an Alternate Ozone Monitoring System

B = Benefits of an Alternate Ozone and Aerosol Monitoring System

C = Marginal Benefits of an Alternate Aerosol Monitoring System (= B-A)

($ Million)

TABLE 4.4 BENEFITS OF ALTERNATE MONITORING SYSTEMS USING DISCOUNT RATES OF 3 PERCENT

AEROSOL TREND (INCREACE %/DECADE)	OZONE TREND (%/DECADE REDUCTION) 1	3	5	7	9
1	3425. 3520. 95.	1781. 1876. 95.	880. 975. 95.	880. 975. 95.	880. 975. 95.
3	3425. 3477. 52.	1781. 1833. 52.	880. 932. 52.	880. 932. 52.	880. 932. 52.
5	3425. 3451. 27.	1781. 1807. 27.	880. 907. 27.	880. 907. 27.	880. 907. 27.
7	3425. 3451. 27.	1781. 1807. 27.	880. 907. 27.	880. 907. 27.	880. 907. 27.
9	3425. 3451. 27.	1781. 1807. 27.	880. 907. 27.	880. 907. 27.	880. 907. 27.

* Legend

X_1 \ X_2	
A	
B	C

X_1 = Trend in Aerosol Increase (%/decade)

X_2 = Trend in Ozone Reduction (%/decade)

A = Benefits of an Alternate Ozone Monitoring System

B = Benefits of an Alternate Ozone and Aerosol Monitoring System

C = Marginal Benefits of an Alternate Aerosol Monitoring System (= B-A)

($ Million)

Table 4.5 BENEFITS OF ALTERNATE MONITORING SYSTEMS OVER 140 YEARS

OZONE TREND (%/DECADE REDUCTION)

AEROSOL TREND (INCREACE %/DECADE)	1	3	5	7	9
1	2280. 2360. 79.	1228. 1307. 79.	610. 689. 79.	610. 689. 79.	610. 689. 79.
3	2280. 2327. 47.	1228. 1275. 47.	610. 657. 47.	610. 657. 47.	610. 657. 47.
5	2280. 2304. 24.	1228. 1252. 24.	610. 634. 24.	610. 634. 24.	610. 634. 24.
7	2280. 2304. 24.	1228. 1252. 24.	610. 634. 24.	610. 634. 24.	610. 634. 24.
9	2280. 2304. 24.	1228. 1252. 24.	610. 634. 24.	610. 634. 24.	610. 634. 24.

* Legend

X_1 \ X_2	
A	
B	C

X_1 = Trend in Aerosol Increase (%/decade)

X_2 = Trend in Ozone Reduction (%/decade)

A = Benefits of an Alternate Ozone Monitoring System

B = Benefits of an Alternate Ozone and Aerosol Monitoring System

C = Marginal Benefits of an Alternate Aerosol Monitoring System (= B-A)

($ Million)

Table 4.6 BENEFITS OF ALTERNATE MONITORING SYSTEMS OVER 25 YEARS

OZONE TREND (%/DECADE REDUCTION)

AEROSOL TREND (INCREACE %/DECADE)	1	3	5	7	9
1	1162. 1241. 79.	780. 859. 79.	396. 475. 79.	396. 475. 79.	396. 475. 79.
3	1162. 1209. 47.	780. 827. 47.	396. 443. 47.	396. 443. 47.	396. 443. 47.
5	1162. 1186. 24.	780. 804. 24.	396. 420. 24.	396. 420. 24.	396. 420. 24.
7	1162. 1186. 24.	780. 804. 24.	396. 420. 24.	396. 420. 24.	396. 420. 24.
9	1162. 1186. 24.	780. 804. 24.	396. 420. 24.	396. 420. 24.	396. 420. 24.

* Legend

X_1 \ X_2	
	A B C

X_1 = Trend in Aerosol Increase (%/decade)

X_2 = Trend in Ozone Reduction (%/decade)

A = Benefits of an Alternate Ozone Monitoring System

B = Benefits of an Alternate Ozone and Aerosol Monitoring System

C = Marginal Benefits of an Alternate Aerosol Monitoring System (= B-A)

($ Million)

toring, but the same marginal benefits as the base case. The shorter time horizon results in smaller benefits and joint benefits, but the same marginal benefits as the base case. This is a reasonable result, since the benefits (in reduced damage costs) appear after long delays. The benefits of additional ozone monitoring only, and additional aerosol and ozone monitoring change, but the difference between these benefits stays the same. Thus the marginal benefits in this case are the same as for the base case.

4.2.4 Population Projections

Three U. S. population projections made in the Statistical Abstract of the United States are illustrated in Appendix C. The Series II projection is used in the base case. Series I assumes a larger fertility rate (average number of lifetime births per 1000 women), while Series III assumes a lower fertility rate than Series II, the base case. The Series III population run resulted in slightly lower benefits. The Series I population projection resulted in slightly higher benefits. In both cases the marginal benefits, and the general character of the benefits of additional ozone and aerosol monitoring is the same as for the base case. Tables 4.7 and 4.8 illustrate the results using the alternate population scenarios.

4.2.5 SST Fleet

In the base case the SST fleet increases linearly to 100 aircraft in 2010, then growth tapers to 200 in 2200. The benefits of additional monitoring were analyzed using twice this fleet projection, and also with 1/2 the projection. The results of the runs are given in Tables 4.9 and 4.10. These results are somewhat unusual. The benefits were generally larger than base case benefits for both large and the small SST fleets. It would seem that the benefits when using the smaller fleet projection would be lower. The reason for the unusual

Table 4.7 BENEFITS OF ALTERNATE MONITORING SYSTEMS USING PROJECTED POPULATION SERIES III

AEROSOL TREND (INCREACE %/DECADE)	OZONE TREND (%/DECADE REDUCTION) 1	3	5	7	9
1	2035. 2114. 79.	1129. 1209. 79.	563. 642. 79.	563. 642. 79.	563. 642. 79.
3	2035. 2081. 47.	1129. 1176. 47.	563. 609. 47.	563. 609. 47.	563. 609. 47.
5	2035. 2059. 24.	1129. 1153. 24.	563. 587. 24.	563. 587. 24.	563. 587. 24.
7	2035. 2059. 24.	1129. 1153. 24.	563. 587. 24.	563. 587. 24.	563. 587. 24.
9	2035. 2059. 24.	1129. 1153. 24.	563. 587. 24.	563. 587. 24.	563. 587. 24.

* Legend

X_1 \ X_2	
A	
B	C

X_1 = Trend in Aerosol Increase (%/decade)

X_2 = Trend in Ozone Reduction (%/decade)

A = Benefits of an Alternate <u>Ozone</u> Monitoring System

B = Benefits of an Alternate <u>Ozone</u> and <u>Aerosol</u> Monitoring System

C = Marginal Benefits of an Alternate <u>Aerosol</u> Monitoring System (= B-A)

($ Million)

Table 4.8 BENEFITS OF ALTERNATE MONITORING SYSTEMS
USING PROJECTED POPULATION SERIES I

OZONE TREND (%/DECADE REDUCTION)

AEROSOL TREND (INCREACE %/DECADE)	1	3	5	7	9
1	2044. 2123. 79.	1134. 1213. 79.	565. 644. 79.	565. 644. 79.	565. 644. 79.
3	2044. 2090. 47.	1134. 1181. 47.	565. 612. 47.	565. 612. 47.	565. 612. 47.
5	2044. 2068. 24.	1134. 1158. 24.	565. 589. 24.	565. 589. 24.	565. 589. 24.
7	2044. 2068. 24.	1134. 1158. 24.	565. 589. 24.	565. 589. 24.	565. 589. 24.
9	2044. 2068. 24.	1134. 1158. 24.	565. 589. 24.	565. 589. 24.	565. 589. 24.

* Legend

X_1 \ X_2	
A	
B	C

X_1 = Trend in Aerosol Increase (%/decade)

X_2 = Trend in Ozone Reduction (%/decade)

A = Benefits of an Alternate Ozone Monitoring System

B = Benefits of an Alternate Ozone and Aerosol Monitoring System

C = Marginal Benefits of an Alternate Aerosol Monitoring System (= B-A)

($ Million)

Table 4.9 BENEFITS OF ALTERNATE MONITORING SYSTEMS USING TWICE THE PROJECTED SST FLEET

OZONE TREND (%/DECADE REDUCTION)

AEROSOL TREND (INCREACE %/DECADE)	1	3	5	7	9
1	2039. 2197. 159.	1131. 1290. 159.	564. 722. 159.	564. 722. 159.	564. 722. 159.
3	2039. 2132. 93.	1131. 1224. 93.	564. 657. 93.	564. 657. 93.	564. 657. 93.
5	2039. 2086. 47.	1131. 1179. 47.	564. 611. 47.	564. 611. 47.	564. 611. 47.
7	2039. 2086. 47.	1131. 1179. 47.	564. 611. 47.	564. 611. 47.	564. 611. 47.
9	2039. 2086. 47.	1131. 1179. 47.	564. 611. 47.	564. 611. 47.	564. 611. 47.

* Legend

X_1 \\ X_2	
A	
B	C

X_1 = Trend in Aerosol Increase (%/decade)

X_2 = Trend in Ozone Reduction (%/decade)

A = Benefits of an Alternate Ozone Monitoring System

B = Benefits of an Alternate Ozone and Aerosol Monitoring System

C = Marginal Benefits of an Alternate Aerosol Monitoring System (= B-A)

($ Million)

Table 4.10 BENEFITS OF ALTERNATE MONITORING SYSTEMS USING ONE HALF THE PROJECTED SST FLEET

OZONE TREND (%/DECADE REDUCTION)

AEROSOL TREND (INCREACE %/DECADE)	1	3	5	7	9
1	2039. 2078. 40.	1131. 1171. 40.	564. 603. 40.	564. 603. 40.	564. 603. 40.
3	2039. 2062. 23.	1131. 1155. 23.	564. 587. 23.	564. 587. 23.	564. 587. 23.
5	2039. 2050. 12.	1131. 1143. 12.	564. 576. 12.	564. 576. 12.	564. 576. 12.
7	2039. 2050. 12.	1131. 1143. 12.	564. 576. 12.	564. 576. 12.	564. 576. 12.
9	2039. 2050. 12.	1131. 1143. 12.	564. 576. 12.	564. 576. 12.	564. 576. 12.

* Legend

Cell layout (X_1 rows, X_2 columns): A (top); B C (bottom)

X_1 = Trend in Aerosol Increase (%/decade)

X_2 = Trend in Ozone Reduction (%/decade)

A = Benefits of an Alternate Ozone Monitoring System

B = Benefits of an Alternate Ozone and Aerosol Monitoring System

C = Marginal Benefits of an Alternate Aerosol Monitoring System (= B-A)

($ Million)

behavior is the temperature changes which resulted. Some of the SST effluents tend to increase temperature, while others lead to a temperature decrease (refer to Appendix C). Reducing the SST emissions results in less positive temperature change due to the effluents which increase temperature, and less negative temperature change due to the effluents (and ozone reduction) which cause temperature reduction. The total positive change, however, is less than the total negative change, giving a net temperature change that is larger than for the base case SST fleet.

4.2.6 CFM Production Scenario

The CFM production scenario used in the base case is given in Appendix C. Two deviations are considered on this base case. The first, assuming twice the production results in benefits as shown in Table 4.11. The second, assuming one half of the base case production gives the benefits shown in Table 4.12. The larger production scenario gives larger benefits and joint benefits than the baseline case, but the same marginal benefits. The increased production scenario results in more pollution damage, and therefore the potential benefits of avoiding the damage are greater. The inverse is true for the reduced production scenario. Since only the CFM's are affected, the marginal benefits of aerosol monitoring remains the same as for the baseline case.

4.2.7 Skin Cancer Cost

The direct costs of a case of non-melanoma skin cancer were estimated to be in the range of $1900 per case. In the base run, a value of $1000 per case was selected. Tables 4.13 and 4.14 illustrate the results when $190/case and $1900/case are used. Again the benefits and joint benefits are directly related to the skin cancer cost, but the joint benefits are effectively independent, and the same as those of the base case.

Table 4.11 BENEFITS OF ALTERNATE MONITORING SYSTEMS USING TWICE THE PROJECTED CFM PRODUCTION

OZONE TREND (%/DECADE REDUCTION)

AEROSOL TREND (INCREACE %/DECADE)	1	3	5	7	9
1	4100. 4179. 79.	2275. 2354. 79.	1134. 1213. 79.	1134. 1213. 79.	1134. 1213. 79.
3	4100. 4146. 47.	2275. 2322. 47.	1134. 1180. 47.	1134. 1180. 47.	1134. 1180. 47.
5	4100. 4123. 24.	2275. 2299. 24.	1134. 1158. 24.	1134. 1158. 24.	1134. 1158. 24.
7	4100. 4123. 24.	2275. 2299. 24.	1134. 1158. 24.	1134. 1158. 24.	1134. 1158. 24.
9	4100. 4123. 24.	2275. 2299. 24.	1134. 1158. 24.	1134. 1158. 24.	1134. 1158. 24.

* Legend

X_1 \ X_2	
A	
B	C

X_1 = Trend in Aerosol Increase (%/decade)

X_2 = Trend in Ozone Reduction (%/decade)

A = Benefits of an Alternate <u>Ozone</u> Monitoring System

B = Benefits of an Alternate <u>Ozone</u> and <u>Aerosol</u> Monitoring System

C = Marginal Benefits of an Alternate <u>Aerosol</u> Monitoring System (= B-A)

($ Million)

Table 4.12 BENEFITS OF ALTERNATE MONITORING SYSTEMS USING ONE HALF THE PROJECTED CFM PRODUCTION

AEROSOL TREND (INCREACE %/DECADE)	OZONE TREND (%/DECADE REDUCTION) 1	3	5	7	9
1	1010. 1089. 79.	560. 639. 79.	279. 358. 79.	279. 358. 79.	279. 358. 79.
3	1010. 1057. 47.	560. 607. 47.	279. 326. 47.	279. 326. 47.	279. 326. 47.
5	1010. 1034. 24.	560. 584. 24.	279. 303. 24.	279. 303. 24.	279. 303. 24.
7	1010. 1034. 24.	560. 584. 24.	279. 303. 24.	279. 303. 24.	279. 303. 24.
9	1010. 1034. 24.	560. 584. 24.	279. 303. 24.	279. 303. 24.	279. 303. 24.

*** Legend**

X_1 \ X_2		
	A	
	B	C

- X_1 = Trend in Aerosol Increase (%/decade)
- X_2 = Trend in Ozone Reduction (%/decade)
- A = Benefits of an Alternate Ozone Monitoring System
- B = Benefits of an Alternate Ozone and Aerosol Monitoring System
- C = Marginal Benefits of an Alternate Aerosol Monitoring System (= B-A)

(A, B, C in $ Million)

Table 4.13 BENEFITS OF ALTERNATE MONITORING SYSTEMS USING SKIN CANCER COST OF $190./CASE

AEROSOL TREND (INCREACE %/DECADE)	OZONE TREND (%/DECADE REDUCTION) 1	3	5	7	9
1	2010. 2089. 79.	1115. 1194. 79.	556. 635. 79.	556. 635. 79.	556. 635. 79.
3	2010. 2057. 47.	1115. 1161. 47.	556. 602. 47.	556. 602. 47.	556. 602. 47.
5	2010. 2034. 24.	1115. 1138. 24.	556. 579. 24.	556. 579. 24.	556. 579. 24.
7	2010. 2034. 24.	1115. 1138. 24.	556. 579. 24.	556. 579. 24.	556. 579. 24.
9	2010. 2034. 24.	1115. 1138. 24.	556. 579. 24.	556. 579. 24.	556. 579. 24.

* Legend

X_1	A	
	B	C
	X_2	

X_1 = Trend in Aerosol Increase (%/decade)

X_2 = Trend in Ozone Reduction (%/decade)

A = Benefits of an Alternate Ozone Monitoring System

B = Benefits of an Alternate Ozone and Aerosol Monitoring System

C = Marginal Benefits of an Alternate Aerosol Monitoring System (= B-A)

($ Million)

Table 4.14 BENEFITS OF ALTERNATE MONITORING SYSTEMS USING SKIN CANCER COST OF $1900./CASE

AEROSOL TREND (INCREACE %/DECADE)	OZONE TREND (%/DECADE REDUCTION) 1	3	5	7	9
1	2070. 2149. 79.	1150. 1229. 79.	573. 652. 79.	573. 652. 79.	573. 652. 79.
3	2070. 2117. 47.	1150. 1196. 47.	573. 620. 47.	573. 620. 47.	573. 620. 47.
5	2070. 2094. 24.	1150. 1173. 24.	573. 597. 24.	573. 597. 24.	573. 597. 24.
7	2070. 2094. 24.	1150. 1173. 24.	573. 597. 24.	573. 597. 24.	573. 597. 24.
9	2070. 2094. 24.	1150. 1173. 24.	573. 597. 24.	573. 597. 24.	573. 597. 24.

*** Legend**

X_1 \ X_2	
A	
B	C

- X_1 = Trend in Aerosol Increase (%/decade)
- X_2 = Trend in Ozone Reduction (%/decade)
- A = Benefits of an Alternate Ozone Monitoring System
- B = Benefits of an Alternate Ozone and Aerosol Monitoring System
- C = Marginal Benefits of an Alternate Aerosol Monitoring System (= B-A)

($ Million)

4.2.8 Temperature Costs

The cost per degree change in average global surface temperature is given in Appendix C, Link 7.2. These figures are indeed gross approximations. Table 4.15 and 4.16 indicate results when the temperature cost is varied plus and minus ten percent. Since temperature is affected by both CFM's and SST effluents, there are changes in benefits, joint benefits, and marginal benefits. The larger temperature cost factor gives larger benefits since there are more potential costs which may be averted. Likewise, the reduced temperature costs result in smaller benefits.

4.2.9 Alternate Monitoring Systems

The alternate monitoring system, used in the base case analysis was postulated to require one half of the length of time required by the baseline monitoring system to detect any particular trend (with 95 percent confidence). To test the sensitivity of the results to this postulated improvement, model runs were made using an alternate monitoring system which required 2/3 of the time required by the baseline system, and one which required only 1/3 of that required by the baseline system. Table 4.17 and 4.18 give the results. The benefits of additional ozone monitoring and joint benefits of additional ozone and aerosol monitoring are similar in character (but scaled in magnitude) with the base case. The better alternate system has larger benefits and the lesser alternate has lower benefits than the base alternate system. The result was expected, because the benefits derive from differences in monitoring system capabilities.

4.2.10 Iterative Policy Selection

A limited run was made using the iterative policy selection procedure discussed under Appendix C, Link 2. The result of this run is given in Table 4.19. The benefits resulting using the smallest level of trend are very close to those

Table 4.15 **BENEFITS OF ALTERNATE MONITORING SYSTEMS WITH TEMPERATURE COSTS UP 10 PERCENT**

AEROSOL TREND (INCREACE %/DECADE)	OZONE TREND (%/DECADE REDUCTION) 1		3		5		7		9	
1	2241.		1243.		620.		620.		620.	
	2329.	88.	1331.	88.	708.	88.	708.	88.	708.	88.
3	2241.		1243.		620.		620.		620.	
	2292.	51.	1295.	51.	671.	51.	671.	51.	671.	51.
5	2241.		1243.		620.		620.		620.	
	2267.	26.	1270.	26.	646.	26.	646.	26.	646.	26.
7	2241.		1243.		620.		620.		620.	
	2267.	26.	1270.	26.	646.	26.	646.	26.	646.	26.
9	2241.		1243.		620.		620.		620.	
	2267.	26.	1270.	26.	646.	26.	646.	26.	646.	26.

* Legend

X_1 \ X_2		
	A	
	B	C

X_1 = Trend in Aerosol Increase (%/decade)

X_2 = Trend in Ozone Reduction (%/decade)

A = Benefits of an Alternate Ozone Monitoring System

B = Benefits of an Alternate Ozone and Aerosol Monitoring System

C = Marginal Benefits of an Alternate Aerosol Monitoring System (= B-A)

($ Million)

Table 4.16 BENEFITS OF ALTERNATE MONITORING SYSTEMS WITH TEMPERATURE COSTS DOWN 10 PERCENT

OZONE TREND (%/DECADE REDUCTION)

AEROSOL TREND (INCREACE %/DECADE)	1	3	5	7	9
1	1836. 1907. 71.	1019. 1090. 71.	508. 579. 71.	508. 579. 71.	508. 579. 71.
3	1836. 1878. 42.	1019. 1061. 42.	508. 549. 42.	508. 549. 42.	508. 549. 42.
5	1836. 1858. 21.	1019. 1040. 21.	508. 529. 21.	508. 529. 21.	508. 529. 21.
7	1836. 1858. 21.	1019. 1040. 21.	508. 529. 21.	508. 529. 21.	508. 529. 21.
9	1836. 1858. 21.	1019. 1040. 21.	508. 529. 21.	508. 529. 21.	508. 529. 21.

* Legend

X_1 \ X_2	
A	
B	C

- X_1 = Trend in Aerosol Increase (%/decade)
- X_2 = Trend in Ozone Reduction (%/decade)
- A = Benefits of an Alternate Ozone Monitoring System
- B = Benefits of an Alternate Ozone and Aerosol Monitoring System
- C = Marginal Benefits of an Alternate Aerosol Monitoring System (= B-A)

(A, B, C: ($ Million))

Table 4.17 BENEFITS OF ALTERNATE MONITORING SYSTEMS
ALTERNATE 1 1/2 TIMES "BETTER" THAN BASELINE

AEROSOL TREND (INCREACE %/DECADE)	OZONE TREND (%/DECADE REDUCTION) 1	3	5	7	9
1	1495. 1553. 58.	567. 626. 58.	564. 622. 58.	564. 622. 58.	564. 622. 58.
3	1495. 1518. 23.	567. 590. 23.	564. 587. 23.	564. 587. 23.	564. 587. 23.
5	1495. 1519. 24.	567. 591. 24.	564. 588. 24.	564. 588. 24.	564. 588. 24.
7	1495. 1519. 24.	567. 591. 24.	564. 588. 24.	564. 588. 24.	564. 588. 24.
9	1495. 1519. 24.	567. 591. 24.	564. 588. 24.	564. 588. 24.	564. 588. 24.

* Legend

X_1 \ X_2	
A	
B	C

X_1 = Trend in Aerosol Increase (%/decade)

X_2 = Trend in Ozone Reduction (%/decade)

A = Benefits of an Alternate Ozone Monitoring System

B = Benefits of an Alternate Ozone and Aerosol Monitoring System

C = Marginal Benefits of an Alternate Aerosol Monitoring System (= B-A)

($ Million)

Table 4.18 BENEFITS OF ALTERNATE MONITORING SYSTEMS
ALTERNATE 3 TIMES 'BETTER' THAN BASELINE

OZONE TREND (%/DECADE REDUCTION)

AEROSOL TREND (INCREACE %/DECADE)	1	3	5	7	9
1	3174. 3298. 124.	1131. 1255. 124.	5791. 5915. 124.	5791. 5915. 124.	5791. 5915. 124.
3	3174. 3221. 47.	1131. 1178. 47.	5791. 5837. 47.	5791. 5837. 47.	5791. 5837. 47.
5	3174. 3218. 43.	1131. 1175. 43.	5791. 5834. 43.	5791. 5834. 43.	5791. 5834. 43.
7	3174. 3218. 43.	1131. 1175. 43.	5791. 5834. 43.	5791. 5834. 43.	5791. 5834. 43.
9	3174. 3218. 43.	1131. 1175. 43.	5791. 5834. 43.	5791. 5834. 43.	5791. 5834. 43.

* Legend

X_1 \ X_2	
A	
B	C

X_1 = Trend in Aerosol Increase (%/decade)

X_2 = Trend in Ozone Reduction (%/decade)

A = Benefits of an Alternate Ozone Monitoring System

B = Benefits of an Alternate Ozone and Aerosol Monitoring System

C = Marginal Benefits of an Alternate Aerosol Monitoring System (= B-A)

($ Million)

Table 4.19 BENEFITS OF ALTERNATE MONITORING SYSTEMS
ITERATIVE POLICY SELECTION USED

AEROSOL TREND (INCREACE %/DECADE)	OZONE TREND (%/DECADE REDUCTION) 1	3	5	7	9
1	2024. 2126. 102.	-21. 81. 102.	-24. 78. 102.	5. 107. 102.	5. 107. 102.
3	2016. 2016. 0.	5. 5. 0.	2. 2. 0.	0. 0. 0.	0. 0. 0.
5	2016. 2016. 0.	5. 5. 0.	2. 2. 0.	0. 0. 0.	0. 0. 0.
7	2016. 2016. 0.	5. 5. 0.	2. 2. 0.	0. 0. 0.	0. 0. 0.
9	2016. 2016. 0.	5. 5. 0.	2. 2. 0.	0. 0. 0.	0. 0. 0.

* Legend

X_1 \\ X_2	
A	
B	C

X_1 = Trend in Aerosol Increase (%/decade)

X_2 = Trend in Ozone Reduction (%/decade)

A = Benefits of an Alternate Ozone Monitoring System

B = Benefits of an Alternate Ozone and Aerosol Monitoring System

C = Marginal Benefits of an Alternate Aerosol Monitoring System (= B-A)

($ Million)

of the base case. At other levels of trend, however, the benefits are erratic. The reason for this stems from the manner and timing with which policy implementation is made. One critical factor turned out to be the minimum number of years between policy considerations. Five years was used as this minimum period. This resulted in some negative benefits for two levels of trend in ozone. This resulted because the timing with the baseline monitoring system happened to fall on the best year for a policy implementation. The alternate monitoring system had detected the trend earlier, but at the earlier time period the policy was not implemented. The five year minimum between policies skipped over the optimum year for policy implementation. Some of the benefits were zero. For these cases the timing between policy implementation turned out the same, giving no difference between baseline and alternate costs. Clearly these results are a function of irregularities in the mechanism of policy selection.

4.3 Summary

The results of the simulation indicate that the present value of the benefits of an improved monitoring system (ozone and aerosols) is in the range of ½ to 2 billion dollars (1976) over the next 50 years. Marginal benefits of including the aerosol capability are between 80 and 20 million dollars over the same time period. Generally, the benefits are highest at the low trends, and lowest at the high trends, forming a rough quarter gausian surface when plotted three dimensionally (Figure 4.14). Though the model is certainly sensitive to some of the parameters, the results of the sensitivity analysis show that, for the most part, the benefits remain within a factor of two of the base case results.

APPENDIX A

LITERATURE SURVEY: Review of Selected Reports

A.1 Preliminary Economic Impact Assessment of Possible Regulatory Action To Control Atmospheric Emissions of Selected Halocarbons, by Arthur D. Little, Inc.

A.2 Bureau of Domestic Commerce Staff Study, Economic Significance of Fluorocarbons, December 1975.

A.3 Fluorocarbons and the Environment Report of Federal Task Force on Inadvertant Modification of the Stratosphere (IMOS)

A.4 Department of Transportation Climatic Impact Assessment Program Effects of Stratospheric Pollution by Aircraft

A.5 Environmental Impact of Stratospheric Flight National Academy of Sciences, 1975.

A.6 Aircraft Emissions: Potential Effects on Ozone and Climate.

A.7 Halocarbons: Effects on Stratospheric Ozone.

A.8 Halocarbons: Environmental Effects of Chlorofluoromethane Release.

A.1. PRELIMINARY ECONOMIC IMPACT ASSESSMENT OF POSSIBLE REGULATORY ACTION TO CONTROL ATMOSPHERIC EMISSIONS OF SELECTED HALOCARBONS

Prepared for

The U. S. Environmental Protection Agency

by

Arthur D. Little, Inc.

This report was prepared for the Strategies and Air Standards Division of the U. S. Environmental Protection Agency by Arthur D. Little, Inc. (ADL) in order to provide a preliminary assessment of the economic consequences following potential restrictions in the manufacture and use of five primary chemicals in the United States. The chemicals in question are three fluorocarbons, F-11, F-12, and F-22; and 2 chlorocarbons, carbon tetrachloride and methyl chloroform.

A recently concluded study by the Federal Task Force on inadvertent modification of the stratosphere (IMOS) has concluded that fluorocarbons emitted into the atmosphere may have harmful environmental effects and are a cause for concern. Fluorocarbons are used primarily as aerosol propellants and refrigerants. They are also used in the manufacture of plastic foam and as special solvents. It is believed that fluorocarbons released in the atmosphere eventually reach the stratosphere where they may act to decrease the earth's ozone layer and permit an increased level of ultraviolet radiation to reach the earth's surface. It is proposed that this increased level of ultraviolet radiation will have serious adverse biological and climatological effects. Since the ozone theory has not been proved conclusively because of elements of uncertainty, it is felt additional research and analysis should be conducted before any final conclusions are reached.

This report develops data on 24 halocarbons (fluorocarbons and chlorocarbons are classes of halocarbons) including the five primary chemicals already mentioned. Expanding the list to 24 halocarbons anticipates additional research which may add or subtract from the basic list of five halocarbons, which have been identified by the EPA as being important contributors to possible ozone depletion. Data will also be developed to include U.S. as well as world-wide production use and emissions of halocarbons into the atmosphere. The report will also attempt to identify suitable chemical substitutes, non-chemical substitutes and methods for reducing emissions of halocarbons by improving equipment and maintenance techniques.

Those industry sectors which might be affected by the potential restriction of the production or use of the five halocarbons will be identified. A variety of regulatory scenarios will then be considered and the economic impact expected to follow will then be viewed in terms of each industry sector. This report is preliminary in nature in that relative rather than absolute economic consequences are assessed.

Report Summary

Carbon tetrachloride, from a production standpoint, is the singlemost important item of the five principal chemical compounds. However, almost all carbon tetrachloride production is used for the manufacture of fluorocarbons F-11 and F-12. The most important applications for the three fluorocarbons (F-11, F-12 and F-22) are as propellants and refrigerants. These uses account for an esimated 80% of total demand for these compounds. Methylchloroform is used primarily as a commerci cleaning solvent.

Fluorocarbon emissions into the atmosphere stem primarily from the use of these chemicals as aerosol propellants. This source of emission accounts for an estimated 60% of world-wide emissions. The largest sub-category of aerosols that are responsible for fluorocarbon emissions are the personal care products, hair sprays and anti-perspirants. The second important source of fluorocarbon emissions stems from refrigeration and air conditioning equipment. They account for an estimated 25% of world-wide flurocarbon emissions. The main sub-category within this group are mobile and large commercial air conditioning units.

In aerosol products, particularly personal care items, fluorocarbons have been chosen because of their low toxicity, nonflammability and, finally, controlled vapor. Other substitute propellants are available, however, they have different performance characteristics and, perhaps, more importantly, do not have the consumer acceptance that fluorocarbons have. Non-aerosol substitutes, such as roll-on deodorants and pump sprays have been on the market for a number of years. These products, however, do not enjoy the level of consumer acceptance as aerosol products. This is reflected by their small share of the market. In the event fluorocarbon propellants were banned, consumers may not completely convert to available substitutes, which might produce a net loss in industry sales.

The second largest use of fluorocarbons is as a refrigerant. The fluorocarbons in primary use are F-12 and F-22. Those systems presently designed to use F-11 and F-12 could be converted to use F-22, which is considered to be the safest of the three compounds, but not without considerable redesigning costs. An additional obstacle would be that F-22 has not proven to be an effective substitute when used in automobile air conditioning. An examination of alternative refrigeration systems which do not use F-11 and F-12 reveals that no system appears commercially viable at this time.

An alternative approach wherein limited fluorocarbon emissions would be considered acceptable, would concentrate on reducing existing emissions. Such emission reduction could be achieved by instituting new maintenance and repair procedures and redesigning certain component parts of existing systems. Also, recovering fluorocarbon refrigerants from discarded equipment would also be important in reducing emissions. This approach would also have a much more modest impact, economically, on both industry and consumers, than the banning of fluorocarbon use as a refrigerant.

Fluorocarbon use in foam blowing agents produces emissions that may be eliminated by switching to methylene chloride. Methylene chloride may act as a substitute for F-11 in producing flexible foams. This could eliminate approximately 60% of F-11 foam use. Although the use of other agents in foam use is possible, important insulating characteristics made possible by fluorocarbon use would be eliminated. In solvent applications, only one of the five primary chemicals, methylchloroform, is significant. Methylchloroform is used primarily as a cleaning solvent. Although substitute solvents are available, they are not compatible with existing equipment. Non-halocarbon cleaning systems, though available, are found to be more hazardous and expensive to operate. Reduced emissions can be achieved by using existing, but refined, solvent recovery systems which are often cost effective.

The industrial sectors that would be primarily affected from restricting the use of fluorocarbons would be producers of raw materials, aerosol producers, the refrigeration and air conditioning industry, the foam products industry, and solvent applications.

In the raw materials sector, the two principal chemicals used in the productio of halocarbons are chlorine and hydrochloric acid. Approximately 13% of chlorine output by weight, with an estimated market value of 60 million dollars in 1973, was used in the production of the five primary chemicals, F-11, F-12, F-22, methylchloroform and carbon tetrachloride. Approximately 42% of hydrofluoric acid output, with an estimated value of 55 million dollars in 1973, was used in the production of F-11, F-12 and F-22.

The value of F-11, F-12 and F-22 production was approximately 240 million dollars in 1973, while the value of output for carbon tetrachloride and methylchlor oform was approximately 590 million dollars. Since this sector is basically capital-intensive, the number of employees associated with the production of the five chemicals is small, totaling about 4,500.

In 1973, the aerosol sector had a manufacturing value estimated at 2 billion dollars. Three billion units were produced, approximately 60% of which were propelled by fluorocarbons. Aerosol cans are filled by two basic groups: contract fillers and aerosol product marketeers. The former comprises some large companies, but most are small firms who rely on contract filling for a major source of their revenue. The aerosol marketeers tend to be large corporations which have diversified operations and are therefore much less reliant on contract filling as an important source of revenue. Approximately 13,000 persons are employed in this sector.

The refrigeration and air conditioning sector is the largest, both in terms of value of output and persons employed. Output in 1972 was valued at 7.2 billion dollars, with employment estimated at 150,000. An additional 280,000 persons are indirectly employed. Although there are large automobile and appliance manufacturers that do not rely heavily on refrigeration and air conditioning as a source of revenue, there are many smaller companies that are heavily reliant on this line of activity for sales revenue. This sector would be most affected by any restrictions regarding the use of halocarbons.

The foam products sector, it is estimated, would be only moderately affected by restrictions governing the use of halocarbons because of their ability to use alternate products.

A qualitative economic analysis of the impact on industry following restrictions governing the use of halocarbons was made under several different regulatory scenarios. Three time frames were considered, six months, three years, and six years. Within each of these time frames, different degrees of regulation were considered.

These scenarios were defined following discussions with the EPA and are designed to identify an array of alternatives that may be considered in efforts to reduce emissions to various levels, and the economic considerations associated with these options.

The regulatory scenarios have a range of economic consequences for the affected industrial sectors that go from basically none to severe. One option would be to ban F-11, F-12 and carbon tetrachloride after six months. This would result in an estimated 92% decrease in projected U. S. emissions over a 20 year period. Narrowing that option to ban the use of these chemicals as propellants would decrease emissions by 70% over the 20 year period. Extending the time horizon from six months to three years, effective January 1976, produces new emission reduction levels of 63% and 54%, respectively.

Banning F-11, F-12 and carbon tetrachloride after six months would have a severe impact on contract fillers of aerosol cans, manufacturers of aerosol valves and the refrigeration industry. The aerosol marketeers would be only moderately affected. Extending the time horizon to three years would reduce the impact on contract fillers of aerosol cans and manufacturers of aerosol valves from severe to limited to moderate. The refrigeration industry might still be severely affect but it is more probable that the effect would be moderate. The impact on chemical producers for the six month and three year scenarios would remain the same, limite

If halocarbon emissions do affect the ozone layer, cost and benefits should be considered on a world-wide basis. Even though the United States accounts for approximately one half of total world emissions, it is believed our emission growt rate has stabilized and that future growth will occur outside the United States. Therefore, if effective emission control is to be achieved, world-wide cooperation would be necessary.

A.2. BUREAU OF DOMESTIC COMMERCE STUDY

ECONOMIC SIGNIFICANCE OF FLUOROCARBONS DECEMBER 1975

The purpose of this report is to assess the significance of fluorocarbon production and use in the U.S. economy. This industrial information has been gathered to augment the growing body of scientific information concerning the effects of fluorocarbon and other products on the atmosphere. The economic analysis of the significance of fluorocarbons is designed to identify and trace forward the linkages associated with this product. The analysis identifies the originating linkages, which are the chemical manufacturers of fluorocarbons as well as those industries dependent upon supplies of fluorocarbons. The analysis is further amplified to include data on production, employment, manufacturing considerations and investments of the associated industrial groups. Consideration is also given to the development of alternative products.

The Bureau of Domestic Commerce (BDC) has drawn heavily upon the A. D. Little Incorporated study which was sponsored by the Environmental Protection Agency and industry sources in preparing this report. The combined sources of data do provide a reasonably complete and up to date core of information. However, since the sources have been diverse and the intent of the original generation of this data were for different objectives, comparison of data must be made with care.

It should be noted that the economic analysis undertaken by this study is aimed at identifying and tracing the fluorocarbon linkages. It was not the purpose of this study to measure the economic impact of fluorocarbon restrictions such as changes in employment resulting from the manufacture of new or substitute products. Also, due to a lack of availability, no information concerning cash flows or profits have been included in this study. The report does include data regarding all of fluorocarbons, some of which are not currently suspected of adversely affecting the ozone layer.

In recent years there has been a growing concern over possible harmful effects to the earth's environment from man-made pollutants. One area that has been a focal point of attention has been the earth's stratosphere. The cause of this concern has been that man-made atmospheric emissions may be producing stratospheric changes that can have significant effects on human, animal, and plant life. More specifically, attention has been directed toward those chemicals which are accumulating in the stratosphere and have the potential to reduce the earth's ozone layer. A significant reduction in the ozone layer could result in an increased amount of harmful ultraviolet radiation reaching the earth's surface. It is proposed that this would result in increased levels of skin cancer as well as environmental and climatic changes of an undesirable nature.

Fluorocarbons and nitrogen oxides have been of particular interest because they tend to diffuse from the earth into the stratosphere with potentially adverse effects on ozone concentrations. The process by which this occurs is as follows: Hydrogen free fluorocarbons from refrigeration equipment, aerosol sprays, and solvents disperse into the stratosphere where high energy ultraviolet rdiation decomposes them. It is postulated that the decomposition process produces free chlorine atoms which are destructive to the ozone layer. The body of scientific knowledge has not been sufficiently developed to be able to prove or disprove this theory. There are a number of other products and natural phenomena that may account for variations in the ozone umbrella.

The Commerce Department agrees with the concern expressed in the inadvertant modification of the stratosphere (IMOS) report concerning the depletion of ozone by fluorocarbons. However, the Commerce Department is also concerned about prematurely restricting the use of fluorocarbons before more comprehensive research has been conducted and the results evaluated. This position is reflected in a statement by Commerce Secretary Rogers Morton which reads as follows: "In view of the uncertain scientific evidence on the effect of fluorocarbon use in the stratosphere's ozone shield I would like to emphasize the importance of obtaining more hard evidence from accelerated Federal R&D programs before making decisions on specific limitations on fluorocarbons' use. The Commerce Department sees this research as the most urgent focus for the national effort to resolve this problem. There is time to conduct a deliberate, well-thought out R&D program to determine the actual degree of danger before implementing regulatory action.

We all share concern for the possible impact of ozone reduction on human health and well-being; but since over a million jobs may be associated with the production and use of fluorocarbon products, decisions on any limitations and the timing of their implementation should carefully weigh the benefits against the adverse effects. There must be balanced consideration of the obvious impacts to the Nation of adoption of restrictions. Such impacts could result from unilateral U.S. restrictions without regard to international accord that would lead only to loss of trade for the United States without sufficient compensating environmental benefits. Additional impacts could result from insufficient consideration of the time required for industrial adjustment. I have every confidence that such considerations as these will be weighed very carefully against the environmental protection that could be achieved."[12]

The Department of Commerce through the Bureau of Domestic Commerce has promised to continue its investigation and analysis of the potential economic and industrial impact of fluorocarbon regulation. The BDC will approach this objective in two phases. The first phase covers the development of a data base on fluorocarbon production and its use in the U.S. economy, and is presented in this report. The second phase which is an economic impact study, will be undertaken to evaluate the economic impact of regulations to limit the use of fluorocarbons once such regulations are actually proposed. The results of this study, it is hoped, would prove useful to federal decision makers in assessing the effects of potential restrictions.

The United States is both the world's largest producer and user of fluorocarbons. However, there has been a rapid growth in the international use of fluorocarbons. The fact that fluorocarbons are produced and used throughout the world suggests the need for international cooperation in approaching the ozone question. The United States and Canada have taken lead positions in conducting an international survey on fluorocarbon use and production through the Environment Committee of the Organization for Economic Cooperation and Development (OECD). Members of OECD have also been asked to coordinate current and proposed research efforts in order to increase the effectiveness of these programs.

Report Summary

In 1974, six U.S. manufacturers of fluorocarbons produced just over 1.1 billion pounds of this product with a market value of slightly greater than $500 million. In the event restrictions were imposed on the production and use of fluorocarbons, five industrial sectors would be affected. These areas are primary fluorocarbon manufacturing, aerosol formulating, aerosol container and valve manufacturing, air conditioning, and refrigeration and plastics manufacturing

Of the thirty fluorocarbon compounds which have commercial significance three of these, F-11, F-12, and F-22 account for over 90% of fluorocarbon production and use in the United States. Of these three fluorocarbon products, F-11 and F-12 are produced in the greatest quantity and are used primarily as propellants in aerosols. One half of all F-12 production and three-quarters of all F-11 production are used as propellants in aerosol products, and it is these two fluorocarbons that are considered capable of depleting the ozone layer.

F-22 along with F-12 are also frequently used as refrigerants. F-12 is used most frequently accounting for 56% of total refrigerant production. Since F-22 is considered to be more reactive in the lower atmosphere than either F-11 or F-12, it is not considered at this time to be a primary contributor to the depletion of the ozone layer.

U.S. production of fluorocarbons accounts for almost 50% of total free world production. Twenty-two other nations account for the remainder. Nearly 5% of 1974 U.S. production, or 50 million pounds, was exported to more than 65 different nations with a market value in excess of $20 million. Consequently, the production or use of fluorocarbons is nearly world-wide.

The most important use of fluorocarbons may be in the refrigeration and air conditioning systems. This is because they are essential to food processing, storage, distribution and to a variety of medical and surgical applications. Between the years 1964 and 1973 approximately 210 million units of air conditioning and refrigeration equipment using fluorocarbons as refrigerants were produced.

Air conditioning and refrigeration equipment are designed to use a specific fluorocarbon as a refrigerant. A change to a substitute refrigerant cannot be achieved without costly redesigning. It has been estimated by BDC that the replacement value of the air conditioning and refrigeration equipment now in use exceeds $100 billion.

The release of fluorocarbons into the atmosphere can be significantly reduced through improved servicing techniques, while at the same time controlling the retrieval and recycling of refrigerants once the useful life of the equipment in which they were contained is at an end.

In 1974, there were approximately 2.8 billion filled aerosol units shipped with a market value of approximately $2.6 billion. Nearly half, or approximately 55% of these products use fluorocarbons. Nearly 90% of all fluorocarbons used as propellants are found in personal care products such as hair sprays and deodorants.

Nearly 1.5 million jobs are either directly or indirectly connected with fluorocarbon production or use, which accounts for approximately 1.7% of the total employed labor force of 8.59 million in 1974. Of the 1.5 million positions, approximately 600,000 or more are directly tied to fluorocarbon production and use. Fluorocarbon dependent employment is most significantly tied to the refrigeration and air conditioning industry which accounts for approximately 83% of this 600,000 figure.

Suitable substitutes for fluorocarbons in commercial and industrial applications are not readily available. Further, the time horizon required to develop replacement products may require a decade or more. Although industry has a number of research programs currently in progress the consensus is that there is no expected technological breakthrough that might change this picture. It is also estimated that any substitute products would be more expensive than those currently in use.

Fluorocarbons are used almost exclusively as the refrigerants in air conditioning, heat pump equipment, and in refrigeration. Existing substitutes for fluorocarbon refrigerants all have serious deficiencies such as flammability, toxicity, and chemical or thermal instability. Manufacturers of air conditioning and refrigeration equipment continue to seek and improve refrigerants. However, this is little evidence to prompt optimism over such a product becoming commercially viable in the immediate future.

There is also not available at this time a suitable substitute for fluorocarbon propellants in aerosol products. The fluorocarbons F-11 and F-12 are used as propellants primarily in personal care products because of their fine, well controlled spray. Present alternatives include pump sprays, roll-on applicators, emoillent creams and lotions. The possibility of using alternative propellants is limited either because the propellant has hazardous characteristics, such as the flammability of propane, or the spray characteristics of the substitute may be too coarse or too cold to permit them to be used in personal care products. Industry indicates that there is nothing on the horizon that would serve as a suitable substitute for the fluorocarbons F-11 and F-12.

Another area associated with fluorocarbon production includes other chemicals essential to the manufacturing process. Several chemicals used almost exclusively for fluorocarbon production include chlorine carbon disulfide, hydrochloric acid, carbon tetrachloride, and chlorofoam. Nearly all of the carbon tetrachloride and chloroform produced are used in the manufacture of fluorocarbons. In 1974, the market value of all these associated chemicals totaled approximately $340 million.

Fluorocarbons have been successfully used to achieve substantial energy and materials conservation. In the manufacture of air conditioning and refrigeration equipment, fluorocarbon refrigerant systems have been found to be three to four times more energy-efficient than absorbtion systems such as the Lithium Bromide-water cycle and amonia water systems. Material conservation has been achieved by using fluorocarbons in the manufacture of foamed plastics for thermal insulation, because of its greater thermal efficiency.

A.3 FLUOROCARBONS AND THE ENVIRONMENT REPORT OF FEDERAL TASK FORCE ON INADVERTANT MODIFICATION OF THE STRATOSPHERE (IMOS)

The interagency task force on inadvertant modification of the stratosphere (IMOS) conducted a five month study of the effect of fluorocarbons (F-11 and F-12) on the earth's ozone layer. These fluorocarbons have their widest use as refrigerants and propellants for aerosol products. It was found that F-11 and F-12 are not destroyed in the lower atmosphere by chemical reaction, but slowly diffuse and move upward to the upper atmosphere. When they reach the stratosphere, they are decomposed by ultraviolet radiation and produce free chlorine atoms. Then through a catalytic chain reaction, the free chlorine atoms act to gradually decrease the ozone layer. It has been estimated that the fluorocarbon chlorine chain is three times more effective at reducing the ozone layer than the nitrogen oxide chain caused by NO_X emissions from aircraft flying near or in the stratosphere.

In its natural state ozone is concentrated in the atmosphere where an equilibrium level is maintained through the continual formation and destruction of ozone. The significance of the fluorocarbon chlorine change is that it decreases the ozone layer which permits an increased amount of harmful ultraviolet radiation to reach the earth's surface. The heightened ultraviolet radiation levels may induce skin cancer, as well as affect the growth and development of certain plant and animal species. Further concern is expressed over the effect on the climate due to significant changes in the stratosphere.

Stratospheric Effects

The possibility of ozone reduction due to F-11 and F-12 has been carefully studied by a number of scientists. Although they have not been able to take direct atmospheric measurements of ozone reduction, none of the effects have produced seriously conflicting results regarding the theory of ozone reduction, nor on the magnitude of ozone reduction due to F-11 and F-12. The finding of fluorocarbon levels in the atmosphere, in amounts consistent with the world-wide release of these elements to date, seems to offer corroborating support for the ozone theory.

Several independent research efforts regarding the reduction of ozone due to varying use patterns for F-11 and F-12 have produced similar findings. The release of fluorocarbons to date has resulted in a 0.5% to 1% reduction in ozone, with the possibility that the reduction might be as high as 2%. Since it takes a considerable period of time for released F-11 and F-12 to reach the stratosphere, it is felt that if no further releases were made that ozone reduction would continue and approach a magnitude of 1.3% to 3%. Moreover, the ozone reduction theory suggests that further reduction in the ozone layer will continue for about ten years subsequent to the discontinuance of fluorocarbon releases into the atmosphere. This would be followed by a very slow period of recovery in which we would not see the re-emergence of normal ozone levels for perhaps a century or more.

These forecasts would have to be re-examined if a major natural chlorine sink were discovered or if chlorine were found naturally in such large quantitities as to dwarf the man-made chlorine levels found in the atmosphere. The latter would suggest an insufficient understanding of stratospheric dynamics.

There are uncertainties associated with the projected decreases in the ozone layer due to F-11 and F-12. These uncertainties have not been sufficient to dampen the expressed concern of the effect of F-11 and F-12 on the atmosphere. The assumptions of the model could be tested by measuring the change in the equilibrium level of ozone in the stratosphere over time. However, such measurements must be made against the background of ozone's natural variability. These natural variations occur from day to day, season to season, and at different latitudes. The magnitude of these natural variations is many times larger than those attributed to man. Consequently, in order to measure a change attributable to human activity, a persistent decrease in ozone of 5-10% would be required. In addition, it would also be necessary to measure this activity over a period of several years.

There is an important difference between the natural variations in ozone and the reduction in ozone due to human activities. The former is a change in the level of ozone concentration from one place to another, but not in the average level of ozone in the stratosphere. The man induced reductions in ozone affect the average ozone level and consequently increase the level of ultraviolet radiation reaching the earth's surface.

It is estimated that carbon tetrachloride (CCL_4) has produced a 0.5% to 2% decrease in the ozone layer to date. However, it has not been determined whether the carbon tetrachloride measured in the troposphere is due to human activities or natural sources, or both. Although the use of carbon tetrachloride has been restricted, the effect of this constituent on the stratosphere is cause for concern and should be the basis for subsequent study.

Biological Effects of Ozone Reduction

There is considerable clinical and epidemiological evidence available which supports a direct linkage between solar radiation and skin cancers (non-melonoma) in humans. The incidence of non-melonoma skin cancers doubles for every 8° to 11° decrease in latitude. This change in incidence is presumed to relate to the increased level of ultraviolet radiation which reaches the earth's surface at decreased latitudes. It is estimated that every 1% observed decrease in ozone due to a decrease in latitude produces 2100 to 15,000 new cases yearly of non-melonoma skin cancers in the United States, in light skinned individuals. Estimates by the National Cancer Institute show that the incidence of non-melonoma skin cancers in the U.S. is approximately 300,000 per year. Though not supported by direct human measurement, this link between non-melonoma and ultraviolet radiation is strongly supported by clinical and epidemiological statistics on animals, which show that an increase in exposure to ultraviolet radiation produces an increased incidence of non-melonoma.

In addition to the linking of ultraviolet radiation to skin cancer, there are other expected health effects. One is an expected increase in the general level of sunburning, with its attendant side effects, one of which may be earlier skin aging. Other possible effects are eye damage and excessive synthesis of vitamin D in the skin. These last two areas would require further study before a more definitive statement regarding cause and effect could be offered.

Other life forms show great sensitivity to ultraviolet radiation. Therefore, a general increase in the cumulative exposure to ultraviolet radiation may have important biological and agricultural consequences. This may be reflected in the following ways: changes in the physiological, anatomical, biochemical, and growth characteristics of certain animal and plant species. In addition, health effects on livestock, alterations to the balance of aquatic and terrestial eco-systems, and changes in the effectiveness of the stability of agricultural chemicals. These effects should be viewed as tentative and subjected to further investigation.

Fluorocarbon Industry

The fluorocarbon industry in the United States consists of six producers. World-wide production includes another 48 or more producers in 23 additional nations. The U.S. production of fluorocarbons had been increasing at a yearly rate of 10% to 20% or doubling approximately every six years. However, in 1974 aerosol sales were 5% - 10% less than they were in 1973 (aerosol sales account for nearly one-half of all fluorocarbon production). This accompanied by an absence of scheduled new facilities for fluorocarbon production over the next three years, may indicate a slowing in the U.S. production and the use of fluorocarbons. It is estimated that U.S. consumption of fluorocarbons may be near its saturation point and that increased consumer demand would come from other countries. 90% of the fluorocarbons used in aerosol products are for personal care products such as: hair care items, deodorants, anti-perspirants.

Nearly 30% of the U.S. fluorocarbon production is used the the refrigeration industry for residential, commercial, and automobile air conditioning, and for food storage and display purposes. Fluorocarbons are also used in the production of foams, and as fire extinguishers.

Fluorocarbons have properties that make them especially suitable as propellants in personal care products such as a fine well controlled spray. A suitable substitute for fluorocarbons has not yet been found for personal care products, but substitute propellants are more readily available for other aerosol uses. In addition, roll-on deodorants and manual sprays have maintained a share of the personal care market for many years.

In the refrigeration process, suitable substitutes for fluorocarbons are basically not available at this time. F-22 which now accounts for 30% of the refrigeration market might act as a substitute for F-11 and F-12 (F-22 is considered less of a stratospheric hazard because it has greater expected chemical reactivity in the lower atmosphere). However, equipment designed to handle F-11 and F-12 could not be converted to handle F-22 without costly redesigning. The use of non-fluorocarbon substitutes does not appear to hold promise because in addition to the redesigning costs these compounds (i.e., ammonia) may be toxic or have other undesirable characteristics.

Substitutes can be developed; however, it is estimated that they would be expensive and would require a considerable amount of time. Consequently, restricing fluorocarbon use in the refrigeration industry could have consierable economic consequences. One way to approach the potential need for restrictions would be to reduce leakages and to develop a system for recovering fluorocarbons when the units in which they are contained are ready for disposal.

There is insufficient data available to evaluate the impact of restricting fluorocarbon use in the refrigeration and aerosol industries. However, some general observations can be made. The refrigeration industry accounts for approximately $5.5 billion of gross national product while the aerosol industry accounts for an additional $2 billion. Approximately 1 million jobs are associated with fluorocarbon production and use. Within this framework, the extent to which industry may be affected by possible restrictions, is to a large extent dependent upon the severity of the restrictions and the period of time industry will have to adjust to new standards.

Federal Structure to Cope with Fluorocarbon Emissions

Three existing federal agencies have jurisdiction over all consumer products that release fluorocarbons. The Food and Drug Administration has responsibility for food, drug, and cosmetic products that use fluorocarbons, the Environmental Protection Agency has similar responsibility for fluorocarbon propelled insecticides, while the Consumer Product Safety Commission has responsibility for all other consumer aerosol products that are fluorocarbon propelled. In the area of industrial and commercial applications, such as refrigeration, air conditioning, including automobile air conditioning, foaming agents, and fire retardants, there is presently no federal authority to control the use of fluorocarbons. There is proposed legislation in the form of Toxic Substance Control Act. This legislation if passed, would provide federal regulatory authority to control uses of any substances which may have a potential to harm the environment.

The findings of the task force are that fluorocarbons released into the atmosphere have potentially harmful environmental effects, and are therefore cause for concern. Further, in the absence of scientific data to reduce this uncertainty it would appear necessary to limit the use of F-11 and F-12 to closed recycling systems and to the replacement of fluids in refrigeration and air conditioning equipment.

If an indepth study on the subject by the National Academy of Sciences confirms the evaluation of fluorocarbons on the earth's environment by the task force, then restrictions on the use of fluorocarbons would be recommended. Such restrictions could be put into effect by January 1978. The selection of this date would permit the development and evaluation of existing research efforts, as well as give the effected industries and consumers time to adjust to the new circumstances.

Since the emission of fluorocarbons into the atmosphere has global significance, international cooperation is essential. The U. S. State Department will foster the international exchange of information and cooperative research. Should restrictions prove necessary, efforts will be made to bring about a uniform policy on a global basis.

A.4 DEPARTMENT OF TRANSPORTATION

CLIMATIC IMPACT ASSESSMENT PROGRAM

EFFECTS OF STRATOSPHERIC POLLUTION BY AIRCRAFT

This report is the result of Congressional legislation which directed the Department of Transportation to mount a government effort to gather and develop the knowledge needed to evaluate the impact on the environment of SST flights. The legislation was prompted by discussions in 1970 regarding proposed SST flights.

Questions were raised as to the effect of stratospheric flight (over 39,000 feet) on the proportion of trace constituents in the atmosphere. More specifically, could high flying aircraft destroy trace constituents with harmful effects to the environment. The trace constituents are significant because when in natural balance, they screen out harmful radiation and help maintain the earth's temperature level.

During the course of the discussions on SST flight, it was recognized that there was not a sufficient understanding of the dynamic and chemical behavior of the atmosphere and the effect changes in the atmosphere would have on the earth's climate and lifeforms. It was noted that almost all flights were made in the troposphere, where rain and turbulence permit cleansing of most impurities within a few days or weeks. The stratosphere is not able to cleanse itself because of its virtually stagnant nature. Temperature in the stratosphere is either constant or increases with altitude, which are the conditions for a permanent air inversion and account for the slow cleansing process of several years. Further, impurities released in the stratosphere disperse horizontally so that SST flights anywhere tend to effect the atmosphere globally.

Jet aircraft emit effluents in the form of: carbon dioxide (CO_X), nitrogen oxide (NO_X), and sulfur dioxide (SO_2). In the troposphere these effluents are dispersed and then removed by rain and turbulence. When these effluents are released in the stratosphere, they remain there much longer and are dispersed throughout the upper atmosphere. One way these effluents can adversely effect the environment is by decreasing the equilibrium amount of ozone. This increases the amount of ultra-violet radiation reaching the earth's surface with possible biological and climatological effects.

In this study, C.I.A.P. seeks to evalute whether or not future SST aircraft will adversely effect the environment. In order to do this, modeling of stratospheric dynamics required further development. Little was known of how climate affects production, and only inferential conclusions could be drawn concerning the effects of ultraviolet exposure on skin cancer. The study has produced refinements in modeling techniques which clarified many of these and other questions.

The C.I.A.P. study has also helped to define which chain of events have potentia danger and which do not, and the standards needed to maintain a predetermined level of protection, along with the cost of this protection. Of the several sources of ozone pollution that were examined, two effects were isolated because of their potentially dangerous effects during the next thirty years: the ultra-violet effect and the climatic effect. These two chains can be effected by the increase in engine emissions which follow from an increase in the size of either the SST of sub-sonic fleets. These effects can be controlled by limiting the number of flight hours made especially at high altitudes.

The UV Chain is impacted upon this way: high flying aircraft give off NO_X, addi to the amounts found naturally in the stratosphere. Through a complicated process, the NO_X reacts with ozone in such a way as to reduce the ozone layer. This decrease in the ozone layer permits an increased amount of ultra-violet radiation to reach the earth's surface. However, measurement of the ozone layer is complicated by natural events. On any given day, the ozone layer may vary from 300% to 30%. Further, the distribution changes daily and monthly so that daily fluctuations of 25% are commonplace, along with 10% annual changes in the mean value. Within this framework, C.I.A.P. has estimated that the man-made changes in the ozone layer are presently at a level of 0.5%.

The size of the supersonic fleet was estimated to be between 12 and 30 aircraft, averaging approximately 1 hour of flight per day. This level of SST flight, it was judged, might reduce the ozone layer by 0.01%. The sub-sonic fleet has a 10 times greater impact on ozone depletion. However, the potential for ozone depletion lies with the SST fleet as it increases in size. To prevent ozone depletion from exceeding 0.5% from an SST fleet of 500 aircraft would require a four-fold reduction in engine emissions. The development of such an engine would require approximately ten to fifteen years of additional research and development before becoming operational.

The future sub-sonic fleet, it is estimated, would generate more NO_X emissions than the current fleet. The new wide body aircraft, for example, generates 2 1/2 times more NO_X emissions than their older counterparts such as the 707 and DC8. The reason for the greater potential emissions is due to the increased altitude at which these aircraft fly. In addition, the future generation wide body aircraft, the 747SP, will have the capability of flying still higher and faster than present sub-sonic aircraft.

Biological Effects of Ozone

It is estimated that for every 1% decrease in ozone there is approximately 2% increase in ultra-violet flux which causes sunburn and possibly skin cancer. The connection between UV radiation and skin cancer has not been proven by experiments on humans, but is inferred from a epidemiological statistic of humans and laboratory experiments with animals. The data suggests that skin cancer in humans may be brought on by exposure to UV radiation in the wavelength of 290 to 320 nanometers[1]. The following statistical data is offered in support of this:

--Non-fatal skin cancer (non-melanoma) occurs primarily on the exposed parts of the body, particularly on the hands and face.

--Fair skinned individuals, who tend to burn and not tan, are more disposed to non-melanoma.

--Skin cancer seems to be the result of cumulative exposures to the sun since most cases occur to individuals in the 30-80 age range.

--The incidence of non-melanoma is correlated with both latitude and sunlight; average sunlight varies with latitude.

If UV radiation is considered the only factor causing non-melanoma, dismissing other agents whose role has not been fully determined, then it is estimated that a 0.5% decrease in the ozone layer will produce a 1% increase in ultra-violet radiation, which in turn will produce a 1% increase in non-melanoma. A similar 0.5% decrease in ozone could be caused by a fleet of 125 SST aircraft with current engine emissions characteristics. These results have added significance because non-melanom is fairly common, effecting about 250 persons per 100,000 fair skinned individuals in the United States. The disease, though rarely fatal, is expensive to treat, appro: imately 200-400 dollars per case, and is unpleasant.

Climatic Influences

Aircraft emissions, primarily sulfur dioxide (SO_2) and to a lesser extent water vapor (H_2O) and nitrogen oxide (NO_X) can produce changes in temperature, wind and rainfall. These constituents of engine emissions are in the form of particles. If a sufficient number of particles greater than 0.1 micrometers in diameter are added to the stratosphere they could affect the climate by altering the earth-sun radiative heat transfer system. The increased SO_2, engine emissions that would be generated by a growing SST fleet, therefore, holds potential concern. With existing engine emission characteristics, this potentially harmful effect can be curbed by reducing the hours of SST flight, or the sulfur content of aviation fuel.

There are two ways that SO_2 affects the atmosphere and the climate. First, oxidized stratospheric SO_2 interacts with water vapors which produce solid sulfuri acid particles that build up to sizes greater than 0.1 micrometers in diameter. These particles are then dispersed within the stratosphere where they may remain f as long as three years depending upon the altitude they were emitted. These parti tend to increase the stratosphere's opacity to incoming light which then causes a cooling effect on the earth's surface. Secondly, some of the radiation being reflected from the earth's surface to space, are intercepted by these particles and are reflected back to earth again which produces a warming, or greenhouse, effect. The cooling effect is estimated to be 3 times more dominate than the warming effect producing a net decrease in temperature at or near ground level. This decrease in global mean temperature then affects wind and rainfall in complicated ways. Part of this cooling effect, it should be noted, is reduced by the influence of H_2O particles. These particles absorb and emit strongly in the infrared region of the spectrum and produces its own warming or greenhouse effect. The water vapor effect is estimated to be 1/2 the cooling effect due to SO_2. The estimates of both the water vapor and SO_2 effect are characterized by similar degrees of uncertainty.

The NO_2 particles have a dual effect on the atmosphere, which seem to offset one another. One effect tends to reduce the cooling influence while the other a warming influence. Uncertainty concerning the estimates of the magnitude of these influences could favor one effect or the other. Present data suggests that the NO_2 effect is less than the SO_2 effect.

The net effect of a change of global mean temperature on agriculture is both complicated and uncertain. The significance of such a change would be in terms of how local rainfall and growing season length would be effected. These changes could be most significant in marginal areas like the northern border of the wheat belt where a small reduction in the growing season due to a cooling effect could have serious consequences. Some of these losses may be offset by gains in other marginal areas. However, it is estimated that a 1% decrease in global mean temperature could result in a net loss of hundreds of millions of dollars annually in crops.

Measuring changes in temperature is somewhat similar to measuring changes in the ozone layer from the standpoint that there is a great natural variability to temperature. From year to year and over tens of years there are warming and cooling trends amounting to several tenths of a degree. Additional changes in temperature due to aircraft SO_2 emissions could have significant costs attached to it. Using low sulfur fuels, even with the added cost of 1/2 cent per gallon seems much less than the cost associated with crop damage from not de-sulfurizing.

Monitoring

In addition to the emissions from aircraft, more than thirty factors contribute to changes in ultra-violet radiation at ground level. Similarly, many factors contribute to changes in the annual mean temperature besides aircraft pollution. What is needed is a monitoring system that can identify and estimate the contribution made from several different sources, so as to establish a baseline. An on-going monitoring system is also essential for the refinement of analytical models used for measurement. A direct product of such a program would be a decrease in the uncertainties of present data and permit more accurate control. An improved monitoring system would generate more data with greater accuracy. This would permit more accurate policy decisions, insure environmental safety and reduce the costs associated with over-regulation that might be necessary to protect the public in the absence of reliable data.

A.5 ENVIRONMENTAL IMPACT OF STRATOSPHERIC FLIGHT

NATIONAL ACADEMY OF SCIENCES 1975

The U.S. Congress, shortly after deciding not to provide funding for the development of a supersonic transport fleet, authorized that research be conducted to gather scientific data to permit the evaluation of the effects of high flying aircraft on the stratosphere. This authorization was given to the Department of Transportation in 1971. The DOT was to advise Congress on its findings by the end of 1974. It was the wish of the DOT that the National Academy of Sciences (NAS) act as advisor as well as issue an independent report. This report represents the findings of the Academies Climatic Impact Committee, which was appointed by the NAS, and is based on two years of hearings.

Some of the characteristics of the earth's atmosphere vary with latitude. Near the poles as distance from ground level increases temperature decreases to an altitude of about 26,000 feet. Near the equator this temperature decrease continues to an altitude of about 52,000 feet. This area, where temperature decreases as altitude decreases, is known as the troposphere, and is characterized by normally well-mixed air. The area above this, the stratosphere, is more stagnant in nature. As you ascend into the stratosphere, temperature no longer decreases with increases in altitude. This characteristic denotes an area of temperature inversion, or where vertical mixing is occurring at a very low rate.

The present SST fleet is expected to cruise at an altitude of 54,000 feet, while present subsonic fleets cruise at an altitude of 40,000 feet. The high cruising altitude of the SST's places them in the stratosphere where their engine emissions may remain for years, before they move down into the troposphere where they are removed by wind and rain. While vertical mixing is slow, horizontal mixing is fairly rapid and extensive. Due to their higher cruising altitudes SST's have more potential for stratospheric modification than the present subsonic fleet. However, future generation SST and subsonic fleets will fly at still higher altitudes, thereby enhancing the problem of engine emissions in the stratosphere.

The engine emissions that are of concern are nitrogen oxide NO_X, and sulfur dioxide, SO_X. Nitrogen oxide can cause a reduction in the ozone layer and absorb visible sunlight. A lower level of ozone permits increased amounts of solar radiation to reach the earth's surface, which has biological and climatological consequences. Plant and animal life, as we know it, may be altered by a reduction in the ozone layer which would change the environment in which these life forms evolved. The sunlight absorbtion characteristics of nitrogen oxide could also produce small net changes in temperature at the earth's surface. This may also be accompanied by small changes in the level of rainfall. These small changes may have significant agricultural consequences. SO_x, which is emitted in minor levels, leads to the production of sulfate aerosols. These aerosols slightly reduce the solar radiation reaching the earth's surface, and may have an effect on climate.

It is not known at present whether the combined effects of NO_x and SO_x will produce an increase or decrease in temperature, although the latter seems more likely. Temperature changes of more than a few tenths of a degree seem unlikely even for a large fleet of SST's. The redistribution of rain would be difficult to assess. The tropical regions would be least affected, while the sub-polar regions would experience larger changes. Marginal farming in the sub-polar region may disappear due to shorter growing seasons and increased temperature variability. It is not possible to determine at this time whether these changes would be beneficial or not.

The period of time the DOT's Climatic Impact Assessment Program has been underway is too short to permit full evaluation of the effect of ultraviolet

(UV) radiation on life forms. However, the deleterious effects of U.V. radiation on higher plant forms has been inferred from laboratory experiments. The effect on human beings of UV radiation is skin tanning and sunburn. Decreased ozone levels would increase skin tanning, sunburn, and skin cancer due to increased UV radiation.

There are two forms of skin cancer. Nonmelanoma is found in older people suggesting a cumulative effect over many years. Death is rare, being one in 100,000 population. Nonmelanoma is easily diagnosed and can be successfully treated with x rays and surgery. This disease effects the sun-exposed areas of the body. It is also a recurring illness that can result in disfigurement. Melanoma is the more dangerous form of skin cancer, with a few deaths per 100,000 population annually. This disease affects individuals in the 30 to 50 age range. This disease also affects the sun exposed or lightly covered areas of the body. Statistics show that the incidence of this disease is greater for light-skinned caucasians, and at low altitudes, than for darker skinned groups at higher altitudes. These facts suggest a strong probability that the incidence of skin cancer is connected with increased exposure to solar radiation.

The potentially harmful effects of ozone reduction caused by SST flights on climate and life forms may be controlled in a number of ways. Existing aircraft engines may be modified so as to reduce NO_x emissions. However, while technically feasible, this would require technology and materials that are not currently available. Fuels can be desulfurized to reduce SO_x emissions. The technology for sulfur reduction is available but it will increase fuel costs. Emission reduction can also be achieved by limiting SST flight over certain altitudes, either in part or in total.

Deciding which emission control option to select would be a very difficult assignment for a single nation, since the actions of other nations must be taken into account as well. The most effective approach lies in international cooperation. The organizations needed to achieve multinational goals already exist. The International Civil Aviation Organization (ICAO) sets minimum standards for member nations to follow. Most nations belong to ICAO and have adopted their standards. However, on engine emission standards for stratospheric flight ICAO concluded that the primary responsibility rests with the World Meteorological Organization (WMO). The WMO would have responsibility to monitor changes that take place in the stratosphere.

Although there is uncertainty associated with measuring the climatic effects of engine effluents on the stratosphere, those effects associated with human well being can be measured with greater accuracy. The effects of aircraft emissions on the stratosphere are better understood. Methodological imperfection still exists none the less. The NAS Panel on Atmospheric Physics and Chemistry has concluded that a decrease in the ozone layer can be achieved by the emission of NO_x into the stratosphere. Further, if the size and engine characteristics are known along with traffic routes and flying hours the magnitude of the decrease in the ozone layer can be predicted. This in turn will permit increased levels of U.V. radiation to reach the earth's surface, which can also be predicted.

Based upon the modeling just described a fleet of 300 to 400, previously considered U.S. type, SSTs would in most likelihood produce a 10% decrease in ozone and an increase in skin cancer of about 20%. Similar results can be achieved by a new generation wide body subsonic fleet. The data supports the contention that a large number of aircraft flying in the stratosphere will produce increased levels of skin cancer.

A. 6

Aircraft Emissions: Potential Effects on Ozone and Climate

A Review and Progress Report

Prepared for

High Altitude Pollution Program

by
Institute for Defense Analyses

This report presents a critical review of the State-of-the-Art (as of 1976) modeling of ozone reduction and climate change due to aircraft emissions. The review indicates that effects of the emissions are highly dependent on the altitude at which they are injected. The large uncertainties present in the models emphasize the need for further research. In fact ongoining research may change the nature of the results reported.

The report reflects on and compares with several previous studies (CIAP, 1974; NAS, 1975; COMESA, 1975). Consideration is given to stratospheric chemistry as altered by the chlorine chains (NAS, 1976).

The report indicates uncertainties larger than had previously been indicated. The fleet growth rates projected by CIAP were considered to be high. The NO x emission index may be several-fold low, and emission reduction schedules envisaged in CIAP may be hard to realize. Larger uncertainties about ozone chemistry as affected by NO x and more complexies exist than was previously recognized. The current chemistry indicated possible ozone enhancement at certain altitudes. Climatic modeling efforts have addressed individual species rather than a comprehensive emphasis on the overall effects of aircraft exhaust.

Problem areas were identified. They are as follows:

1. Improved NO_x emission data and forecasts are needed. Estimates should be made as a function of altitude, latitude and season.
2. More detailed regional study is needed in the primary air traffic corridor: 30° to 55° N at altitudes 6Km to 20Km.
3. Additional measurement and study is needed for ozone-forming reactions, reactions involving the HO_2 radical, and reactions forming and/or destroying HNO_3, NO_3, N_2O_5 and .
4. Ozone reduction models should incorporate stratespheric NO_x, chlorine, and water content.
5. The transport, chemistry, and climatic impacts of stratospheric water vapor should be given more attention.
6. Modeling uncertainties for ozone should be reduced. Present uncertainties in 1-D, 2-D and 3-D models are unacceptably large.
7. Overall interactive effects of aircraft exhausts on climate should be modeled. The feedback effects will require at least a 2-D model.
8. The problems associated with the monitoring of aircraft effects will require additional study, measurements, and modeling. The many potential sources of ozone change (aircraft NO_x, solar proton fluxes N_2O from fertilizers and power plants, halocarbons, etc.) should be separated in time and place where effects could most easily be discerned. Model exercises are necessary to guide efforts aimed at distinguishing among these presently small and complex effects.

A. 7 Halocarbons: Effects on Stratospheric Ozone

Panel on Atmospheric Chemistry
Assembly of Mathematical and Physical Sciences
National Research Council

National Academy of Sciences

Concern over human effects on stratespheric ozone was first raised in investigations of the possible effects of stratospheric aircraft flight. Several species were hypothesized to catalytically reduce the equilibrium level of stratospheric ozone. Among these species were chlorine compounds which may derive from chlorofluoromethanes (CFMs) used in spray cans, refrigeration units, and some industrial applications. This report concerns the effects of these chlorine compounds on stratospheric ozone.

A conclusion reached in the report is that long term release of F-11 and F-12 at present rates will cause an appreciable reduction in the amount of stratespheric ozone. Specifically, continued release at 1973 production rates would potentially cause the ozone to decrease steadily until a reduction of 6 to 7.5 percent is reached with an uncertainty range of 2 to 20 percent, using about 95 percent confidence limits. The time required to attain 1/2 of this reduction would be 40 to 50 years.

Study of the problem was broken into the following parts: a) release rates, b) transport, c) stratospheric chemistry and d) other factors.

The completeness and reliability of data on past production of CFM's has been significantly improved. The uncertainty as to the total amount of F-11 and F-12 produced has been reduced to 5 percent. A one dimensional model has been used to estimate the transport of CFM to the stratesphere. The estimated uncertainty is a factor of $\pm$ 1.7 in the predicted amount of the globally averaged reduction (a three-fold range). Stratospheric chemistry modelers also employed 1-D techniques. Uncertainties in seven of the rate constants cause a five-fold uncertainty range in predictions of ozone reduction by CFM's. Additional uncertainties in the photochemical processes and the concentrations of natural species are estimated to increase the overall uncertainty range associated with stratospheric chemistry to a six-fold range. Other factors contributing to the uncertainty are 1) Inactive Removal; 2) Competing Reactions; 3) Feedback Mechanisms; 4) Natural Sources of Stratospheric Chlorine and 5) Overall uncertainty in ozone reduction.

No direct verification of model predictions has been accomplished due to inadequate measurement and monitoring capabilities. It is pointed out, however, that if current CFM production rates continue, significant change will be unavoidable by the time current monitoring systems detect the problem. It is also pointed out that world-wide regulation is needed for effective reduction of CFM related damage.

A.8

Halocarbons: Environmental Effects of Chlorofluoromethane Release

Committee on Impacts of Stratospheric Change
Assembly of Mathematical and Physical Sciences
National Research Council

National Academy of Sciences

The report concluded that CFM releases to the environment are a legitimate cause for concern. Moreover, unless new scientific evidence is found to remove cause for concern, it would seem necessary to restrict uses of F-11 and F-12.

Findings

A. CFM's in the stratosphere increase the absorption and emission of infrared radiation. This retards heat lossed from the earth and thus affects the earth's temperature and climate.

B. CFM's eventually rise to the stratosphere where they decompose and cause catalytic reduction of ozone. Results of this are 1) more biologically active ultraviolet radiation reaches the earth's surface and 2) temperature distribution is altered.

C. Direct verification of ozone reduction due to CFM's will not be feasible for several years.

D. Large uncertainties exist, but continued release of CFM's at the 1975 level is estimated to reduce ozone by 2 to 20 percent.

E. Continued CFM release at the 1975 level may produce significant climate effects by the year 2000.

F. At the present state of knowledge it is imprudent to continue increasing the rate of CFM production.

G. Advances in knowledge of climatic mechanism are needed to improve assessment of the climate effects. Climatic effects will still be less precisely known than ozone effects.

H. Improved measurement programs will improve predictions of ozone reduction.

I. Many improvements in knowledge are attainable, but others will take longer to attain.

J. If CFM releases continue at a constant rate, it will take approximately 50 years to reach one half of the steady state value.

K. After a drastic reduction in CFM releases ozone reduction would continue to increase for at least a decade before subsiding.

L. If CFM use were to continue at a oonstant rate, approximately 50 years would be required to reach 1/2 the steady state climatic effects.

M. Climatic effects due to infrared absorption and emission would decrease almost immediately after a reduction of CFM release.

N. Effects of Increased Ultraviolet Radiation would be:

Increased incidence of malignant melanoma

Increased incidence of basal-and squamous-cell carcinomas

Effects on plants and animals of unknown magnitude

O. The most important impacts of climate change would be on agriculture particularly in "boundary-regions".

P. Worldwide CFM releases grew 10 percent in 1974, but declined 15 percent in 1975, primarily due to decreases in US releases.

Q. Uses of CFM's differ significantly in magnitude and importance.

R. Reducing CFM production in 1978 and 1980 would alter ozone reduction by only 1/6 percent.

S. Halving CFM uses in 1978 or 1980 would alter the total amount of CFMs in the atmosphere by no more than 10 percent of the amount now present.

Recommendations

1. Selective regulation of CFM uses and releases should be undertaken based on ozone reduction.
2. There should be periodic reviews of the state of knowledge and uncertainties in climate modeling.
3. Regulations should be considered based on each end use of the CFM.
4. Steps should be taken to provide legislative authority for regulation of CFMs.
5. Informative labeling on products containing F-11 and F-12 should be undertaken.
6. Other regulations should be postponed for two years pending the results of ongoing measurement programs.
7. Other countries should be encouraged to cooperate with US regulations.
8. Measurement and research programs should be given high priority in order to expedite resolution of uncertainties.
9. Long term research programs should be started to study 1) mechanisms of climate change and 2) effects of UV on plants and animals.
10. A program to identify the most susceptible groups of people to UV damage should be undertaken.
11. Information about the relative release of CFMs from different uses should be gathered.
12. Study of possible preventative medical actions for UV damage should be gathered.

APPENDIX B

An Example Application

of Equation (3):

The "Time-to-Detection" Curve

APPENDIX B

An Example Application of Equation (3): the "Time-to-Detection" Curve

The purpose of this appendix is to illustrate, via example, the nature of the variable defined in (3):

$$\bar{B} = \frac{\hat{\sigma}_u}{\sqrt{t-\bar{t}^2}} \left[t_c^{.025}(n-2) + t_c^{.05}(n-2)\right]. \tag{B-1}$$

$\bar{B}$ is the smallest trend that can be expected to be detected at the .05 significance level with n observations against a null hypothesis trend of 0 tested at the .05 significance level with a two tail test, where $\hat{\sigma}_u$ is the estimate of the standard deviation of the disturbance term. Since this is not a standard concept employed in statistical analysis, it is thought that an example may prove useful to some readers.

Assume the true, but unknown, relation is

$$\tilde{Y}_t = 1 + .10t + U_t^N \tag{B-2}$$

where t is time and U_t^N is the natural disturbance term. Let t be measured in years, so t = 5.5 refers to a time five and one half years later than the initial time. We assume U_t^N is from a normal distribution with 0 mean and variance 3. U_t^N is independent of any other U_t^N. Because of inaccuracies in the monitoring system, the EMS "sees"

$$Y_t = \tilde{Y}_t + U_t^M \tag{B-3}$$

where U_t^M is normal with 0 mean and variance equal to 1. It follows that the observations are generated by a process represented by

$$Y_t = 1 + .10t + U_t \tag{B-4}$$

$$U_t \text{ distributed } N(0,4) \tag{B-5}$$

Assume there are 10 equally spaced observations per year. B- 1 can be used to construct the time-to-detection curve, which appears in Figure B.1. The curve predicts that it will take 12 years to detect the true trend of .10 when the null hypothesis is a trend of 0, and significance levels of .05 are used for both Type I and Type II errors.

Table B.1 is constructed to simulate an experiment of 160 observations by a monitoring system over a sixteen year period. The first column is the time of the observation; the second column the true concentration value calculated as $\tilde{Y} = 1 + .1t$; the third column contains random normal (mean 0, standard deviation 2) numbers representing the combined natural and monitoring error; the final column, the sum of columns two and three, represents the monitoring system observation.

At the end of each "year," the current simple linear regression equation is determined. A test of the hypothesis B=0 is carried out by computing the Student's t statistic

$$\text{Student's } t = \frac{(\hat{B} - B)\sqrt{\Sigma t^2}}{\sigma_u} \tag{B.6}$$

and comparing it to the appropriate critical region. The hypothesis B=0 is then accordingly accepted or rejected. In addition, the 95% confidence interval for the trend estimate is calculated.

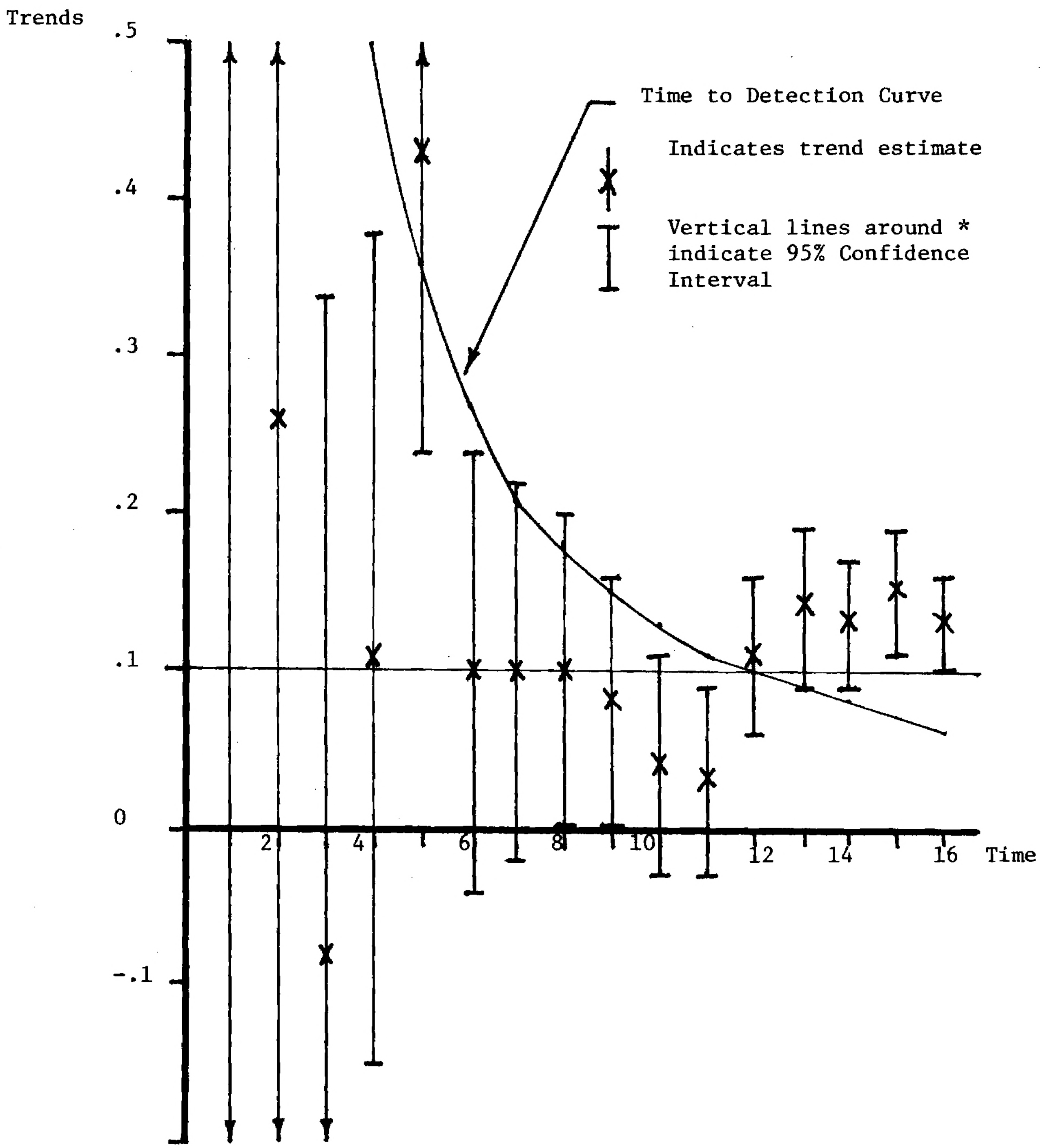


Figure B.1. The Time-to-Detection Curve and Example Trend Estimation Results

Table B. 1 Trend Monitoring Simulation

t	$\tilde{Y}_t$	U_t	$\tilde{Y}_t$	
.1	1.01	-.69	.32	Estimated Equation: $\hat{Y} = .79 - .44t$
.2	1.02	.11	1.13	Student's t = -.43
.3	1.03	-.64	.39	
.4	1.04	-3.09	-2.05	Critical Region = $\pm$ 2.31
.5	1.05	1.02	2.07	
.6	1.06	.13	1.19	∴ <u>Accept B = 0</u>
.7	1.07	1.22	2.29	95% Confidence Interval = [-2.75, 1.87]
.8	1.08	.54	1.62	
.9	1.09	-.40	.69	
1.0	1.10	-3.28	-2.18	
1.1	1.11	3.51	4.62	
1.2	1.12	-.41	.71	Estimated Equation: $\hat{Y} = .16 + .43t$
1.3	1.13	-2.43	-1.30	Student's t = .70
1.4	1.14	.54	1.68	
1.5	1.15	-.81	.34	Critical Region = $\pm$ 2.10
1.6	1.16	-.24	.92	∴ <u>Accept B = 0</u>
1.7	1.17	-1.21	-.04	
1.8	1.18	3.52	4.70	95% Confidence Interval = [-.52, 1.04]
1.9	1.19	-1.08	.11	
2.0	1.20	-1.21	-.01	
2.1	1.21	.41	1.62	
2.2	1.22	-1.81	-.59	Estimated Equation: $\hat{Y} = .84 - .08t$
2.3	1.23	-1.63	-.40	Student's t = -.39
2.4	1.24	-1.18	.06	
2.5	1.25	.37	1.62	Critical Region = $\pm$ 2.05
2.6	1.26	-1.83	-.57	
2.7	1.27	-3.07	-1.80	∴ <u>Accept B = 0</u>
2.8	1.28	-.82	.46	95% Confidence Interval = [-.50, .34]
2.9	1.29	-.78	.51	
3.0	1.30	1.87	3.17	

Table B.1 Trend Monitoring Simulation (Continued)

t	$\tilde{Y}_t$	U_t	$\tilde{Y}_t$	
3.1	1.31	.72	2.03	Estimated Equation: $\hat{Y}$ = .63 + .11t
3.2	1.32	.80	2.12	Student's t = .82
3.3	1.33	-.36	.97	Critical Region = ± 2.02
3.4	1.34	2.88	4.22	∴ Accept B = 0
3.5	1.35	-2.25	-.90	95% Confidence Interval = [-.16, .38]
3.6	1.36	-.29	1.07	
3.7	1.37	-1.43	-.06	
3.8	1.38	.00	1.38	
3.9	1.39	1.30	2.69	
4.0	1.40	-1.69	-.29	
4.1	1.41	-.51	.90	Estimated Equation: $\hat{Y}$ = .16 + .43t
4.2	1.42	.53	1.95	Student's t = 4.45
4.3	1.43	3.82	5.25	Critical Region = ± 2.01
4.4	1.44	1.84	3.28	∴ Reject B = 0
4.5	1.45	.81	2.26	95% Confidence Interval = [.24, .62]
4.6	1.46	4.05	5.51	
4.7	1.47	1.62	3.09	
4.8	1.48	1.73	3.21	
4.9	1.49	-1.58	-.09	
5.0	1.50	1.18	2.68	
5.1	1.51	.68	2.19	Estimated Equation: $\hat{Y}$ = .79 + .10t
5.2	1.52	-.02	1.50	Student's t = 1.36
5.3	1.53	3.19	4.72	Critical Region = ± 2.00
5.4	1.54	-1.00	.54	∴ Accept B = 0
5.5	1.55	-2.50	-1.05	95% Confidence Interval = [-.04, .24]
5.6	1.56	-1.50	.06	
5.7	1.57	-2.38	-.81	
5.8	1.58	-3.95	-2.37	
5.9	1.59	-1.42	.17	
6.0	1.60	-2.81	-1.21	

Table B.1 Trend Monitoring Simulation (Continued)

t	Y_t	U_t	Y_t	
6.1	1.61	3.24	4.85	Estimated Equation: $\hat{Y} = .82 + .10t$
6.2	1.62	1.92	3.54	
6.3	1.63	1.30	2.93	Student's t = 1.71
6.4	1.64	.82	2.46	
6.5	1.65	1.56	3.21	Critical Region = $\pm$ 2.00
6.6	1.66	-.45	1.21	
6.7	1.67	-5.37	-3.70	$\therefore$ Accept $\beta = 0$
6.8	1.68	1.66	3.34	
6.9	1.69	-3.48	-1.79	95% Confidence Interval = [-.02,.22]
7.0	1.70	-1.76	- .06	
7.1	1.71	2.87	4.58	
7.2	1.72	-2.89	-1.17	Estimated Equation: $\hat{Y} = .83 + .10t$
7.3	1.73	.28	2.01	
7.4	1.74	2.58	4.32	Student's t = 2.08
7.5	1.75	1.23	2.98	
7.6	1.76	-3.46	-1.70	Critical Region = $\pm$2.00
7.7	1.77	1.38	3.15	
7.8	1.78	-1.05	.73	$\therefore$ Reject $\beta = 0$
7.9	1.79	-2.70	- .91	
8.0	1.80	.26	2.06	95% Confidence Interval = [0, .20]
8.1	1.81	- .98	.83	
8.2	1.82	- .91	.91	Estimated Equation: $\hat{Y} = .89t + .08t$
8.3	1.83	.03	1.86	
8.4	1.84	-2.69	- .85	Student's t = 1.99
8.5	1.85	1.32	3.17	
8.6	1.86	.39	2.25	Critical Region = $\pm$ 2.00
8.7	1.87	- .74	1.13	
8.8	1.88	-1.77	.11	$\therefore$ Accept $\beta = 0$
8.9	1.89	-1.92	- .03	
9.0	1.90	1.99	3.89	95% Confidence Interval = [0, .16]

Table B.1 Trend Monitoring Simulation (continued)

t	$\tilde{Y}_t$	U_t	Y_t	
9.1	1.91	.33	2.24	
9.2	1.92	-3.03	-1.11	Estimated Equation: $\hat{Y} = 1.01 + .04\,t$
9.3	1.93	-1.28	.65	
9.4	1.94	-.57	1.37	Student's t = 1.16
9.5	1.95	3.39	5.34	
9.6	1.96	-.71	1.25	Critical Region = $\pm$ 1.99
9.7	1.97	-1.21	.76	
9.8	1.98	-3.20	-1.22	$\therefore$ Accept $\beta = 0$
9.9	1.99	-3.46	-1.47	
10.0	2.00	-.20	1.80	95% Confidence Interval = [-.03, .11]
10.1	2.01	-.15	1.86	
10.2	2.02	2.56	4.58	Estimated Equation: $\hat{Y} = 1.03 + .03\,t$
10.3	2.03	-4.59	-2.56	
10.4	2.04	.88	2.92	Student's t = 1.01
10.5	2.05	-4.98	-2.93	
10.6	2.06	-1.75	.31	Critical Region = $\pm$ 1.98
10.7	2.07	-.02	2.05	
10.8	2.08	1.29	3.37	$\therefore$ Accept $\beta = 0$
10.9	2.09	-2.16	-.07	
11.0	2.10	1.13	3.23	95% Confidence Interval = [-.03, .09]
11.1	2.11	2.62	4.73	Estimated Equation: $\hat{Y} = .73 + .11t$
11.2	2.12	2.35	4.47	
11.3	2.13	2.81	4.94	Student's t = 4.2
11.4	2.14	-.25	1.89	
11.5	2.15	2.12	4.27	Critical Region = $\pm$ 1.98
11.6	2.16	.36	2.47	
11.7	2.17	3.30	5.47	$\therefore$ Reject $\beta = 0$
11.8	2.18	2.37	4.55	
11.9	2.19	-2.07	.12	
12.0	2.20	.40	2.60	95% Confidence Interval = [.06, .16]

Table B.1 Trend Monitoring Simulation (continued)

t	$\hat{Y}_t$	U_t	Y_t
12.1	2.21	3.67	5.88
12.2	2.22	-3.54	-1.32
12.3	2.23	-3.94	-1.71
12.4	2.24	.57	2.81
12.5	2.25	- .21	2.04
12.6	2.26	2.62	4.88
12.7	2.27	6.11	8.38
12.8	2.28	- .60	1.68
12.9	2.29	2.43	4.72
13.0	2.30	-1.36	.94

Estimated Equation: $\hat{Y} = .63 + .14t$

Student's t = 6.03

Critical Region = ± 1.98

$\therefore$ Reject $\beta = 0$

95% Confidence Interval = [.09, .19]

t	$\hat{Y}_t$	U_t	Y_t
13.1	2.31	- .13	2.18
13.2	2.32	- .73	1.59
13.3	2.33	-2.42	- .09
13.4	2.34	.80	3.14
13.5	2.35	.10	2.45
13.6	2.36	1.20	3.56
13.7	2.37	- .04	2.33
13.8	2.38	- .48	1.90
13.9	2.39	.35	2.74
14.0	2.40	1.02	3.42

Estimated Equation: $\hat{Y} = .64 + .13t$

Student's t = 6.25

Critical Region = $\pm$ 1.98

$\therefore$ Reject $\beta = 0$

95% Confidence Interval = [.09, .17]

t	$\hat{Y}_t$	U_t	Y_t
14.1	2.41	-2.09	.32
14.2	2.42	- .89	1.53
14.3	2.43	1.88	4.31
14.4	2.44	3.56	6.00
14.5	2.45	1.22	3.67
14.6	2.46	1.33	3.79
14.7	2.47	- .86	1.61
14.8	2.48	2.10	4.58
14.9	2.49	2.93	5.42
15.0	2.50	.13	2.63

Estimated Equation: $\hat{Y} = .54 + .15t$

Student's t = 8.00

Critical Region = $\pm$ 1.98

$\therefore$ Reject $\beta = 0$

95% Confidence Interval = [.11, .19]

Table B.1 Trend Monitoring Simulation (Continued)

t	$\hat{Y}_t$	U_t	Y_t
15.1	2.51	- .33	2.18
15.2	2.52	- .05	2.47
15.3	2.53	- .50	2.03
15.4	2.54	2.23	4.77
15.5	2.55	1.77	4.32
15.6	2.56	-3.51	- .95
15.7	2.57	- .07	2.50
15.8	2.58	- .77	1.81
15.9	2.59	.27	2.86
16.0	2.60	-3.98	-1.38

Estimated Equation: $\hat{Y} = .65 + .13t$

Student's t = 7.63

Critical Region = ± 1.98

$\therefore$ Reject $\beta = 0$

95% Confidence Interval = [.10, .16]

The results show two things. First, because the observations are generated by a random process, and because we are willing to accept a specified chance of error, errors are possible and, indeed, do occur in the example. Specifically, after 50 observations the 95% confidence interval for the trend errs on the high side and after 110 observations the confidence interval errs on the low side. Second, the time-to-detection curve predicts 120 observations are necessary to detect the .10 trend and it happens that beginning at exactly 120 observations, the 0 trend indeed begins to be continuously and soundly rejected in favor of a positive trend. This result can also be seen noting that the confidence intervals about the estimated trend, as depicted in the figure, continually fail to embrace 0 past 120 observations.

Appendix C

Description of Linkage Models

C.1 Introduction

In this appendix the computational form of each of the linkages in the Model of Environmental Benefits is documented. Assumptions surrounding the model development are stated, evidence and data related to the models are presented, and the uncertainty of the outputs are addressed.

The overall model relates the monitoring activity (specifically monitoring of ozone and aerosols) to economic benefits to society. The overall model is made up of a sequence of linkages, as illustrated by Figure C.1. Each linkage receives its input from, and provides output to other linkages. The initial inputs are trend in ozone and trend in aerosols. Final outputs are the benefits of additional monitoring ozone, benefits of monitoring aerosols, and marginal benefits of monitoring aerosols given additional ozone monitoring. The following section describing the model is organized in terms of the linkages indicated in Figure C.1.

Following the description of the linkage models is an example of the model output. This example, "walks-through" the intermediate steps for execution of the model at one particular trend. The costs and other effects, over time, of pollution and pollution control are illustrated graphically. These graphs show the impacts of delays throughout the system. It ultimately turns out that the magnitude and character of the benefits of monitoring depend heavily on the formulation of the delay mechanisms.

C.2 Description of Linkages

Link 1 - States of Nature → Monitoring Information

The "states of nature" of interest in this work are the levels, over time (trends) of stratospheric ozone and aerosols. Inputs are postulated states of nature (trends), and outputs are times required to detect the states of nature. Link 1.1 concerns the ozone monitoring system, while Link 1.2 is the aerosol monitoring system.

Link 1.1 Ozone Monitoring

A major assumption implicit in this link is that a good measure of the effects of ozone destruction is trend (percent per decade) as opposed to changes in peak variations or other. This assumption is consistent with the approach adopted by the Climatic Impact Assessment Program (CIAP) [1]. However, it should be mentioned that no extended effort was made by CIAP to justify such a measure and some research should be directed toward an evaluation of its value and whether or not it adequately represents the significant types of stratospheric changes brought about by pollution. Peak variations in stratospheric ozone concentration result in peak variations in surface UV. Present studies, however, indicated that incidence of non-melanoma skin cancer is dependent upon cumulative exposure to UV rather than peak variations. Therefore, ozone trend is an acceptable measure of stratospheric perturbation, based on these conclusions.

The first ozone observations began in 1925 in Oxford, England. Since then, the network of ozone measuring stations has expanded into a global monitoring system. As of 1974 there were 128 active stations reporting ozone measurements to the World Meteorological Organization (WMO). The WMO compiles this data and publishes it in "Ozone Data for the World."

The primary instrument used to measure ozone is the Dobson Spectrophotometer. These instruments make readings only in direct sunlight, with most stations averaging 10 to 20 measurements per month. Various types of filter ozonometers are also used to measure ozone. Measurements from these instruments are adjusted to be comparable with the measurements from Dobson instruments.

The standard unit for ozone is (m atm cm). This unit represents the equivalent depth (in 10^{-3}CM) if all ozone molecules in a vertical atmospheric column of unit cross section were brought to standard temperature and pressure. "Ozone Data for the World" contains daily ozone measurements for each of the stations in the network. Some of the stations have more daily measurements than others. Also, the length of time covered for the stations varies.

A plot of monthly means of total ozone shows a strong cyclical variation with a period of one year. There is also an indication of a longer term cycle. Current interest, however, is on detection of a trend in global ozone.

Several articles have addressed the problem of trend detection [3, 4, 5, 6, 7, 8, 9, 10]. None, however, have addressed the following statistical problems related to the confidence limits of the estimate of the trend:

1) variance due to the accuracy of individual measurements
2) variance due to the averaging of daily ozone measurements into monthly means
3) variance due to averaging of individual station monthly means into a global monthly mean.

As a result of the aggregation of the data into global monthly means, each of the above mentioned points should add to the variance of the trend coefficient. Current analyses, however, treat these aggregates as data points, rather than means of distributions.

Although the current ozone data goes back to 1925, the number of stations reporting, and number of observations per station have varied considerably. This results in the necessity of averaging into global monthly means. Unfortunately, it also creates statistical problems in the trend analysis. Thus, the trend detection ability of a monitoring system depends on the data analysis method, as well as the data acquisition method.

A most widely accepted estimate of the global trend detection ability of the baseline monitoring system is based on analysis by Pittock[7]. As seen in Figure C.1, this estimate is a curve relating trend in global ozone to the number of years of monitoring required to detect the trend at a given level of confidence (based on two sided student's t-test).

A more recent work by Hill[18] and associates indicated a twofold reduction in the time required for the baseline system to detect trends. Figure C.1 illustrates a comparison of results of the two analyses. The work by Hill will be used in the base case, however Pittock's will be used in a sensitivity analysis run.

Under the various scenarios for production of pollutants, it was recognized that the trend in ozone may change with time. The most likely case would be for a trend in ozone increasing in severity. For example, the trend in ozone may go from 1 percent per decade to 3 percent per decade over a period of, say, 5 years. Clearly, an increasing trend would be detected in less time than if there were a constant trend of 1 percent. Likewise the increasing trend would require a longer time to detect than a constant trend of 3 percent. Since the character of the change in trend is unknown (and probably non-linear), rigorous analytic derivation of the time-to-detection is difficult. As a first cut, the problem is mitigated by using a three year running average of the trend as input to the monitoring system.

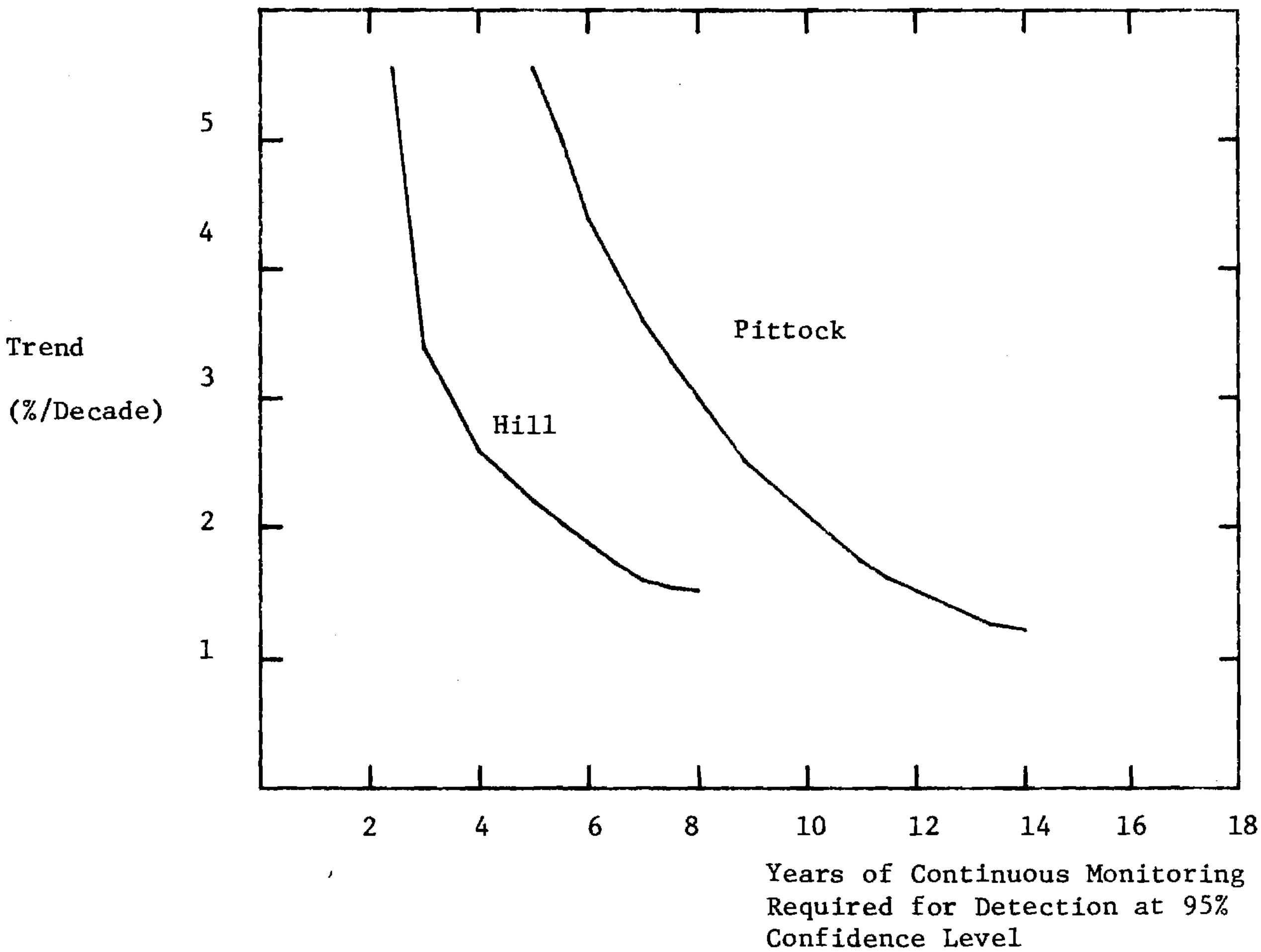


Figure C.1 Hill and Pittock Monitoring Capability Curves.

The average trend is checked in the computer model at each iteration through the program (once per year). A counter is kept to determine how many years have elapsed since the last trend was detected. When the average trend is detected, the counter is re-initialized, and the policy choice model implemented.

Link 1.2 - Aerosol Monitoring

Essentially the same model is used for detecting trend in ozone reduction, and trend in aerosol increase. There is little documentation about the "baseline" aerosol monitoring system, and less on its capabilities for detecting trends. In short, there is no analysis similar to Pittock's or Hill's on ozbne. The approach taken in the absence of any definative information has been to use the same curves for aerosol increase as are used for ozone reduction. Little can be offered in defense of this approach other than to say that some assumption must be made, and that seemed as reasonable as any. Sensitivity of the results to this assumption is included in later sections.

Link 2 - Monitoring Information → Policy Selection

Based on information supplied by the monitoring systems, decisions must be made as to what policies are implemented to deal with the problems. In "real life," the outcome of this decision process depends on many variables. The current political and social situation, the power of various lobbying groups, faith in the monitoring system and many other factors come into play. In this effort, policy decisions are based only on perceived costs to society. The same method is used for aerosol-related policy selections as for ozone-related policy selections, so Link 2.1 and 2.2 are combined in this description.

Two methods of policy selection have been considered. The first method was to use the monitoring information (# of years required to detect the trend with confidence) to determine when a policy was to be implemented. Each policy was simulated (being implemented as indicated by the monitoring system) to determine the total cost to society which would result. The policy with the minimum cost was selected. The assumption here was that once a policy is selected, it would be adhered to from that time forward. The difference then, between the baseline and alternate monitoring systems was the timing of policy implementations. It could occur that different policies be selected for the baseline than for the alternate system, however this was generally not the case. The second method is somewhat more elaborate. It assumes that the decision maker has access to this model, and that he uses it to assess the cost of various policy decisions, and selects the policy resulting in the lowest overall cost to society. Operationally the procedure works as follows: When a trend is detected, the monitoring system "passes" the decision maker the "estimated" trend (which is actually an average of the trends for the previous three years). The decision maker considers this trend and adjusts it to the "worst-case" based on the monitoring information. For the baseline system the worst-case is nominally 1.4 times the estimated trend, while for the alternate system, the worst-case is 1.2 times the estimated trend. Using the worst-case trend, the decision-maker uses the computer model to determine the costs over his planning horizon of each of the applicable policies. Table C.1 lists the applicable policies for aerosol related problems, and Table C.2 lists the policy combinations for ozone related problems. These policies are considered in greater detail in Link 3. The lowest-cost policy is selected for implementation.

The planning horizon turns out to be a critical factor. For short planning horizons, the decision maker is biased against the more restrictive policies. This is because the restrictive policies have large initial costs due to restricting production, but the benefits (in reduced damage costs) occur some years down the road, possibly beyond the planning horizon. Also, discounting serves to diminish the "weight" of the future costs as compared with the immediate costs of regulation.

The process of running trial policies to determine the best one occurs at each point in time that either trend is detected. Following each "trial", the model state is returned to what it was before the trial.

The policy is adhered to until a trend is again detected by the monitoring system. At this point, the policies are reconsidered, and possibly a different policy is chosen. The minimum time between policy changes was considered to be five years.

Though the second policy selection method may be somewhat more realistic than the first, it has some difficulties. It was found to be sensitive to factors such as the minimum time between policy selections. In some cases, the baseline monitoring system was indicated to be better than the alternate monitoring system, simply because its policy selection opportunities were spaced more advantageously. Clearly, this does not reflect the real situation. Another problem was that this decision rule required extensive computer time, making meaningful sensitivity analysis unfeasible.

The first method of policy selection, though less elaborate than the second method, seems a reasonable criterion for comparing monitoring systems. Though it does not mirror reality, it does provide a consistent measure for inspecting results of differences in monitoring systems. Thus, for a base case, the first method of policy selection is used.

Link 3 & 4 -- Policy →Production Available Goods

Links 3 and 4 relate policy selections to changes in production (including SST operations, as well as CFM production) and to costs of those changes. These links are considered jointly in this section, because they are closely inter-related. The "changes in production" correspond to changes in two industrial sectors: CFM and related industry, and the aircraft industry. Regulation of CFM's may involve restricting their uses in certain applications, prescribing service procedures or completely banning their production. For the aircraft industry, regulation may involve restrictions on the number of aircraft which may be used to amount of emissions allowed at various altitudes.

Link 3.1 and 4.1 - The CFM Industry

CFM products have been categorized into two groups:

Group 1 (atmospheric lifetime greater than ten years) F-11, F-12, carbon tetrachloride

Group 2 (atmospheric lifetime less than ten years) F-22, methyl chloride

To date,models for predicting ozone reduction due to CFMS have considered only group 1 chemicals, notably F-11 and F-12. Group 2 chemicals are considered a less serious threat because their stratospheric lifetime is short. In this work, only regulations concerning group 1 chemicals will be addressed though others have been considered in the literature. There does not appear to be serious consideration of regulation of group 2 chemicals, at least in the near future. Changes in production of the group 2 chemicals could be estimated in the same way the group 1 chemicals are, but there have been no estimates or models of ozone reduction or temperature change due to the group 2 chemicals. Henceforth in this report "CFM's" will refer only to F-11 ($CFCl_3$) and F-12 (CF_2Cl_2).

CFM's were developed in the late fifties for use in refrigeration systems. Figure C.2 gives the time history of the production. There are now four primary end-use categories for CFM's. They are summarized in Table C.3.

Of primary concern in this effort will be the propellant and refrigerant end-uses, since these categories constitute over 80% of the total production, and some study of the costs of their regulation has been made.

A number of policies and implementation scenarios have been considered. For the purposes of this study the number of policies was reduced to three. These three are representative of the type and range of policies which have been considered. An implementation period of 3 years is assumed.

Policy 1 - "do nothing" - no regulation

Policy 2 - ban "non-essential" propellant uses of CFMs

Policy 3 - ban all use of CFMs

Under policy two virtually all propellant uses are considered non-essential.

A. Model Development

The model is based on two primary assumptions: 1) future CFM production scenarios can be estimated, and 2) proportions used for each end use remain constant. Let α_{ij} denote the fraction of chemical i production devoted to end use j. Then if $P_i(t)$ is the projected production of chemical i in year t, $\alpha_{ij}P_i(t)$ is the projected quantity of chemical i devoted to end use j in year t. Letting v_{ij} denote the value of goods and services from end use j, per unit of chemical i devoted to that end use, the $V_{ij}(t)$, defined as:

$$V_{ij}(t) = v_{ij}\,\alpha_{ij}P_i(t) \qquad (1)$$

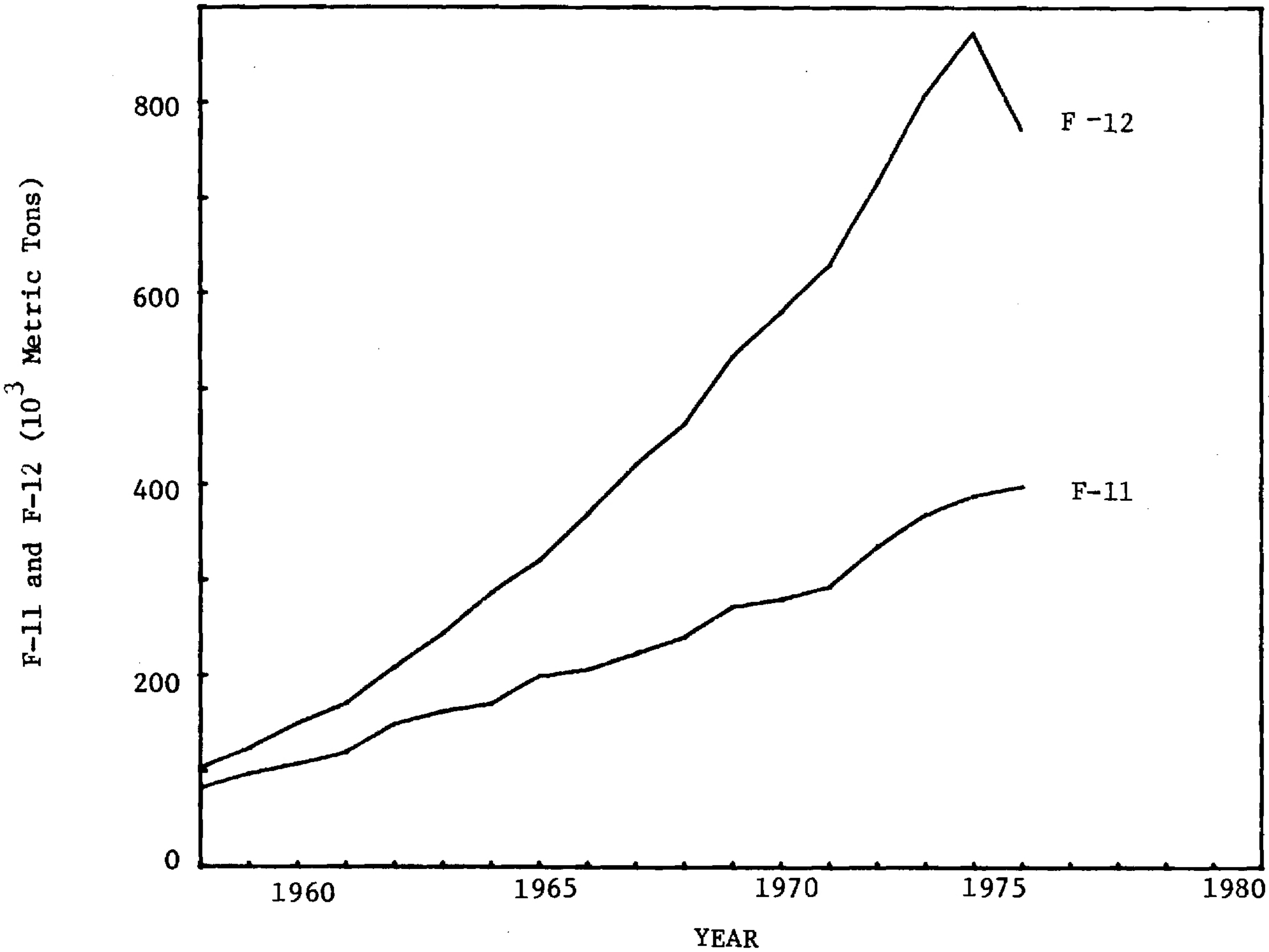


Figure C.2 U. S. and World Production of F-11 and F-12.

Table C.3 End-use Percentages of Total Production

Chemical	Propellant	Refrigerant	Foaming Agent	Other
F-11	71	5	16	8
F-12	51	34	2	13
Average*	10	21	8	11

* Weighted by production amount

provides an estimate of the value of goods and services attributable to chemical i in end use j in year t. This value assumes, of course, that projected production scenario will continue in the absence of regulation.

Suppose that a policy banning chemical i from end use j is announced at the beginning of year τ. Further suppose that the ban takes effect E years after announcement, i.e., at time $\tau + E$. For brevity this is denoted by the 4-tuple (i, j, τ, E). Further assume that a lag of L years would be required to develop and introduce substitute products and/or production processes to replace those banned by (i, j, τ, E). It is assumed that the process can be depicted as in Figure C.3.

Several assumptions are implicit in Figure C.3. First is that value of goods and services from (i,j) will decline linearly to zero over the time interval $(\tau, \tau + E)$. Second is that substitutes will begin to appear at τ with the value of substitutes growing linearly to the projected value of the originals $V_{ij}(\tau + L)$ at time $\tau + L$. This L is the time required for industry to respond to the regulations. These are admittedly over-simplifications, but they seem reasonable as a first approximation.

Under these assumptions the value of originals in year t, and under the assumption of no regulation, is $V_{ij}(t)$. The revised value of originals during any year t, $RV_{ij}(t)$, is represented by the line segment AD for t between τ and $\tau + E$, and is obviously zero for $t > \tau + E$. Further, $RV_{ij}(t)$ can be approximated as follows:

$$(2) \qquad RV_{ij}(t) = \begin{cases} V_{ij}(\tau) - \dfrac{V_{ij}(\tau)}{E}(t-\tau) & t = \tau, \tau+1, \ldots, \tau + E. \\ 0 & t > \tau + E \end{cases}$$

Other approximations are possible, but (2) should suffice.

The value of substitutes in year t, $S_{ij}(t)$, can be estimated as follows:

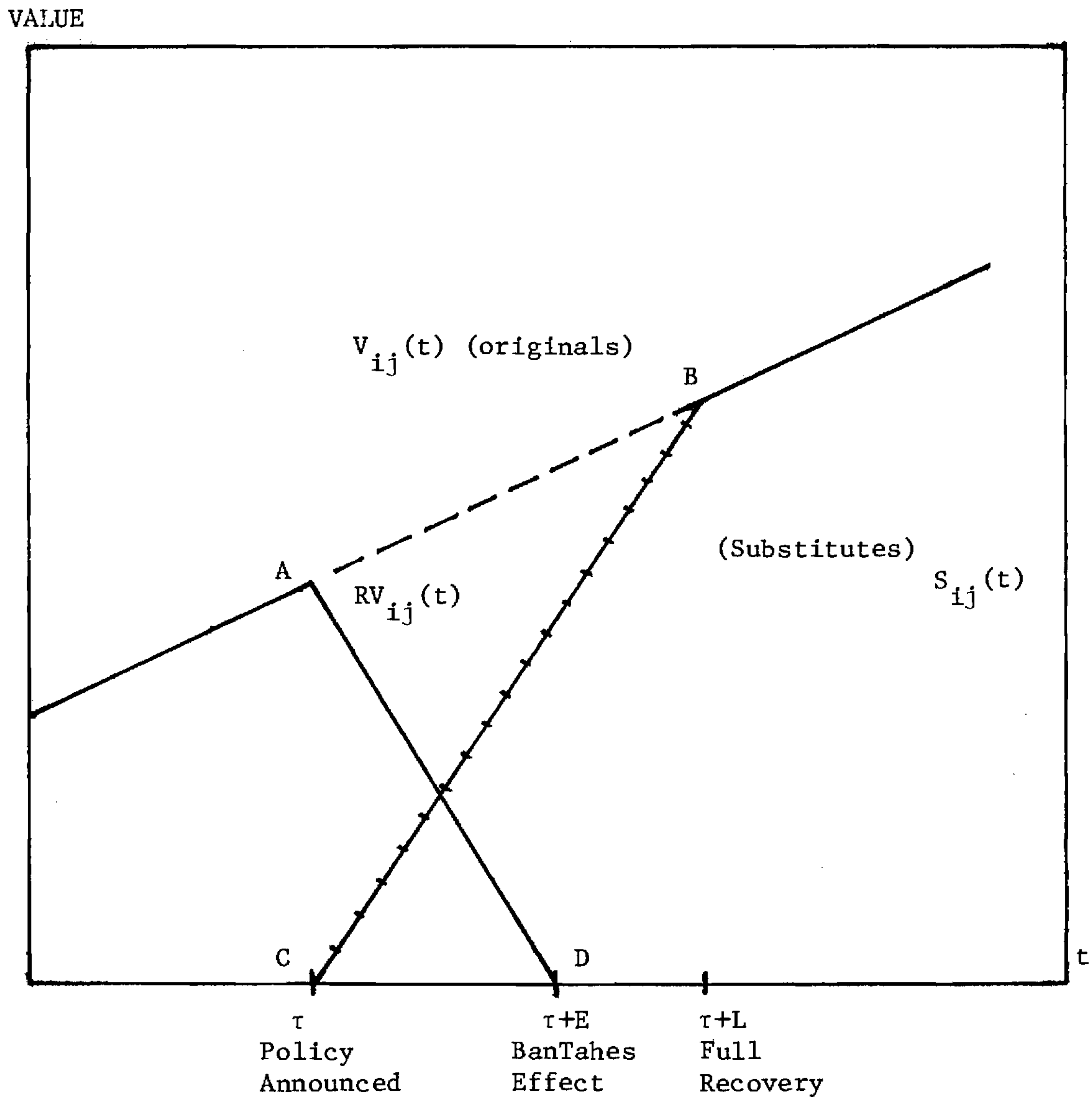


Figure C.3 Assumed Response to (i, j, τ, E)

$$S_{ij}(t) = \begin{cases} \frac{t-\tau}{L} V_{ij}(\tau + L) & t = \tau, \tau + 1, \ldots, \tau + L \\ V_{ij}(t) & t > \tau + L \end{cases} \tag{3}$$

Again other approximations are possible, but (3) is not unreasonable.

The total value of goods and services foregone in year t, $F_{ij}(t)$, is given by:

$$F_{ij}(t) = \begin{cases} V_{ij}(t) - (RV_{ij}(t) + S_{ij}(t)) & t = \tau, \tau+1, \ldots, \tau + E. \\ V_{ij}(t) - S_{ij}(t) & t = \tau + E + 1, \ldots, \tau + L \\ 0 & t > \tau + L \end{cases} \tag{4}$$

R&D and changeover costs arising from (i, j, τ, E) would be comprised of two basic types of costs: (a) out of pocket R&D expenditures required to develop substitutes and (b) obsolescence costs of existing plant and capital equipment arising from (i, j, τ, E). Letting $C_{ij}(t)$ denote the total R&D and changeover costs arising from (i, j, τ, E) in year t, and assuming that $C_{ij}(t) = 0$ for $t \notin \{\tau + 1, \ldots, \tau + L\}$. Then the total direct economic cost from (i, j, τ, E), discounted to the beginning of the year τ is:

$$NPV = \sum_{t=\tau}^{\tau + L} \frac{F_{ij}(t) + C_{ij}(t)}{(1 + d)^{t + 1 - \tau}} \tag{5}$$

where d is the discount rate and costs are assumed to be incurred at the end of each year. Note again that this measure ignores any differential costs and/or characteristics of substitutes vis-a-vis original products and/or processes.

B. Parameter Estimation*

Important parameters are summarized in Table C.4. Note here that rather than calculating costs for each chemical, F-11 and F-12 are averaged. Thus the subscript denoting "chemical" in the model development section is eliminated.

The V_j's are the values of one unit of CFM to each of the J end uses. In this work, only propellant and refrigerant (which constitute most of the production and value) end-use categories are used.

Good estimates of the v's are not easily obtained, although rough values of these quantities can be generated. Very rough lower bounds on the v's would be provided by the unit cost of chemical i. Estimates of these costs, taken from BDC and ADL, are shown in Table C.5.

Shreve estimates the total value of fluorocarbon-propelled aerosol product shipments in 1974 as $1.43 billion (BDC Table V-2), so that this lower bound accounts for roughly 12 percent of that value. This is probably too low for several reasons. First, although demand for these goods would continue in spite of a fluorocarbon ban, it would be unlikely that production capacity for non-fluorocarbon propelled aerosols and substitute packaging (mechanical pumps, stick deodorants, etc.) could meet total demand immediately. Thus, prices of these substitutes would likely increase. Secondly, part of the cost of aerosol products is due to the container (BDC estimates the average cost of a metal aerosol can to be 13¢ versus 6¢ average for all metal cans in 1974.) To the extent that discontinued fluorocarbon-propelled aerosols would

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*Note that many of the parameter estimates in this section were adapted from (1) the Arthur D. Little(ADL) Report [11] and (2) the Economic Impact of Potential Regulation of Chlorofluorocarbon-Propelled Aerosols [19] by IR&T and (3) the Bureau of Domestic Commerce (BCD) report [12].

Table C.4. Parameters in the Model of Costs of Foregone CFM Production

v_i	Value of one unit of CFM to end-use i
α_i	proportion of CFM's used in end-use i
P(t)	total production of CFMs in year t
τ_i	primary industry response time to a ban of CFM's in end-use i
E_i	implementation period allowed for regulation
RD_i	cost of research and development to develop products to replace those which are restricted

Table C.5 AVERAGE VALUE (SALES PRICE) PER KILOGRAM *

Chemical	Average Value $/Kilogram
F-11	$.77
F-12	.92
Carbon Tetrachloride	.13
F-22	1.38
Methyl Chloroform	.20

*Adapted from [11] and [12].

be replaced by non-aerosol products, the value of these cans would be lost. Thirdly, in some cases (e.g. alternate propellants), costs of substitues would likely continue to be higher than the original products, even after the response time. The omission of these price differences from (2) argues in favor of biasing the estimates of v's toward the high side.

Very rough upper bounds on the v's can be found by considering the total value of production dependent on these chemicals. Table C.6 presents estimates extracted from Table II-3 of BDC.

Since none of the regulatory policies considered here bans replacement uses in refrigeration, it is assumed that a ban on fluorocarbon refrigerants would affect only the manufacturing portion of the industry, i.e. no new equipment using the affected chemicals would be produced. Under this assumption upper bounds on some of the v_{ij} are given in Table C.7 .

The estimates in Table C.6 were computed by dividing the total value of fluorocarbon-dependent production in end use j by the total weight of the relevant input chemicals. For example total value of aerosol propellant products dependent on fluorocarbons is given as $1,873 million in Table C.6. Total combined input of F-11 and F-12 was 486 million pounds (ADL Table VII-3) so that V_1 = $1876/486 million lbs) = $3.85/million lbs. Converted to millions of 1976 dollars per 10^3 metric tons, this final number is 8.55 million dollars/ 10^3 metric tons.

The α's represent the percentage of the total production of CFM's used in each end-use. Estimates of the α's were adapted from ADL Table VII-3. Again, only propellant and refrigerant end use categories are implemented. These categories constitute over 80% of the total production of F-11 and F-12. Table C.3 illustrates the numbers as adapted from ADL.

Table C.6 INDUSTRY DEPENDENCE ON FLUOROCARBONS (1974)
Source: BDC Table II-3

End Use	Value of fluorocarbon-dependent production in 1974 ($ million)
Propellant	1,873
Refrigerant	
Manufacturing	9,167
Non-manufacturing	13,602
Plastics	
Foamed	840
Fluoropolymer	125

Table C.7 Upper Bound Unit Values* for CFMs

	Million $/10^3 Metric Ton
Propellant	8.55
Refrigerant	73.5

* adjusted to 1976 dollars

P(t) is the amount (in units of 10^3 metric tons) of F-11 and F-12 produced in the United States in year t. Figure C.2 illustrates historical US and global CFM production figures. It should be noted here that while US production will be affected by the regulations, non-US production is not.

Several future production scenarios are considered. These scenarios represent estimates of what the future production of CFM's would be in the absence of any regulation. There appears to be no practical upper limit on the raw materials from which the CFM's are made. Figure C.4 illustrates the nominal-case scenario.

The L's are the response times for acting on regulations. Response times are estimated in ADL (Table I-5). Actually, the ADL report defines and estimates two response times: primary response times and conversion to substitute chemical time. The primary response times are the elapsed times required for the consuming industries to introduce substitute products to meet the demand now satisfied by the controlled chemicals. Conversion times are those required to develop new chemicals with properties similar to the banned compounds and to modify the products using the banned chemicals.

The shorter primary response times seem relevant to Figure C.3 and these times are used for L in that figure. To the extent that R & D and changeover costs are incurred over the longer conversion to substitute chemical times, expression (5) should be changed accordingly. Some relevant estimates from ADL are contained in Table C.8.

"E" is the length of the policy implementation period. This is the amount of time that manufacturers are given to comply to regulations. Most suggested policies allow three years for full compliance, so this is used in the model.

Research and development costs are modeled as fixed yearly charges over the response time for each end-use. For the propellant end use, the implementation period is shorter than the primary response time. For this reason, there

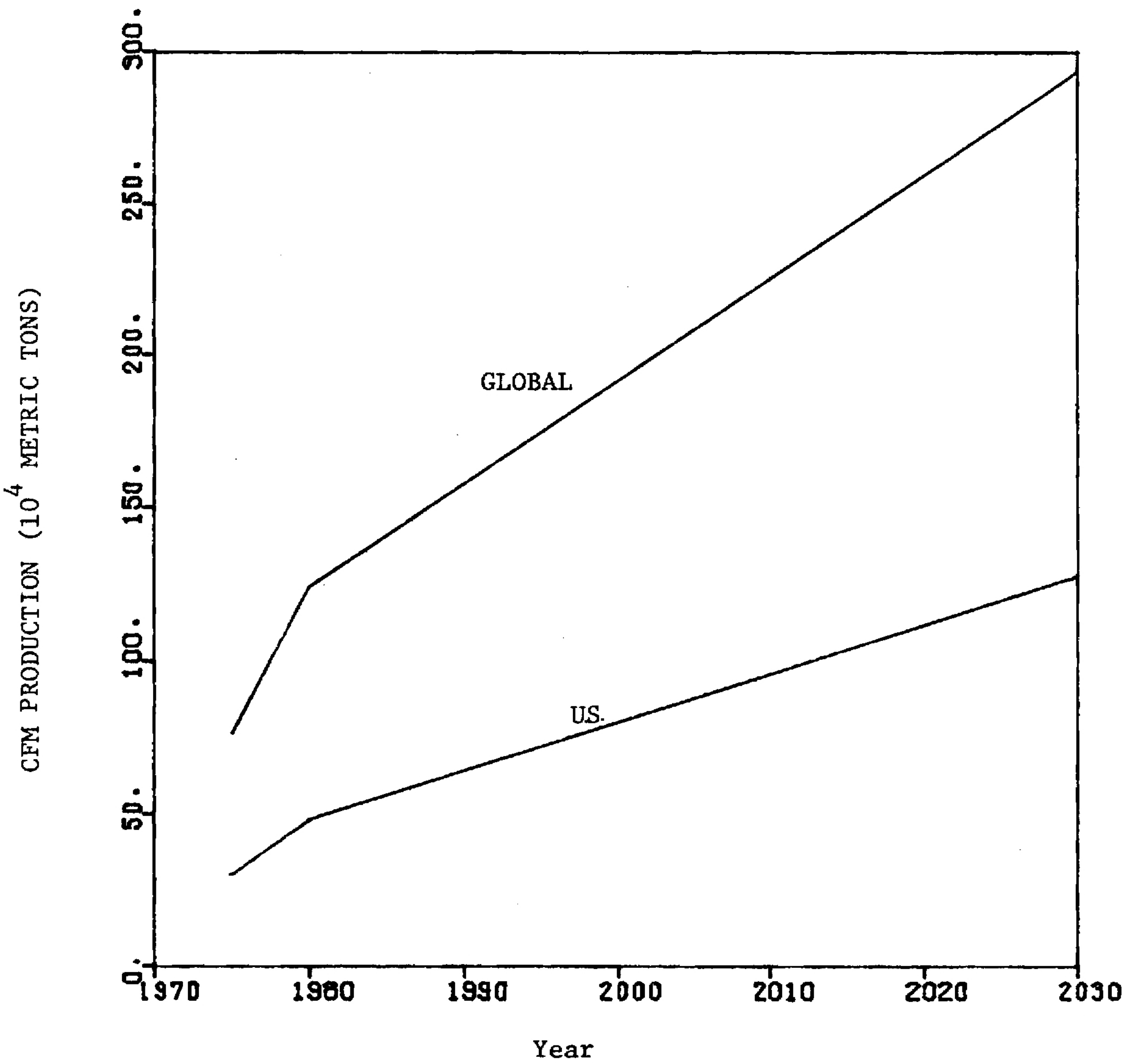

Figure C.4 Projected CFM Production

TABLE C.8

INDUSTRY PRIMARY RESPONSE TIMES

END USE	PRIMARY RESPONSE TIME (years)
Propellant	1 - 2
Refrigerant (to absorption),	4 - 6
(to F-22),	3 - 4
Plastics	1.75[a]
Solvent	1 - 2

Estimated Primary Response Times by

End Use

Source: ADL Table 1-5

a. unweighted average of 6 months for flexible foams and three years for rigid foams.

is no cost due to propellant goods and services foregone, however there are research and development costs, which are required to develop the substitute products. Some analysis of these costs were done in [19]. Based on this analysis a yearly cost of 68 million dollars per year is used for R&D for substitute propellant products. Less study has been made on R&D requirements for refrigerant uses. 100 million per year is the estimate used in the base-case.

Links 3.2 and 4.2 SST Regulation → ΔCosts, ΔProduction

Options for regulating SST operations are as follows:

1. No regulation
2. Regulation of operations only
3. Regulation of emissions only (through regulation of fuel and/or engine design.
4. Regulation of operations and emissions.
5. Banning stratospheric flight.

Regulations of operations is defined to mean regulation of the amount of flight which is allowed in the stratosphere. Though some "conventional" airlines fly in the lower stratosphere on long flights, the primary emphasis is on super-sonic transports which fly at higher altitudes. Emissions in the lower stratosphere (below 15 km) are removed from the stratosphere relatively quickly, so they don't do as much harm as emissions at higher altitudes. Henceforth in this report regulations dealing with "stratospheric flight" refer only to commercial supersonic aircraft.

A. Model Development

The first step to estimating the economic costs of regulating stratospheric flight is to forecast the SST fleet size assuming no curtailment of stratospheric flight. Costs of future regulations may then be evaluated based on their impact on the projected fleet.

The various regulatory options lead to the following types of direct economic costs:

a. curtailing operations leads to idle equipment and costs of increased travel times

b. controlling emissions leads to engine redesign and for fuel desulfurization costs.

Engine redesign costs are concluded (in CIAP) to be rather insignificant, assuming orderly development and incorporation of design revisions. Fuel desulfurization costs are more substantial and are estimated in the CIAP Final report. Thus if desulfurization were mandated in year t, the direct economic costs of desulfurization are readily computed from these estimates. If operations were curtailed in year t the direct economic costs from increased travel time could be estimated by estimating extra travel hours per year and multiplying that total by an estimated value per hour of passenger time.

B. Parameter Estimation

Table C.9 describes the critical parameters in the SST cost model,

Several SST fleetsize predictions were described in the CIAP work. These are illustrated in Figure C.5. These forecasts are considered by many [20] to be unrealistically high. They will be used in further sensitivity analysis, but for the basecase the projected SST fleet shown in Figure C.5 will be used.

The costs of fuel desulfurization were estimated by CIAP to be .13 per liter(1971 dollars). Converted to 1976 currency, this is .24¢ per liter.

No estimates for the cost of airline passengers time was found in the literature. It was estimated, for this effort, to be $500 per aircraft hour.

Table C.9 Parameters in the SST Regulation Cost Model

PFHOURS(t)	Projected flight hours - of SST's in the stratosphere in year t
DESULCST	cost per gallon of desulfurizing fuel
TRAVCST	cost per hour of airline passenger's time

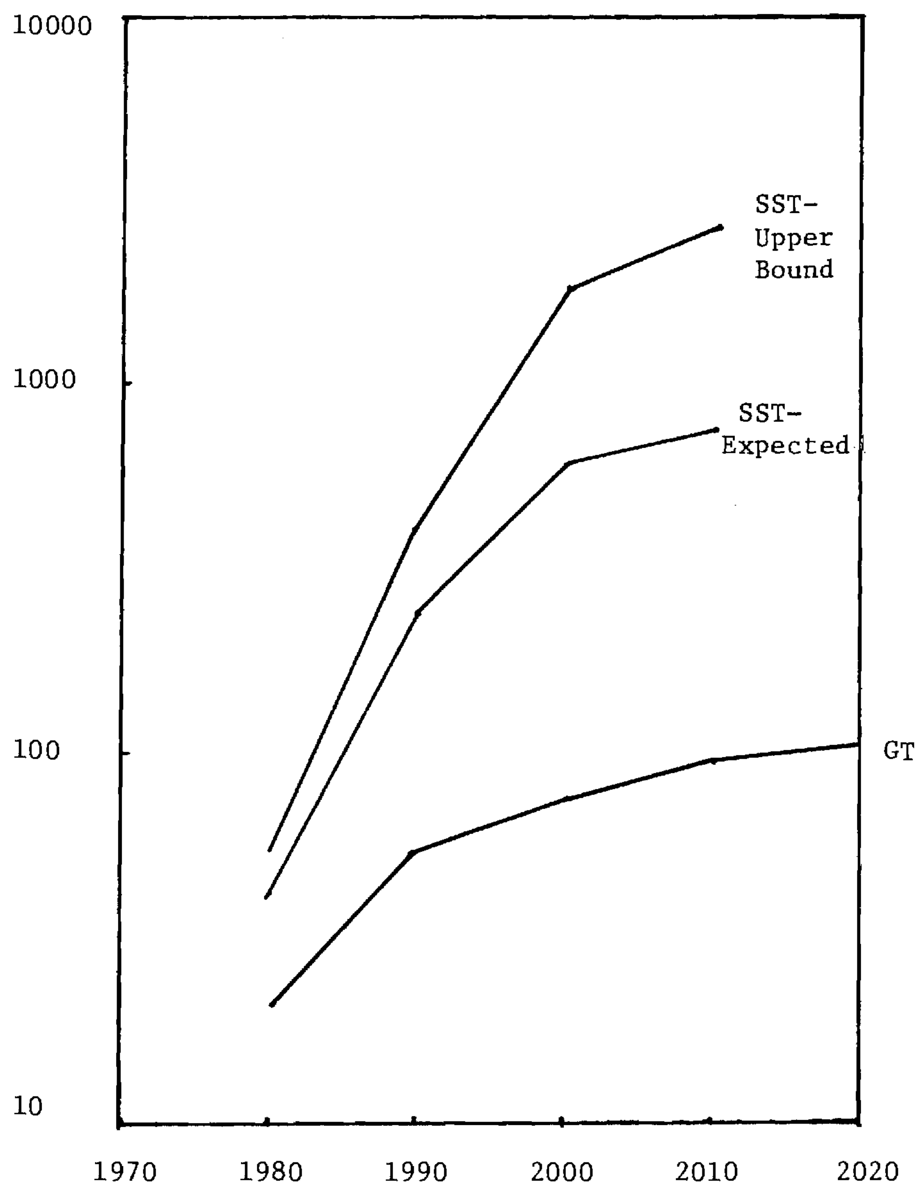

Figure C.5 Projected SST Fleet Size

Link 5 - Change in Production → Change in Stratospheric Pollution

Link 5 relates production to stratospheric pollution charges. The sources considered here are CFM's and SST's.

Link 5.1 - Stratospheric CFMs

Almost all CFM's produced are eventually released to the atmosphere. CFM's used as propellants are released almost immediately, whereas those used in refrigeration units may be released only after several decades of use. Once released, the CFM's mix quickly in the troposphere. To date [17] no tropospheric sinks have been discovered to prevent their eventual "leaking" into the stratosphere. Modeling of the transport lag is included in the sections describing the effects of CFM's in the stratosphere.

Link 5.2 - SST Effluents

SST effluents differ significantly from CFM's in that they are injected directly into the stratosphere, and thus have no transport delay. The effluents of primary concern here are NO_X, SO_2, and H_2O.

A. Model Development

Equations 1, 2, and 3 give the models used for estimating the fractional change in the stratospheric burden of each of the SST effluents.

$$\Delta NOX(t) = \frac{FF(t) * EINOX * RTNOX}{NOXNAT} \quad (1)$$

$$\Delta H2O(t) = \frac{FF(t) * EIH2O * RTH2O}{H2ONAT} \quad (2)$$

$$\Delta SO2(t) = \frac{FF(t) * EISO2 * RTSO2}{H2ONAT} \quad (3)$$

Table C.10 gives a brief description of the parameters used above. The general form of these equations is as follows:

$$\Delta PO(t) = \frac{FF(t) * EI * RT}{NAT}$$

where:

FF(t)	is the amount of aircraft fuel burned in the stratosphere in year t
EI	is the emission index for the given constituent
RT	is the residence time in the stratosphere
NAT	is the natural (unperturbed) stratospheric burden of the constituent
ΔPO(t)	is the fractional change from the natural burden of the constituent

B. Parameter estimation

Table C.11 summarizes the values used for each of the model parameters.

Emission indices are from [21] page F-12.

Residence times are from [1]. Figure C.6 shows the various estimates which have been considered.

The natural burden figures are from [21] page F-12.

Fuel flow is calculated as described in Link 5.2.

Table C.10 **Parameters for Modeling SST Effluents in the Stratosphere**

Parameter	Description
EIH20	Emission index for water vapor effluent (mass) per unit mass of fuel burned
EINOX	Emission index for nitrogen oxides effluent (mass) per unit mass of fuel burned
EIS02	Emission index for sulfate effluent (mass) per unit mass of fuel burned
FF(t)	Fuel flow (mass) burned in the stratosphere in year t
NATH20	Natural stratospheric burden (mass) of water vapor
NATNOX	Natural stratospheric burden (mass) of nitrogen oxides
NATS02	Natural stratospheric stratospheric burden (mass) of particulates
RTH20	Residence time (years) in the stratosphere for water vapor
RTNOX	Residence time (years) in the stratosphere for nitrogen oxides
RTS02	Residence time (years) in the stratosphere for particulates

Table C.11 Parameter Estimates for Modeling SST Effluents in the Stratosphere

Parameter	Estimate	Units
EIH20	1250.	g/kg
EINOX	18.	g/kg.
EISO2	2.04	g/kg.
FF(t)	see Figure 3.10	metric tons
NATH20	1.78×10^{12}	kg
NATNOX	5.85×10^{9}	kg
NATSO2	5.0×10^{9}	kg
RTH20 (CIAP)	2.305	years
RTNOX (CIAP)	2.305	years
RTSO2 (CIAP)	0.90	years

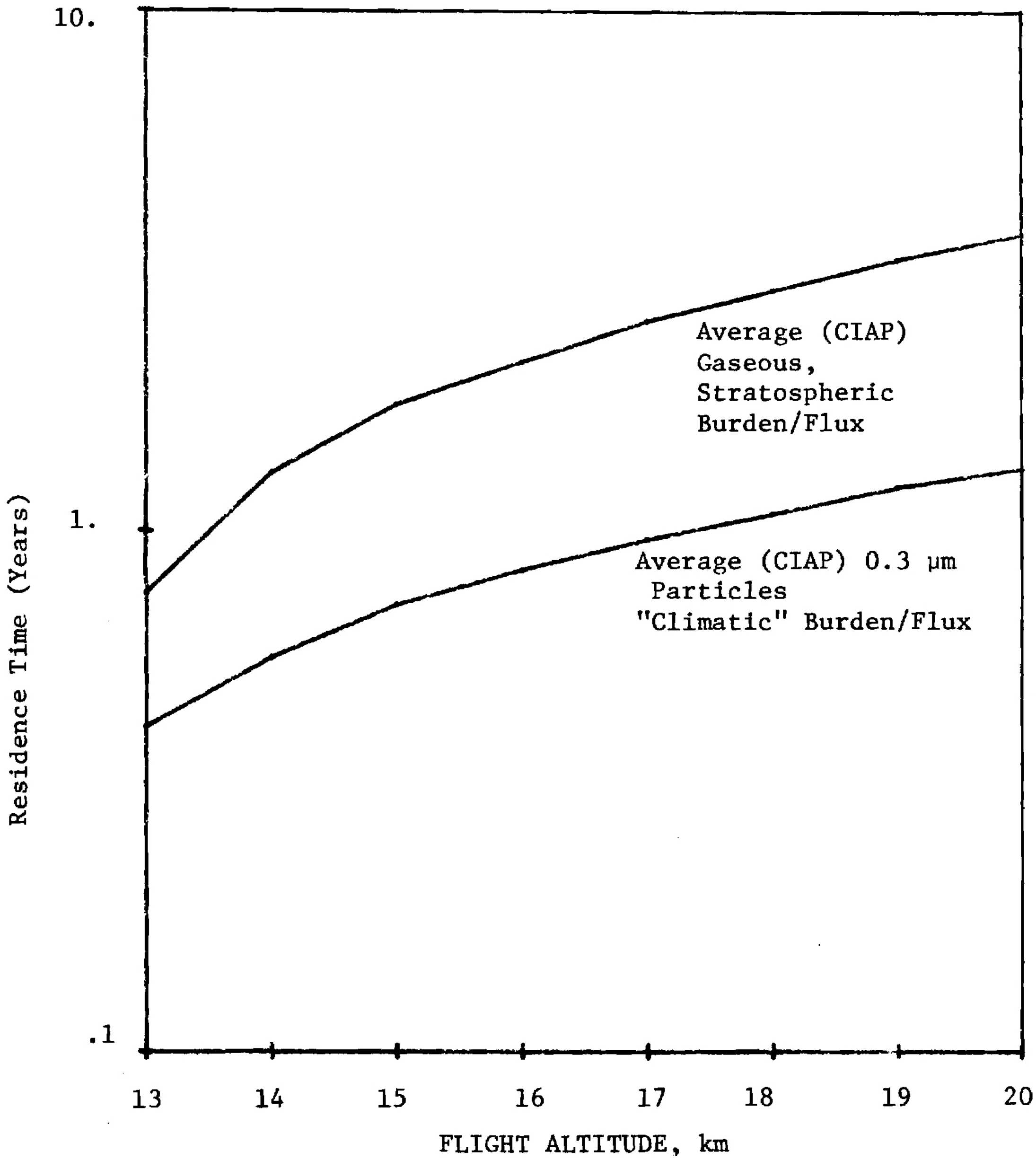

Figure C.6 Residence Time Estimates for SST Effluents

Link 6 - Stratospheric Pollution → Pollution Damage

Two primary categories of pollution damage are considered. These are (1) effects of temperature change and (2) effects of increased ultraviolet radiation. Pollution (CFM's and NO_X's) result in a reduction of ozone. This ozone reduction in turn results in an increase in biologically effective ultraviolet radiation. CFM's, and SST effluents also affect the average global temperature directly, as well as indirectly, through ozone reduction. The following section describes the series of sub-linkages relating stratospheric pollution to its anthropogenic effects. Generally the 6.1 sequence of linkages are related to CFM production while the 6.2 sequence are related to SST operations, but there are interrelationships. Figure C.7 shows the linkages described under Link 6.

Link 6.1 - CFM Related Effects

Link 6.1.1 - Ozone Reduction by CFMs

Ozone in the stratosphere may be catalytically reduced by chlorine compounds. The following equations describe the process [16 page 1].

$$O + ClO \rightarrow Cl + O_2$$

$$Cl + O_3 \rightarrow ClO + O_2$$

$$\text{NET: } O + O_3 \rightarrow O_2 + O_2$$

The rate coefficient of this reaction has been estimated to be five times the corresponding coefficient for ozone reduction by NO_X. Natural, as well as human produced chlorine compounds are present in the atmosphere. In this effort ozone reduction from manmade chlorine compounds are estimated.

A. Model Development

The destruction of ozone by CFM's is modeled as follows:

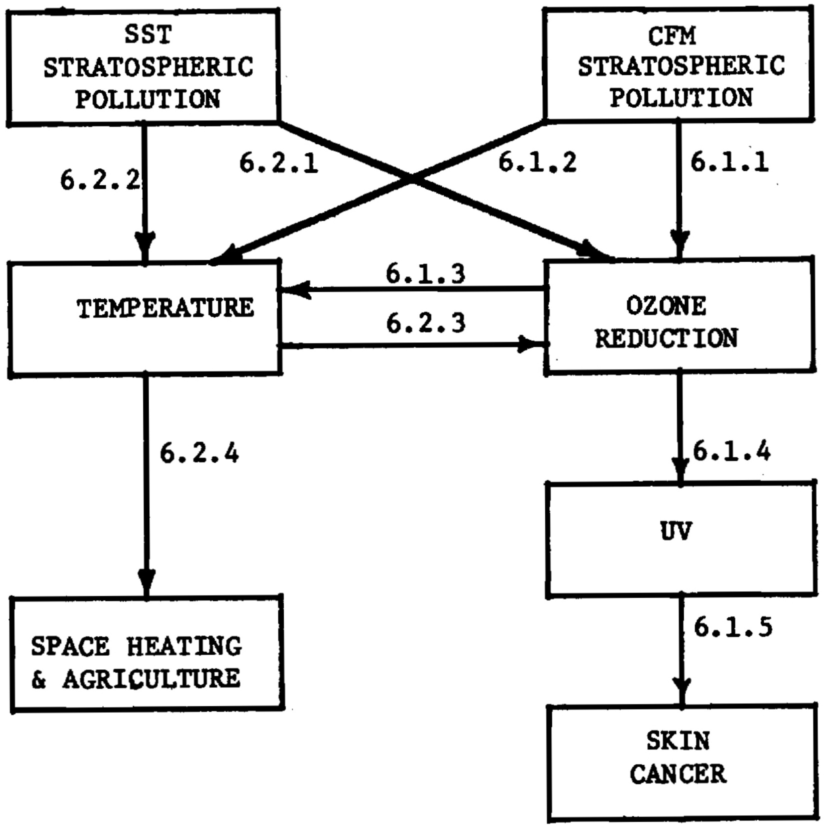

Figure C.7 Detailed Breakdown of Link 6.

$$\Delta O3(t) = A * \Delta O3(t-1) + B * PD(t-D)$$

where

$\Delta O3(t)$	is the percentage reduction of ozone
A,B	constant coefficients
PD(t)	Production of CFM's in year t
D	transport delay

B. Parameter Estimation and Validation

Table C.12 summarizes the parameter values used in this model.

The equation coefficients were estimated using a multiple regression approach to fit Chang's model results [2]for three different CFM production scenarios. The three scenarios were:

1. continue production increasing at 10% per year from 1973 level
2. constant production (at 1973 level)
3. continuing production up through 1978, at which time all production stops.

Figures C.8 , C.9 and C.10 compare the response of the model above to the three scenarios with Chang's predicted response. The curve marked "Chang" is the Chang prediction, while "GT" is the result of the model above.

It is apparent from the figures that this simplified model performs quite well in predicting the response to the three production scenarios.

It is reassuring that the model fits the three scenarios, and the three scenarios cover the probable range of actual production time histories. However, it must be noted that the model response to the actual production (if different from the scenario) may not fit the actual system response as well as it fits the scenarios. A further caveat is that the analysis involves a model of a model, thus compounding estimation errors.

Table C.12 Parameter Estimates for Ozone Reduction by CFMs

Parameter	Value	Units
$\Delta O_3(t)$	Calculated	%
A	.9926	N/A
B	1.72E-6	N/A
PD(t)	Figure 3.9	Metric Tons
D	5	Years

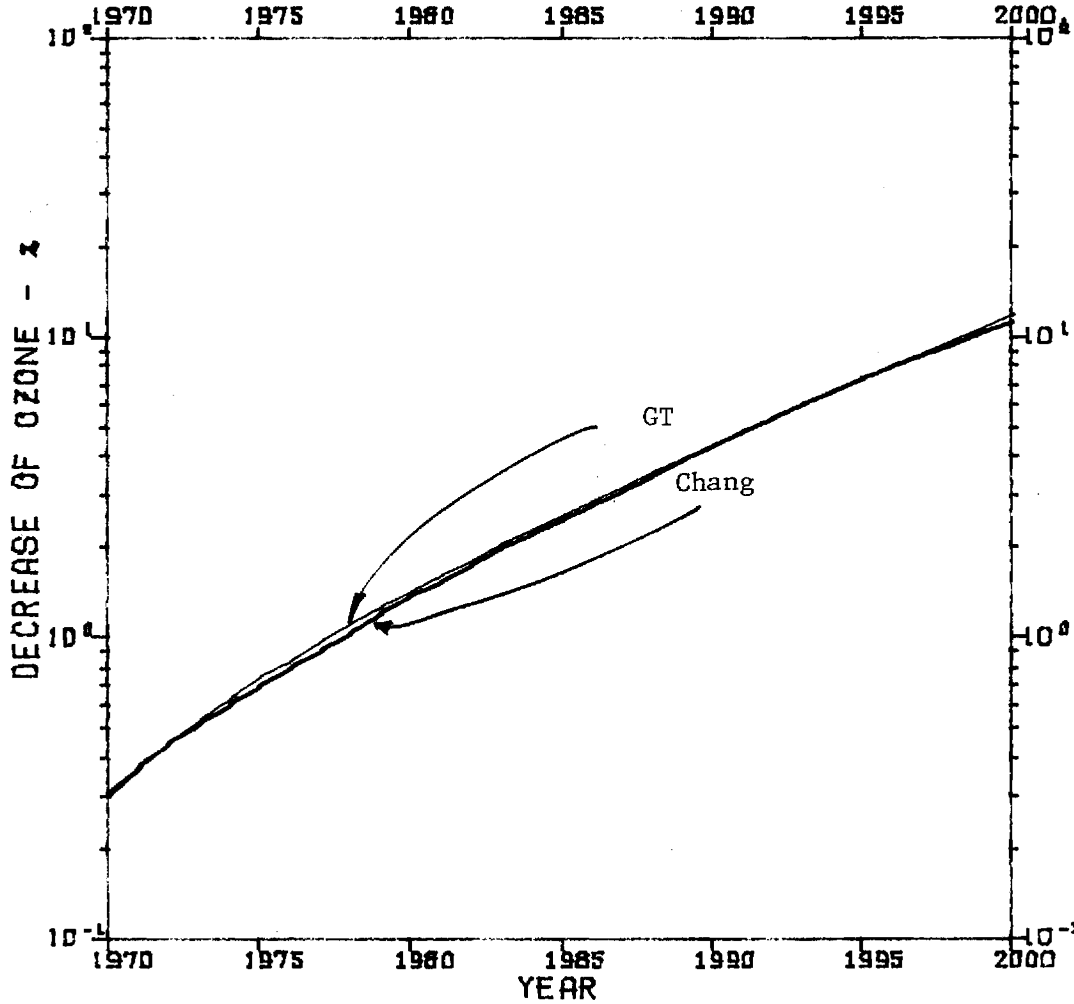

Figure C.8 Model Predictions of Ozone Depletion Due to Production of CFMs Increasing at 10% Per Year from 1973 Rate.

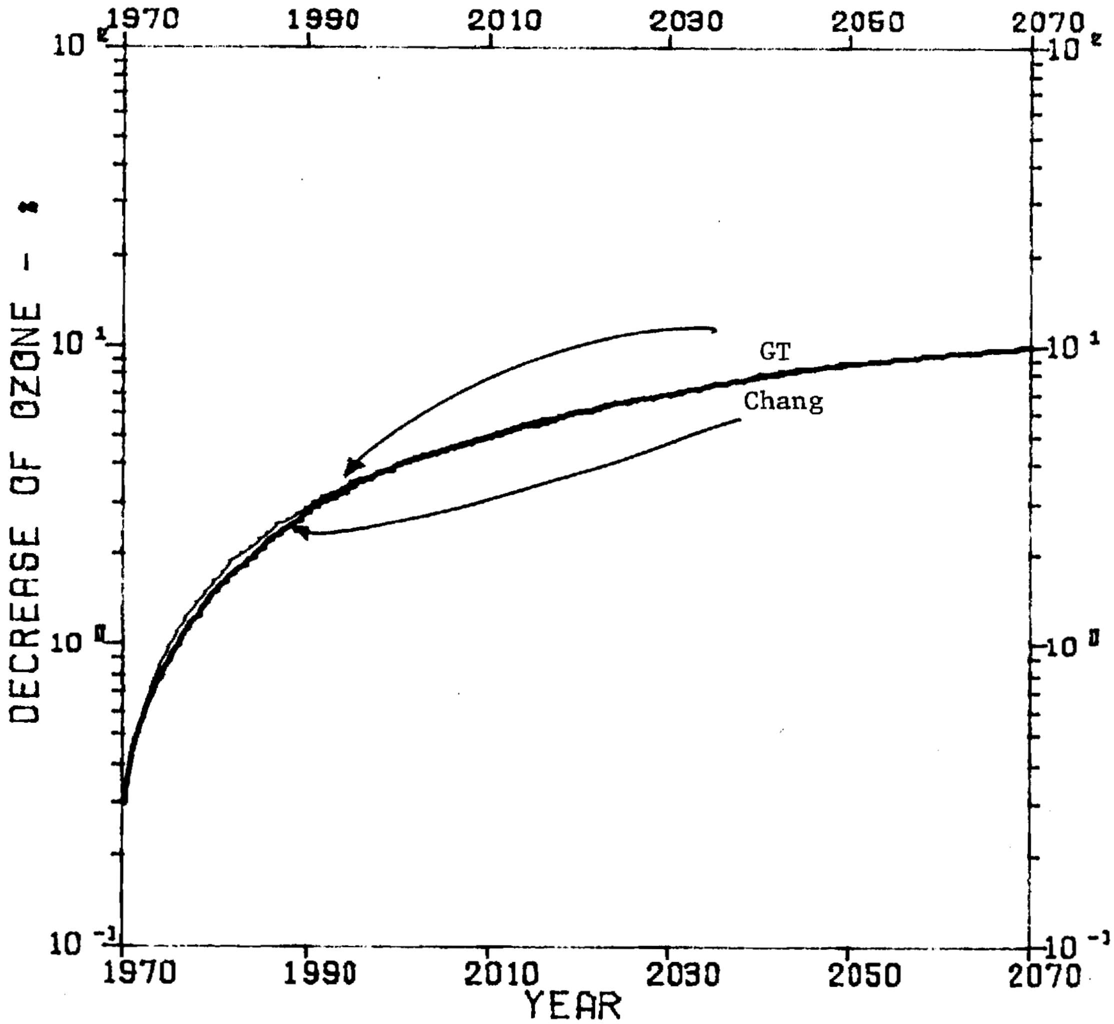

Figure C.9 Model Predictions of Ozone Depletion Due to Production of CFMs Held Constant at 1973 Rate.

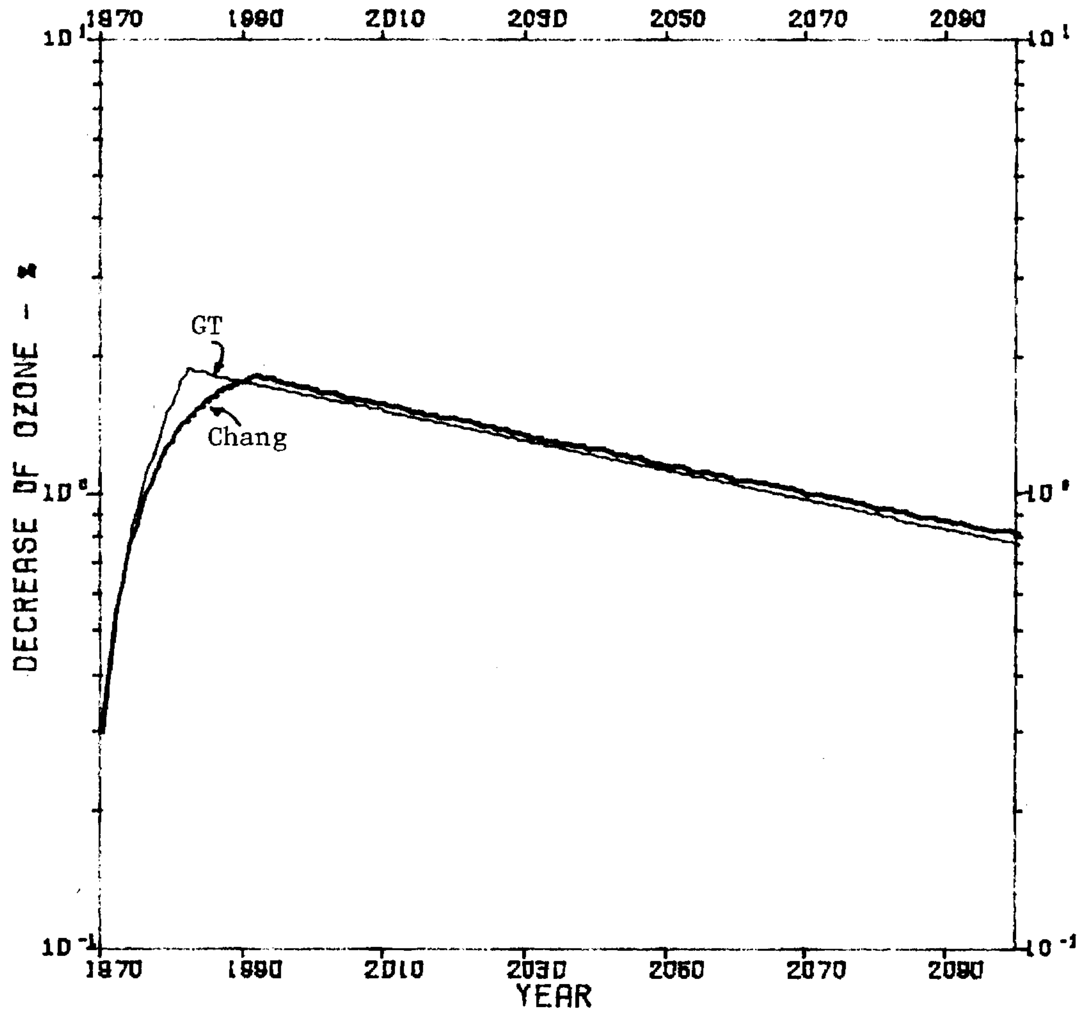

Figure C.10 Model Predictions of Ozone Depletion Due to Productions of CFMs Increasing at 10% Per Year from 1973 Rate, then Ceasing Production in 1978.

Link 6.1.2 Temperature Change by CFMs

A. Introduction

Unlike SST emissions which are injected directly into the stratosphere, chlorofluoromethanes (CFMs) are released at the earth's surface, into the troposphere. CFMs released from spray cans, refrigeration units, and industrial processes diffuse through the troposphere to the stratosphere. Relative to the stratosphere, the troposphere is very turbulent and complete aerodynamic mixing occurs rapidly (in one or two years). The CFMs then slowly "leak" into the stratosphere where moderately rapid horizontal and slow vertical mixing occur. After several more years, the CFMs have ascended (more or less randomly) to a height where 185-225 nm ultraviolet light is encountered and absorbed to produce "odd chlorine" compounds which destroy ozone and hence affect earth surface temperature and ultraviolet radiation. This process pertains mainly to the CFMs F-11, F-12, and carbon tetrachloride which are chemically inert in the troposphere and lower stratosphere. The release rate of carbon tetrachloride has been decreasing in recent years and is only a fraction of those of F-11 and F-12. Others, such as F-22, F-21, methyl chloride, also attack ozone but in a much more limited extent because they are largely decomposed in the troposphere.

CFMs can affect earth surface temperature in a more direct manner since they have strong radiation absorption bands spanning about half of the atmospheric infrared region (at wavelengths of 8-12 mm, where the atmosphere is otherwise optically transparent). This direct effect tends to increase the earth surface temperature (counter to the ozone destruction effect) in the same manner as CO_2, the "greenhouse effect" [24] (since CO_2 is nearly completely absorbing in present-day concentrations, it is of no interest here [17]).

B. Model Development

The approach to modeling the direct temperature effect is to relate global CFM production, through time, to global average temperature change. This can be done by choosing coefficients for the two linear first-order constant coefficient difference equations:

$$CFM(t) = \alpha * CFM(t-1) + \sum_{i=1}^{\ell} \beta_i * P(t-i) \qquad (1)$$

$$T(t) = T(t-1) + \gamma * (CFM(t) - CFM(t-1)). \qquad (2)$$

Equation 1 represents the mass of CFMs affecting the surface temperature of the earth in year t. The fraction, α, of CFMs remaining in the atmosphere from last year, t-1, is 97% as given in [2 ,p.61]; in other words, the natural depletion rate of CFMs is 3% per year. The summation term represents a diffusion pattern, into the atmosphere, of new CFM production. P(t-i) is total CFM production for year t-i, and in the present year, t, onlya certain fraction, β_i, of the total P(t-i) will actually begin affecting the earth's radiative balance, hence temperature. This summation term can be thought of as a weighted moving average of delayed CFM production, with the sum of the weights themselves being less than or equal to one (if all CFMs produced reach the upper atmosphere, then $\sum_i \beta_i = 1.0$; since they are depleted at 3% per year, however, the $\{\beta_i\}$ should sum to 0.97). The i= 1,2,...,ℓ-year diffusion and delay period is based upon aerodynamic mixing as well as upon the fact that CFMs are not released immediately upon production.

Equation 2 represents the cumulative change in global average surface temperature, T, in year t relative to global average temperature in the baseline year, t=0. The parameter γ is a conversion factor relating incremental change in CFM mass to incremental change in temperature. As before, temperature is in terms of degrees Celsius. Table C.13 summarizes the parameter descriptions.

Table C.13 Parameters for Modeling Temperature Change Due to Chlorofluoromethane Release

Parameter	Description
CFM(t)	Atmospheric burden (mass) of chlorofluoromethanes in year t
P(t-i)	Global production (mass) of chlorofluoromethanes in year t-i.
T(t)	Average global temperature change (°C) from baseline in year t
α	Fraction of chlorofluoromethanes remaining in atmosphere from one year to the next
ℓ	Maximum delay time (years) between production and diffusion of chlorofluoromethanes
β_i	Fraction of chlorofluoromethanes produced in year t-i affecting earth's radiative-convective balance in year t.
γ	Conversion factor relating incremental change in atmospheric chlorofluoromethane burden to incremental change in average global temperature.

C. Parameter Estimation and Model Validation

In order to estimate and validate the remaining parameters for the model, historical data for annual global production of F-11 and F-12 were obtained from [2, p. 39] and future values projected according to the scenarios:

1) continue production increasing at 10% per year from 1973 level; and
2) continue production at constant 1973 level.

Various values of the parameters, ℓ, γ, and $\{\beta_i\}$ were used in simulating the above model and scenarios for T, and the results were compared to those obtained by Ramanathan [17]. Using the parameter estimates shown in Table C.14 a reasonable approximation of Ramanathan's results was found as shown in Figures C.11 and C.12. The temperature changes indicated assume uniform global mixing and distribution of CFMs and assume a maintained state of radiative-convective equilibrium.

Though this model "fits" results published in the literature reasonably well, there has been considerably less research in this area than has been reported for other phenomenon. For this reason, this model is not included in the base-case analysis.

Table C.14 Parameter Estimates for Modeling Temperature Change Due to Chlorofluoromethane Release

Parameter	Estimate	Units
CFM(t)	(intermediate dependent variable)	10^3 metric tons
P(t-i)	see	10^3 metric tons
T(t)	see Figures C.11, C.12	°C
α	0.97	n/a
ℓ	6	years
β_1	0.000	n/a
β_2	0.096	n/a
β_3	0.096	n/a
β_4	0.194	n/a
β_5	0.390	n/a
β_6	0.194	n/a
γ	0.000014	°C/10^3 metric tons

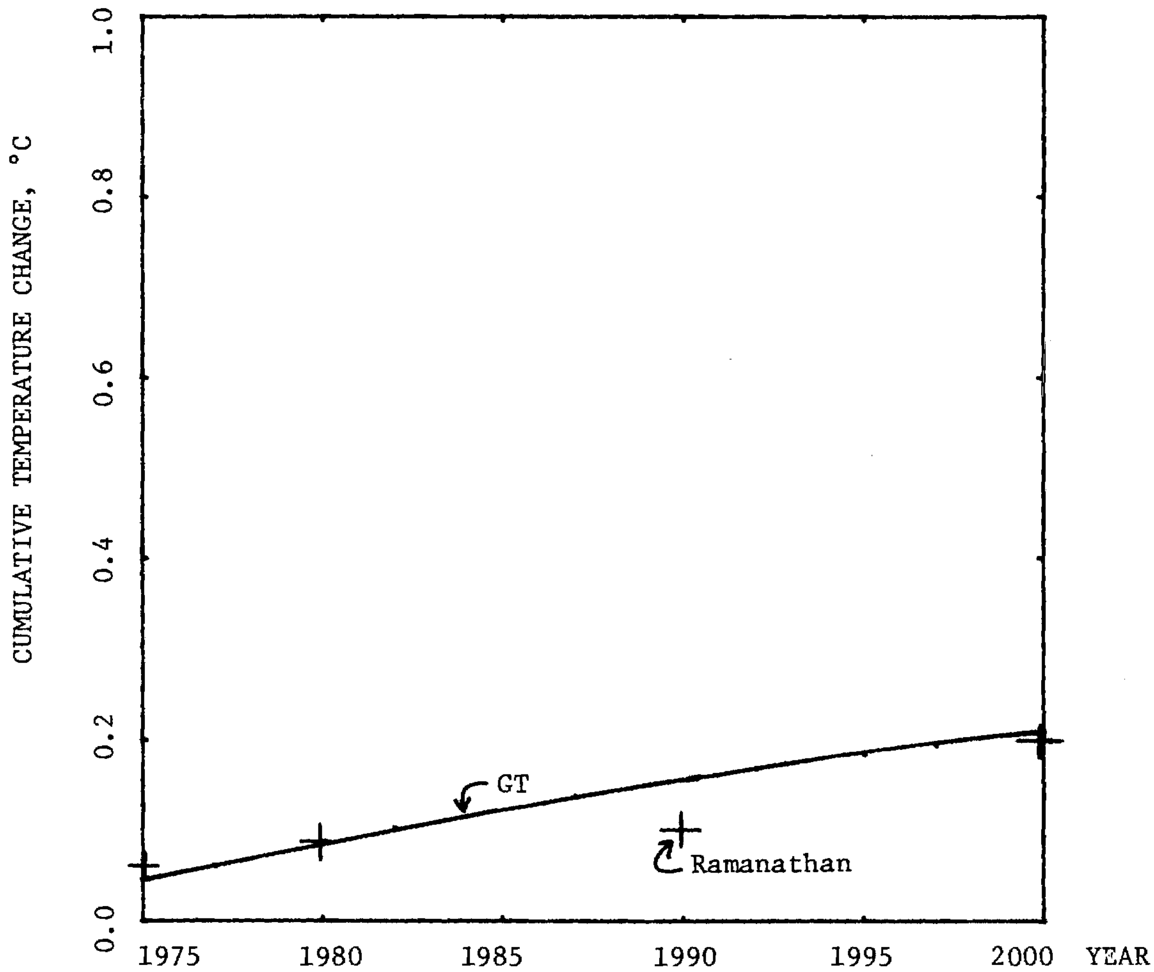

Figure C.11 Model predictions for temperature change due to total global CFM production continuing at the 1973 production level.

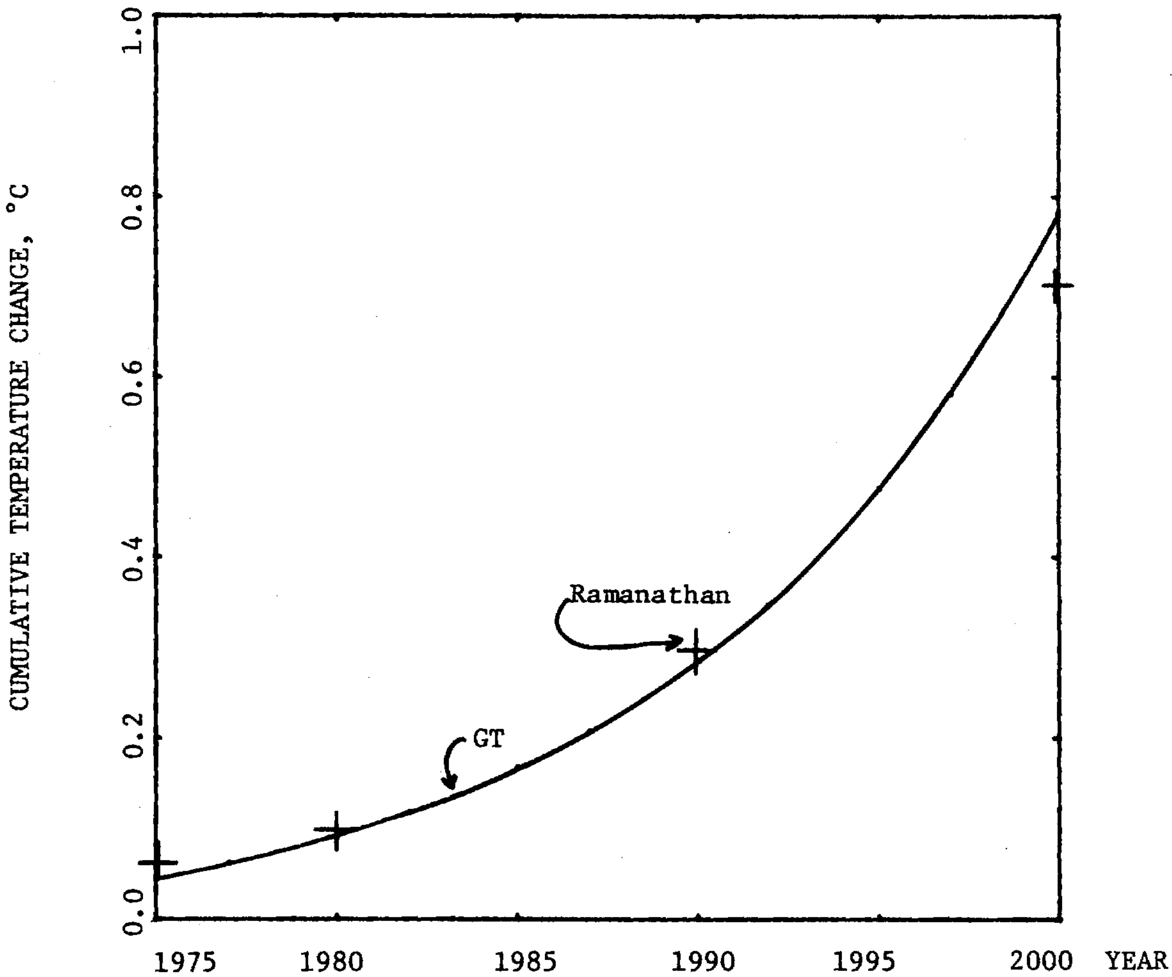

Figure C.12 Model predictions for temperature change due to total global CFM production increasing at 10% per year from the 1973 production level.

Link 6.1.3 Ozone - Temperature Effects

The effects of ozone change or global average temperature are the same, regardless of whether the ozone is reduced by CFM's or SST effluents. The description of temperature effects of ozone is in Link 6.2.2.

Link 6.1.4 Ozone - Ultraviolet Radiation

Observations indicate that there will be approximately a 2 percent increase in biologically effective ultraviolet radiation for each one percent depletion in the ozone level [1]. The two-fold increase will grow gradually with increased ozone thinning until, when total ozone depletion reaches 20 percent, the ratio of irradiance increases for ozone decrease becomes three to one. Figure C.13 gives a plot of percent reduction in global average ozone versus percent increase in global average biologically effective ultraviolet radiation.

The primary assumption for this model is that changes in the "average" level of ultraviolet radiation may be linked directly to change in average global stratospheric ozone. This is a very simplified model, since many variables other than ozone certainly effect the incident ultraviolet radiation. In defense of the simplified approach, it is believed by experts that biological damage is related to cumulative exposure to ultraviolet radiation. [17]. This cumulative exposure has a smoothing or averaging effect. and therefore reduces errors caused by such an assumption.

Link 6.1.5 Ultraviolet Radiation - Skin Cancer

Both CIAP and NAS report that a reasonable working hypothesis is that the long run incidence of skin cancer (non-melonoma) increases by five cases per one hundred thousand population with each one percent increase in biologically effective ultraviolet radiation. As has been mentioned previously, it is cumulative exposure to ultraviolet radiation that is believed to be

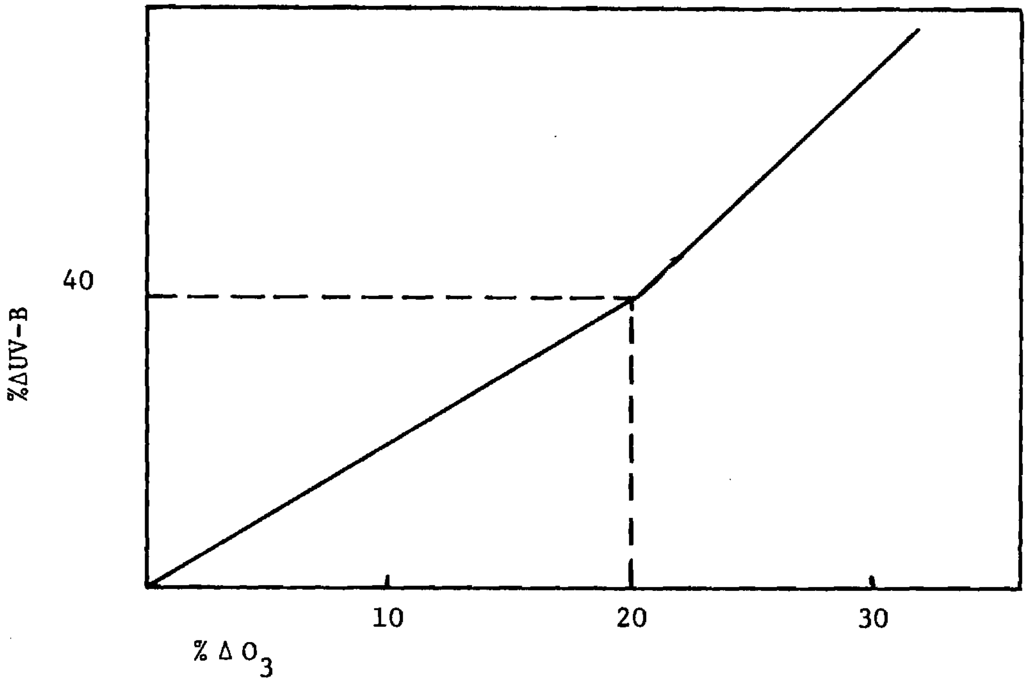

Figure C.13 Percentage Change in Global Average Ozone Versus Percentage Change in Global Average UV-B.

linked to incidence of skin cancer.

The approach for modeling the number of additional cases of non-melanona skin cancer is indicated in Equation 5.

$$N(t) = \sum_{t-60}^{t} \frac{\Delta uv(t)}{6} \qquad (5)$$

Where N(t) is the number of additional cases of non-melanona skin cancer in year t $\Delta uv(t)$ is the percent increase in biologically effective radiation in year t due to ozone reduction.

This assumes that the skin cancer results from a 60 year exposure to ultraviolet radiation. The constant six was obtained by fitting Equation 5 to CIAP predictions of increasing skin cancer due to postulated changes in ultraviolet radiation.

The total number of additional cases of skin cancer is obtained as described by the following equation:

$$NC(t) = N(t) \times P(t)$$

where NC(t) is the total number of additional cases of skin cancer

P(t) is the U.S. population in year t

N(t) is as described above

These parameters are summarized in Table C.15.

Population data was obtained from the Statistical Abstract of the United States [28]. Figure C.14 illustrates population projections under several scenarios. It was recommended [29] that the series II projection be used. Effects of the other scenarios will also be investigated.

TABLE C.15

Parameters in the Model of Skin Cancer Due to Ultraviolet Radiation

Parameter	Description
N(t)	Number of additional cases of skin cancer per 100,000 population in year t
$\Delta uv(t)$	Percent increase in biologically effective ultraviolet radiation in year t
NC(t)	Total number of additional cases of skin cancer in year t
P(t)	Projected U.S. population in year t (see Figure 3.19)

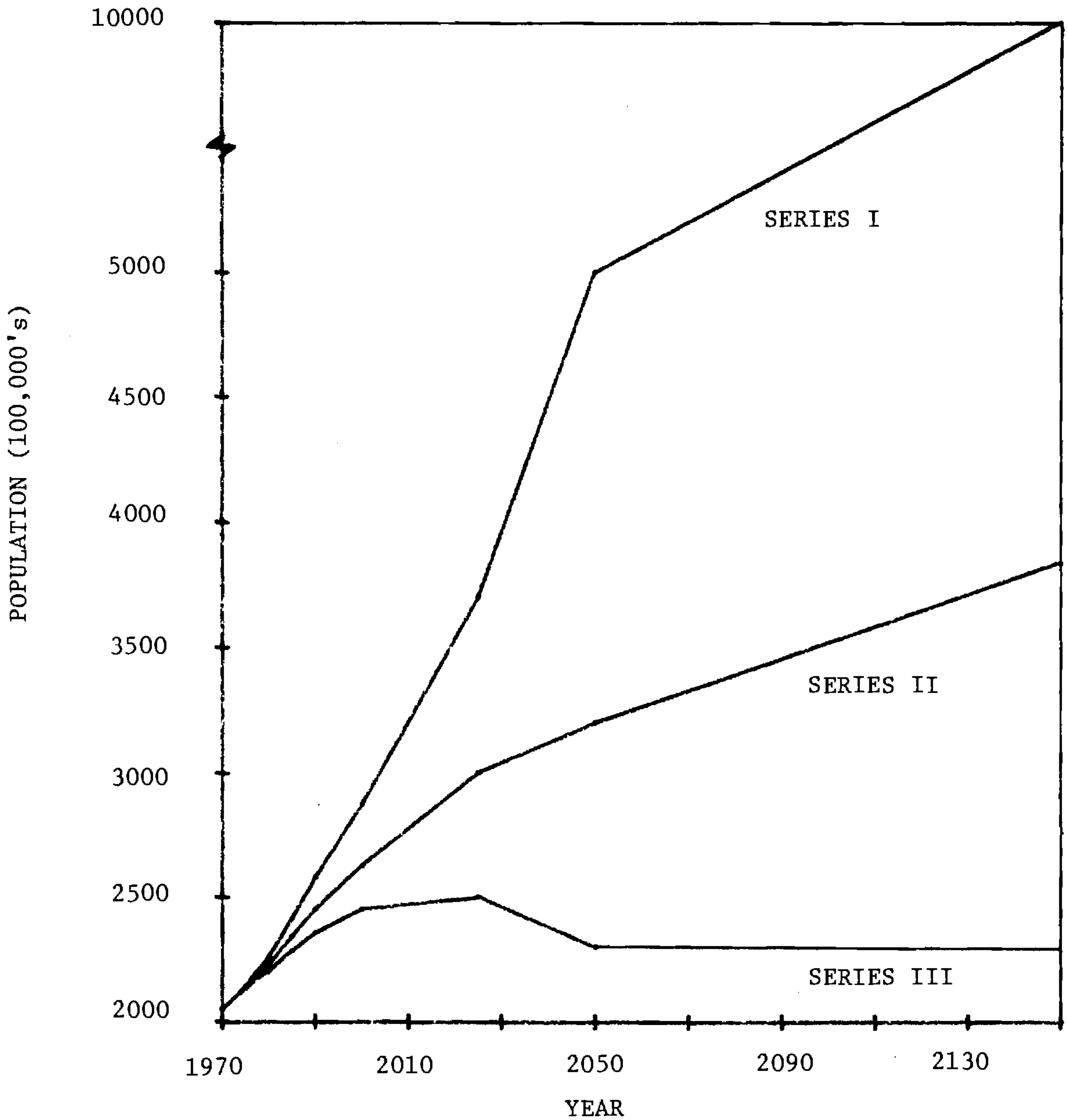

Figure C.14 U. S. Population Projections

Link 6.2 SST Related Effects

There have been several efforts [20,21,22,23,24,25,26] modeling stratospheric pollution effects of aircraft (subsonic, supersonic, and space shuttle). There is substantial disagreement among modeler's results due to various existing data deficiencies, uncertainties, philosophical differences, etc; thus stratospheric pollution modeling is very much an ongoing effort. The approach taken here is to use the best available published results and to maintain a high degree of computational efficiency in modeling and projecting the impacts of stratospheric flight effluents. Consequently the models used here produce results that are at best highly tentative; in addition, since we are modeling the results of more complex models, estimation errors are likely to be compounded.

Link 6.2.1

Ozone Reduction by NO_X

A catalytic cycle involving NO_X's (NO and NO_2) accounts for about 70 percent of the natural ozone destruction rate. The reactions are as follows:

$$O + NO_2 \rightarrow NO + O_2$$

$$NO + O_3 \rightarrow NO_2 + O_2$$

$$\text{NET} \quad O + O_3 \rightarrow O_2 + O_2$$

The major source of NO_X in the stratosphere is from oxidation of N_2O which is produced by bacteria in the soil and water. Supersonic aircraft flying in the stratosphere inject NO_X, thereby shifting the balance between ozone formation and destruction processes.

There has also been research [27] indicating that agricultural practices and fertilization may affect stratospheric NO_x levels. As more become known on this potentially important source, it may be included in the model.

A. Model Development

The approach to modeling reduction in O_3 due to NO_x emissions is to relate percentage changes in level of NO_x emissions to percentage changes in level of ozone reduction [1,14,15]. The approach may be further segmented into the steady-state approach and the transient response approach. The steady-state response approach accounts for the ultimate reduction in O_3 due to step increases in emission rate while the transient response approach accounts for the effects of stratospheric transport and residence times.

Figure C.15 gives steady-state percentage changes in O_3, due to step percentage changes in NO_x emission rate for two injection altitudes, 17km and 20 km. Based on $\%\Delta NO_x$ for a given year (percent changes are in every case related back to the base year) the steady-state value of ozone reduction that will result assuming no further changes occur until steady-state is reached is determined from this curve for 17km.

When assessing total costs to society due to delays in detection of ozone reduction, it is necessary to handle time-dependent changes in ozone.

The transient response is approximated with a first order difference equation, as follows:

$$\Delta O_3(t) = \Delta O_3(t-1) - A + SSO_3(t-1)(1-A)$$

where: $\Delta O_3(t)$ is the change in year t of stratospheric ozone from the base year.

$SSO_3(t)$ is the steady-state change in ozone which would result from injections in year t

A is the difference equation coefficient.

The same approach was used in [21] to model ozone reduction by NO_x.

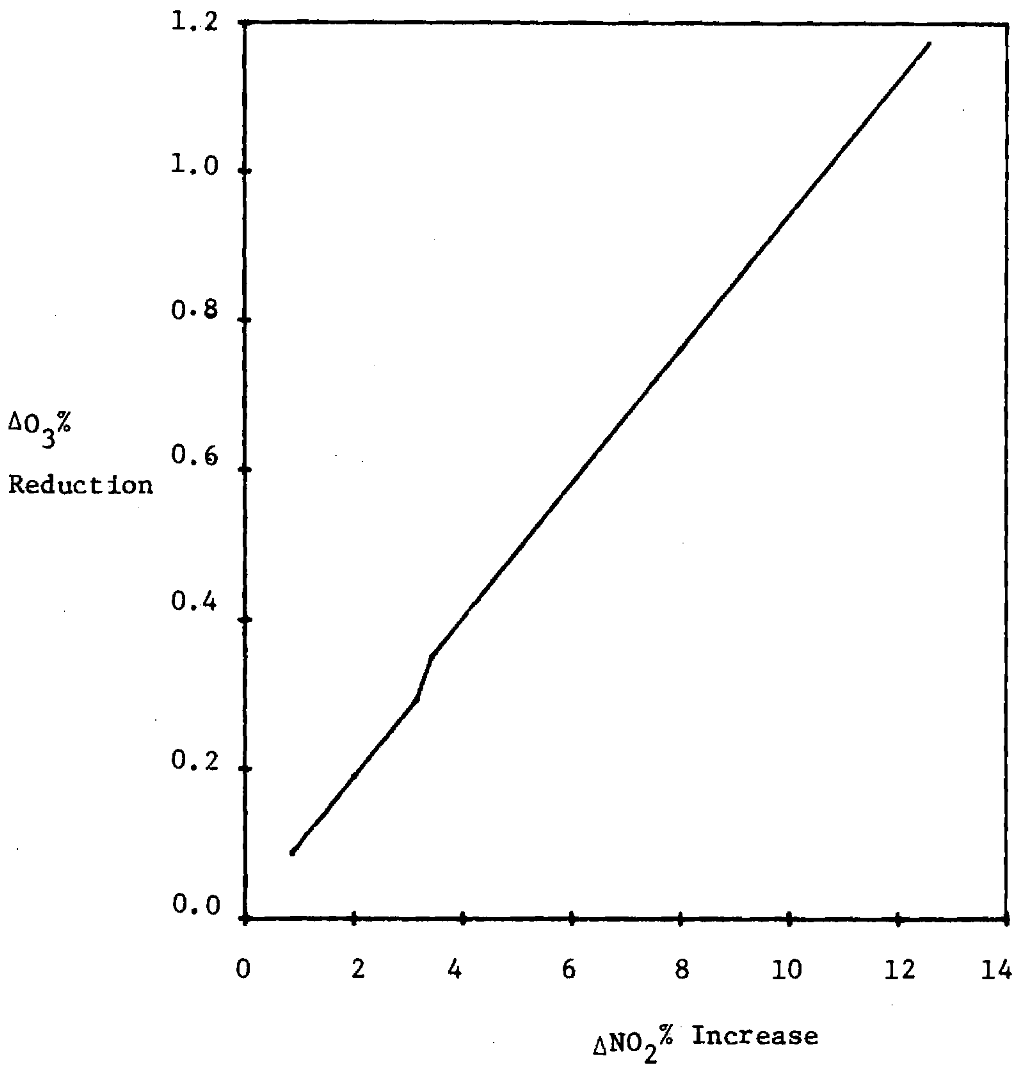

Figure C.15 Steady State Percentage Changes in Global Ozone

The difference equation coefficient A, was found to be .657. This simple model's results are compared with a more complicated model. This comparison is shown in Figure C.16 from [21]. Note the close agreement between the two models.

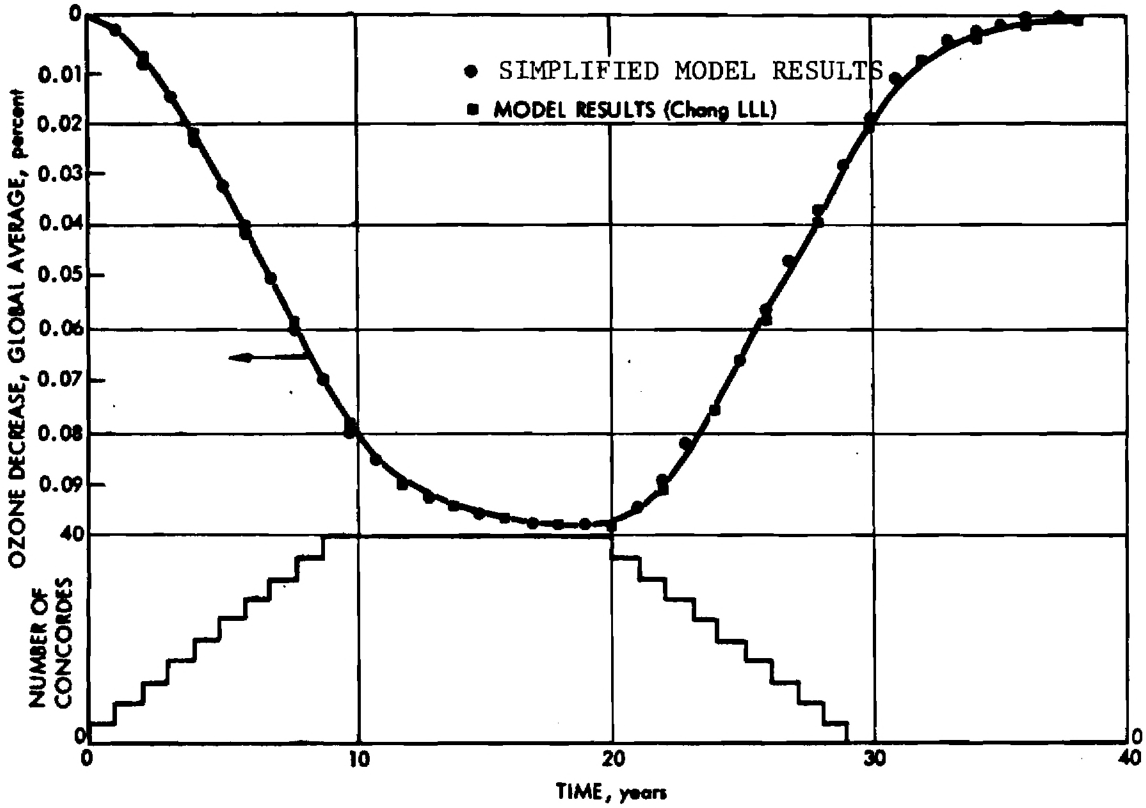

Figure C.16 Comparison of Results of Chang Model and Simplified 1-D Model for a Hypothetical SST Fleet Growth and Decline (from [21]).

Link 6.2.2 Temperature Change by SST Effluents

A. Model Development

SST effluents that have been identified as crucial to global average temperature are H_2O, SO_2, and nitrogen oxides (NO_x): although the primary effluent of fuel combustion is CO_2 influx. The two primary temperature change mechanisms are radiative absorption and the "greenhouse effect."

The climatic effects of these effluents have been estimated [21] using radiative equilibrium, constant relative humidity distribution results from very complex models. These results have been of two forms: constant cloud top altitude (CCTA) and constant cloud top temperature (CCTT). There appears to be no theoretical preference for one or the other. For this treatment, the CCTT models have been adopted. The temperature effects given by these models are steady state temperature changes; for a given influx of effluent, the particular model yields the ultimate temperature change. Therefore, these models have been adapted to include a time delay so that temperature change is not instantaneous; in actuality the full temperature change calculated may require two to six years to be realized [21] Thus the climatic effect of a particular effluent, in a given year t, is modeled in two parts:

1) the ultimate temperature change from the effluent influx is calculated; and
2) the transient response contribution to temperature change for year t is calculated from the ultimate (steady state) change and from the delay (transient response) parameter and is taken to be the temperature change due to the year t influx.

The general form of the model is as follows:

$$\Delta T_{ss}(t) = TC * \Delta PO(t) \tag{1}$$

$$\Delta T(t) = (1-TR) * \Delta T(t-1) + TR * T_{ss}(t) \tag{2}$$

where

$\Delta T_{ss}(t)$ is the steady state change in temperature which would result from pollution in year t

$\Delta T(t)$ is the temperature change resulting from all previous pollution

TC is the temperature coefficient

$\Delta PO(t)$ is the fractional change (from the unperturbed state) in the effluent specie in year t (discussed in Link 5)

TR is the coefficient for the difference equation given the transient response of the temperature change.

Note that Equation (1) calculates the steady state change, while Equation (2) gives the time response.

For reasonably small temperature changes, the total change may be estimated as the simple sum of changes due to each of the constituents. Thus parameters must be estimated for temperature change due to NO_X, SO_2, H_2O and O_3 changes.

These parameters are described in Table C.16 Temperature change due to each of the constituents listed above is estimated by substituting the parameters applicable into the general model (Equations 1 and 2). The change in the level of each of these constituents (ΔPO) is described in Link 4.

B. Parameter Estimation

Parameter estimates are found in Table C.17.

The temperature coefficients (TCH2O, TCNOX, TCSO2, TCO3) are from [21 Appendix F].

The difference equation coefficients (TRH2O, TRNOX, TRSO2, TCO3) were estimated (by trial and error) to give full response in two to three years.

C. Model Validation

Figure C.17 gives the model responses for a step change in SST flight. These may be compared with the steady state temperature changes (as indicated by dashed lines) from [21] page F-10.

Table C.16 Parameters for Modeling Temperature Change due to Aircraft Emissions (Con't)

Parameter	Description
TRNOX	Coefficient for difference equation giving transient response temperature change due to nitrogen oxides
TRSO2	Coefficient for difference equation giving transient response temperature change due to particulates
TRH_2O	Coefficient for difference equation giving transient response temperature change due to water vapor
TRO3	Coefficient for difference equation giving transient response temperature change due to ozone
TCH2O	Temperature coefficient relating change in water vapor burden to steady state change in surface temperature
TCNOX	Temperature coefficient relating change in nitrogen oxides burden to steady state change in surface temperature
TCSO2	Temperature coefficient relating change in particulate burden to steady state change in surface temperature
TCH2O	Coefficient for difference equation giving transient response temperature change due to water vapor

Note: All references to temperature pertain to annual global average.

Table C.17 Parameter Estimates for Temperature Change by Aircraft Effluents

Parameter	Estimate
TRNOX	.5
TRSO2	.5
TRH2O	.5
TRO3	.5
TCH2O	1.5
TCNOX	.06675
TCSO2	-.915
TCO3	1.875

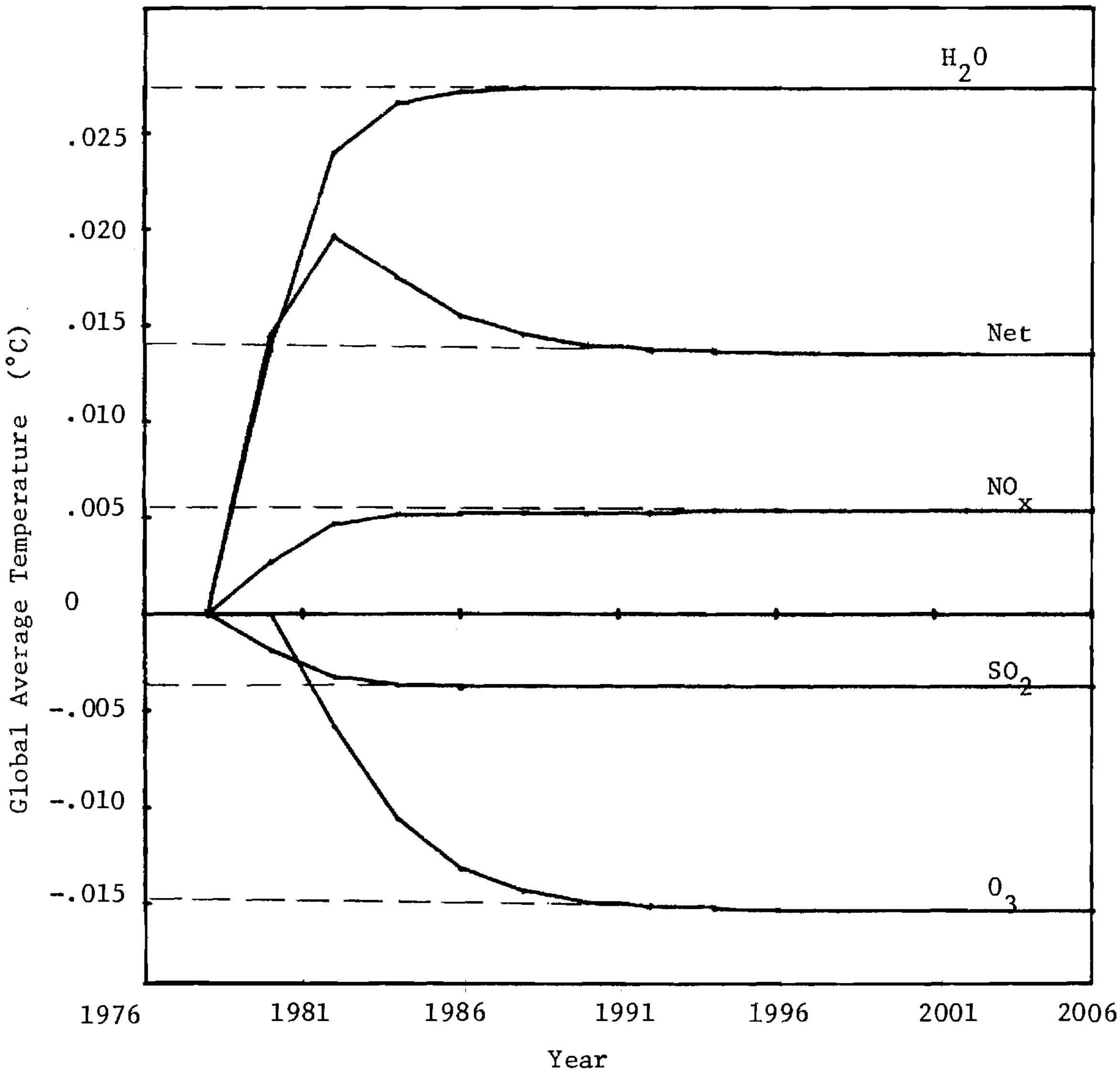

Figure C.17 Global average temperature change due to a step increase in SST flight (11.3 E9 kg/year of fuel)

Link 6.2.3 Temperature - Ozone Effects

Ongoing research suggests that there may be significant "temperature feedback" affecting the rate at which ozone is changed. As more information becomes available on this phenomenon, it should be included in the model.

Link 6.2.4 Temperature - Space Heating & Agriculture Effects

The potential effects of changes in global average temperature are many and varied and little is known with certainty about the magnitude or nature of the possible effects. Link 7.2 describes the process used to estimate the potential costs of global climate modification.

Link 7 Pollution Damage - Damage Costs

This link estimates the economic cost to society of the damage done by stratospheric pollution. The damage is from the two causes already described. They are: 1) increased incidence of skin cancer and 2) climatic changes.

Link 7.1 Ozone Related Costs

The number of additional cases of non-melanona skin cancer is estimated as described in Link 6.1.5. The cost of each case, of course, depends on its severity and possible complications. Many cases may require little more than one office visit. Others, however, may require extensive surgery, and hospitalization. The average cost per case was estimated in [1] to be between $130 and $1300 per case. Adjusted to 1976 dollars (via the Federal Register) the range becomes $190 to $1900. As a base figure $1000 per case is used. To get the cost due to skin cancer in any given year involves simply multiplying the number of additional cases (estimated in Link 6.1.5) by $1000.

Link 7.2 Temperature Related Costs

This link accepts as input the change in average annual temperature and determines the economic costs of this change.

Estimating the economic costs (or benefits) of temperature changes was one of the main thrusts of the CIAP's Volume 6. While much of that work was admittedly tentative, it does provide the best information currently available. Thus, our modeling is based on the CIAP results. As better information becomes available, it will be incorporated into the model.

Table C.18 based directly on CIAP results , is self-explanatory. It forms the basis for our modeling effort. Note there is no attempt to aggregate the estimated costs into a "bottom line" figure. This reflects the fact that, by and large, different methodologies were used to arrive at the different figures, so comparability is not assured. Moreover, as is clear from the table, some figures reflect more geographical coverage than others. Finally, there is overlap in some of the figures. Most notably, the indirect cost estimate of effects on urban and physical resources is a substitute figure for the less complete, but more detailed, direct cost estimates.

While there are undoubtedly some lagged effects of temperature changes on natural and human resources, most effects appear to be more or less immediate. That is, a temperature change in a given year affects crops that year, marine resources that year, etc. Thus, our first cut model will abstract from the lagged effects of temperature on resources.

Another simplifying assumption is the linearity of the temperature effect on resources. This assumption was often adopted in the CIAP research, where it was felt to be the only reasonable approach, given a lack of firm evidence to the contrary.

Finally, in order to make the model tractable, it is assumed that reported economic values of temperature changes for different classes of efforts may

Table C.18 Estimates of Economic Costs of Temperature Change Assuming 5% Discount Rate
(For Changes in Mean Annual Temperature)

Sector Impacted (Coverage)	-1° Change Col. 1	Col. 2	Col. 3	Col. 4	+5° Change Col. 5	Col. 6	+1° Change Col. 7	Col. 8	Col. 9
A. Natural Resources Agriculture									
1. Corn (60% World)	-21	-420	-916.81	-90.42	14	28	560	1222.41	120.55
2. Cotton (65% World)	11	220	480.23	47.36	-3	-6	-120	-261.84	-25.83
3. Wheat (55% World)	92	1840	4016.49	396.10	?	?	?	?	?
4. Rice (85% World)	956	19120	41736.56	4116.03	0	0	0	0	0
Forest Products (U.S.)	661	13220	28857.60	2845.92	?	?	?	?	?
Marine Resources (World)	1431	28620	62473.87	6161.13	-613	-1226	-24520	-53524.08	-5278.51
Water Resources (2 U.S. River Basins)	-2	-40	-87.31	-8.61	0.5	1	20	43.66	4.31
B. Human Resources Health (World) Excluding skin cancer	2386	47720	104166.78	10272.86	?	?	?	?	?
Urban and Physical Resources									
1. Indirect Cost Estimate (wages)	3667	73340	160092.02	15788.17	-1551	-3102	-62040	-135425.54	-13355.53
2. Direct Cost Estimate									
Residential, commercial industrial, fossil fuel demand	176 to 232	3520 to 4640	7683.72 to 10128.54	757.76 to 998.87	-88 to -116	-176 to -232	-3520 to -4640	-7683.72 to -10128.54	-757.76 -998.87
Residential and commercial electricity demand	-748	-14960	-32655.80	-3220.49	353	706	14120	30822.19	3039.66
Housing, Clothing Expenditures	507	10140	22134.35	2182.87	-253	-506	-10120	-23090.69	-2178.57
Public Expenditures	24	480	1047.78	103.33	-11	-22	-440	-960.46	-94.72
Esthetic Costs	219	4380	9560.99	942.90	147	294	5880	12835.30	1265.81

Col. 1 Annualized Cost as of 1974 in millions of 1971 dollars (minus sign denotes benefits) as reported in CIAP Report of Findings, page H-26, Table 2.

Col. 2 Present Value of costs as of 1974 =(Col. 1) x 20 since PV = AV $\left(\sum_{1}^{\infty} \frac{1}{1.05}\right)$ = AV x 20

Col. 3 Present Value of Cost as of 1990 = (Col. 2) x $(1.05)^{16}$

Col. 4 Equilibrium Value of Costs as of 2025 and thereafter = (Col. 3)/10.14 since PV(1990) = $\frac{x/36}{1.05^0} + \frac{2x/36}{1.05^1} + \ldots + \frac{36x/36}{1.05}35 + \frac{x}{1.05}36 + \frac{x}{1.05}37 + \ldots$

which implies that $x = \frac{PV(1990)}{10.14}$

Col. 5 Annualized Cost as of 1974 in millions of 1971 dollars (minus sign denotes benefits) as reported in CIAP Report of Findings, page H-27, Table 3.

Col. 6 Annualized Cost of +1° Change = (Col. 5) x 2

Col. 7 Present Value of Costs as of 1974 = (Col. 6) x 20

Col. 8 Present Value of Costs as of 1990 = (Col. 7) x $(1.05)^{16}$

Col. 9 Equilibrium Value of Costs as of 2025 and thereafter = (Col. 8)/10.14

be meaningfully aggregated. Thus, the annual sum of the effects (at the 2025 equilibrium) of a -1°c change is 24,628 millions of 1971 dollars (this excludes the indirect cost estimate for urban and physical resources) and of a +1°c change is -4026 millions of 1971 dollars.

To convert to 1976 dollars the following price indexes [30] were used:

Year	Index	(Farm products)
1971	112.9	
1976	196.5	

So, converting to 1976 dollars.

$$\frac{196.5}{112.9} \times (24{,}628) = 42864$$

$$\frac{196.5}{112.9} \times -4026 = -7007$$

Therefore, letting

C_t = Costs at time t of temperature change, in millions of 1976 U. S. dollars

ΔT_t = Change in mean annual temperature in °C

$$C_t = \Delta T * 42864 \quad \Delta T<0$$

$$= \Delta T * -7007 \quad \Delta T>0$$

Link 8 Total Costs to Society - Net Present Cost

Link 8 discounts the total costs to society to a base year. The "total cost" is composed of two components: 1) cost of regulations (link 3) cost of pollution damage (link 7). The costs are discounted to a common base year in order to compare the effects of various monitoring systems. The costs are reduced to a single figure to provide a means of evaluating the "trade-offs" between the long term cost reductions of restrictive policies and the more immediate costs of implementing these policies. The total discounted cost is a quantification of the level of social well-being.

The calculation is as follows:

$$PV = \sum_{i=1}^{N} \frac{C_i}{(1+d)^i}$$

where

PV = present value of the time stread of costs

d = discount rate for future costs

i = year index

N = time horizon for costs to be considered

Ci = costs incurred in year i

The discount rate selected was 5 percent. Any discounting at all understates the weight of future costs. Since the onus for this work is concern for future generations this seems contradictory. However, in keeping with government tradition, discounting is used, but at 5 percent rather than the usual 10%. The sensitivity of the results to this assumption are explored in the next section.

The base time horizon considered was 50 years. Since there are long delays in some of the linkages, the affects of a policy may lag its implementation by several decades.

C.3 Representative Benefit Calculation

The purpose of this section is to present a representative procedure for calculation of benefits of additional monitoring of the stratosphere. The steps taken by the model to relate postulated monitoring system improvements to benefits to society are illustrated graphically. Table C.19 presents the major assumptions for this benefit calculation.

Figure C.18 illustrates the postulated trend detection capabilities of ozone and aerosol monitoring systems. In each case the "alternate" monitoring system requires one half of the time needed by the baseline system to detect any trend. For a trend in ozone reduction of say 1 percent per decade, the baseline system detects it in 8 years, while the alternate system requires only 4 years of continuous monitoring for detection with 95 percent confidence. Since the aerosol monitoring systems are postulated to have the same capabilities as the ozone monitoring system, the same trend (i.e., 1 percent per decade increase of aerosol loading) requires the same length of monitoring time. Thus an increase in aerosol loading of one percent per decade requires 8 years for the baseline system to detect, but only 4 years for the baseline system to detect.

The method of policy selection was to compute the total cost to society which would result from each of the policies, then select the one with the minimum total cost. Table C.20 illustrates these results for our trial point (1% per decade increase in aerosols and 1% per decade decrease in ozone). The minimum cost policy (policy number 4) reflects the costs of pollution regulation and damage. These cost figures are present worth figures - future costs are discounted at 5% per year.

Figure C.19 presents the global production of CFMs for three cases: both baseline monitoring systems, 2) baseline aerosol and alternate monitoring systems, 3) both alternate monitoring systems. These three cases will be

TABLE C.19 Assumptions Used in the Illustrative Example

- Postulated trend in ozone reduction of 1 percent per decade.
- Postulated trend in aerosol increase of 1 percent per decade.
- "optimal" policy selection.
- Alternate monitoring systems require only half the time required by baseline to detect trends.

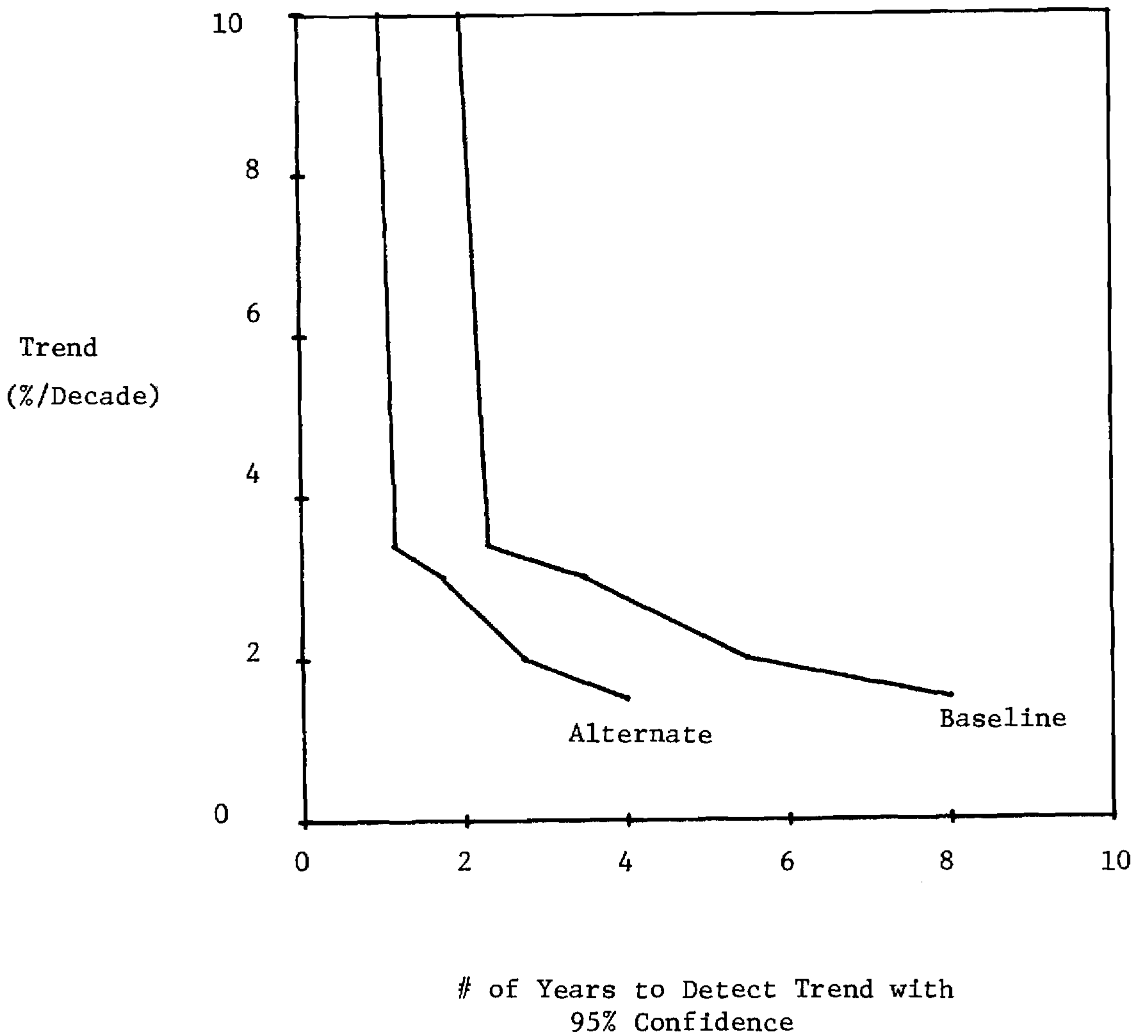

Figure C.18 Postulated Capabilities of Monitoring Systems. (Trend applies to Ozone Reduction or Aerosol Increase).

TABLE C.20 Social Cost of Policies

	CFM Policy	SST Policy	Cost to Society (Million $)
1	Do-Nothing	Do-Nothing	89,529
2	Ban Propellants	Do-Nothing	82,682
3	Ban Propellants	Reduce SST Fleet by 1/2	83,151
4	Ban Propellants	Desulfurize Fuel	82,292
5	Ban Propellants	Ban SST's	83,580
6	Ban All CFM's	Do-Nothing	90,427
7	Do-Nothing	Ban SST's	90,792

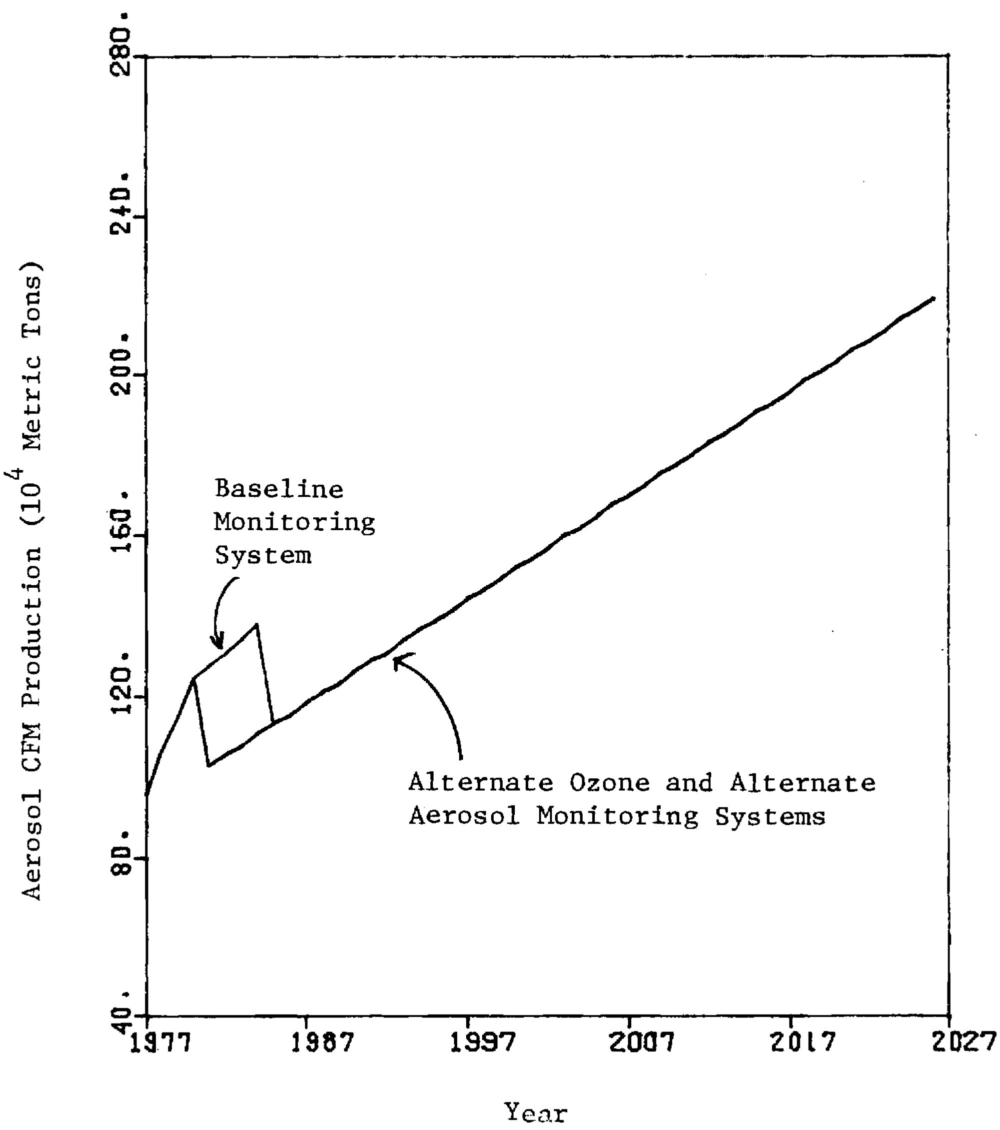

Figure C.19 Global CFM Production

presented throughout this illustration. For the baseline case CFM production abruptly decreases in 1994; when the alternate ozone monitoring system is used, the decrease occurs in 1985. These decreases correspond to banning propellant uses of CFMs, which is about 1/2 of the U.S. production of CFMs. It is assumed that the non-U.S. production of CFMs is unaffected by the policy. Since the policy does not call for regulation of the amount of flight allowable, fuel consumption reflects the full projected SST fleet.

Figures C.20 to C.23 show the global average surface temperature changes which may result from the SST flights. Note that changes due to NO_x and watervapor are the same for all three cases, while changes due to ozone, and aerosols is different. The temperature change due to ozone is different because ozone reduction varies according to policy selection, and date of implementation. Temperature change due to aerosols also varies since the policy selected involves de-sulfurization of aircraft fuel.

Figure C.24 indicates the cost of fuel desulfurization in each case. Note that the difference between the cases with the baseline aerosol monitoring system and the case with the alternate aerosol monitoring system is simply when the costs begin to occur.

Figure C.25 shows the cost of regulating CFM production. Again the costs are the same, the only difference being when it occurs. The costs of banning CFM's in propellant uses has been characterized by a single cost for two consecutive years.

Figure C.26 and C.27 show the ozone reduction over time, which results from each of the scenarios. Note that the alternate aerosol monitoring system has no effect on ozone reduction, since desulfurization of fuel is the policy affected by it.

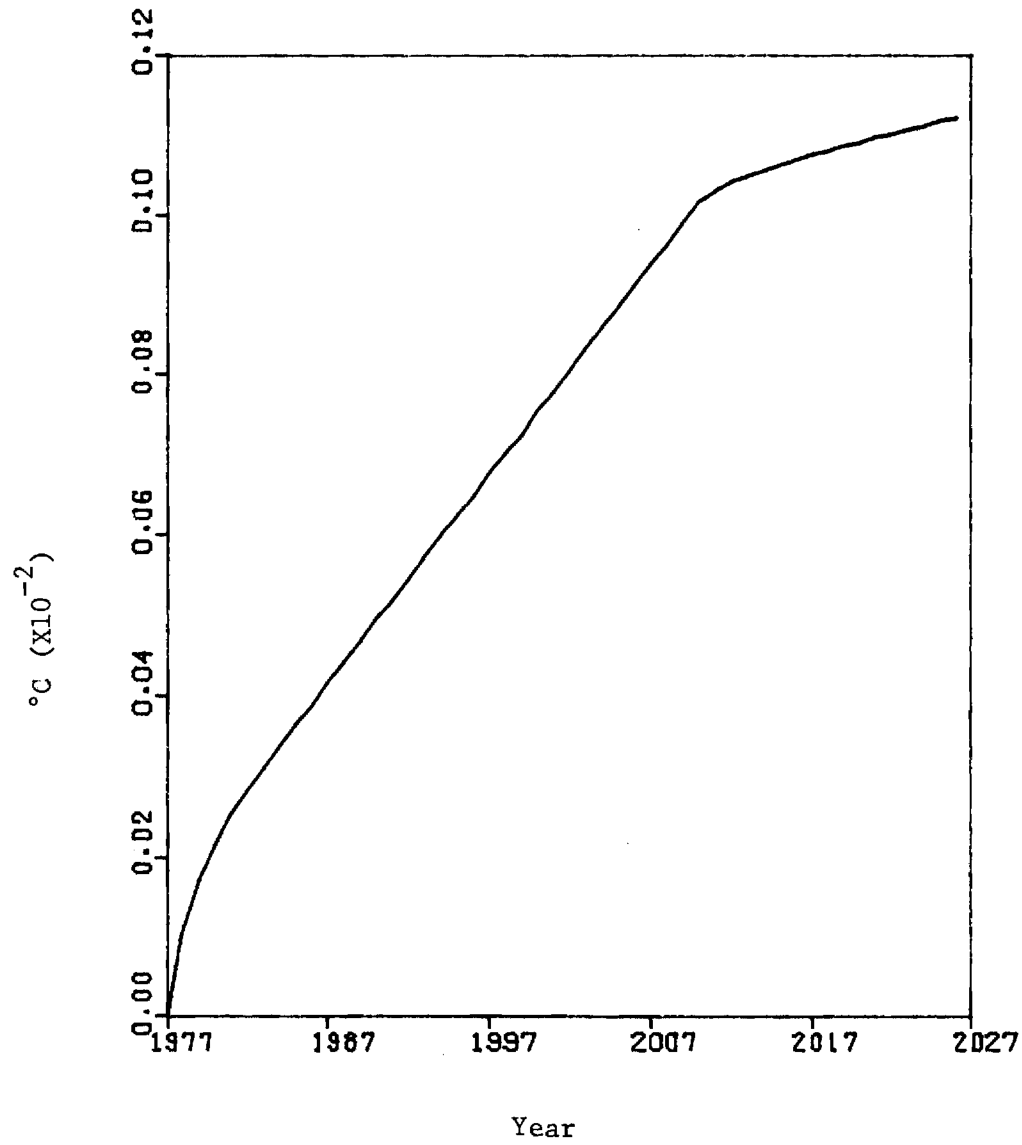

Figure C.20 Global Average Temperature Change Due to NO_X

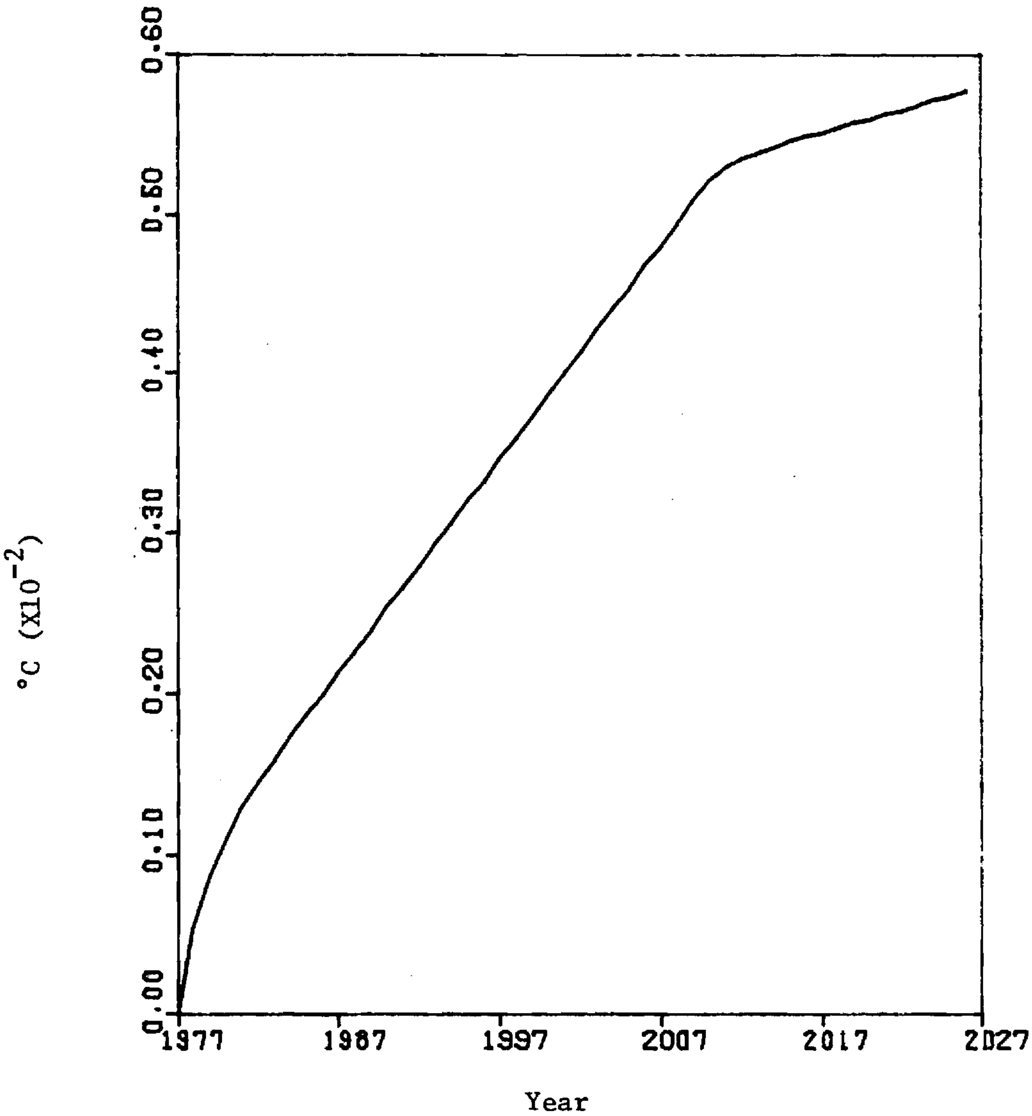

Figure C.21 Global Average Temperature Change
Due to Water Vapor

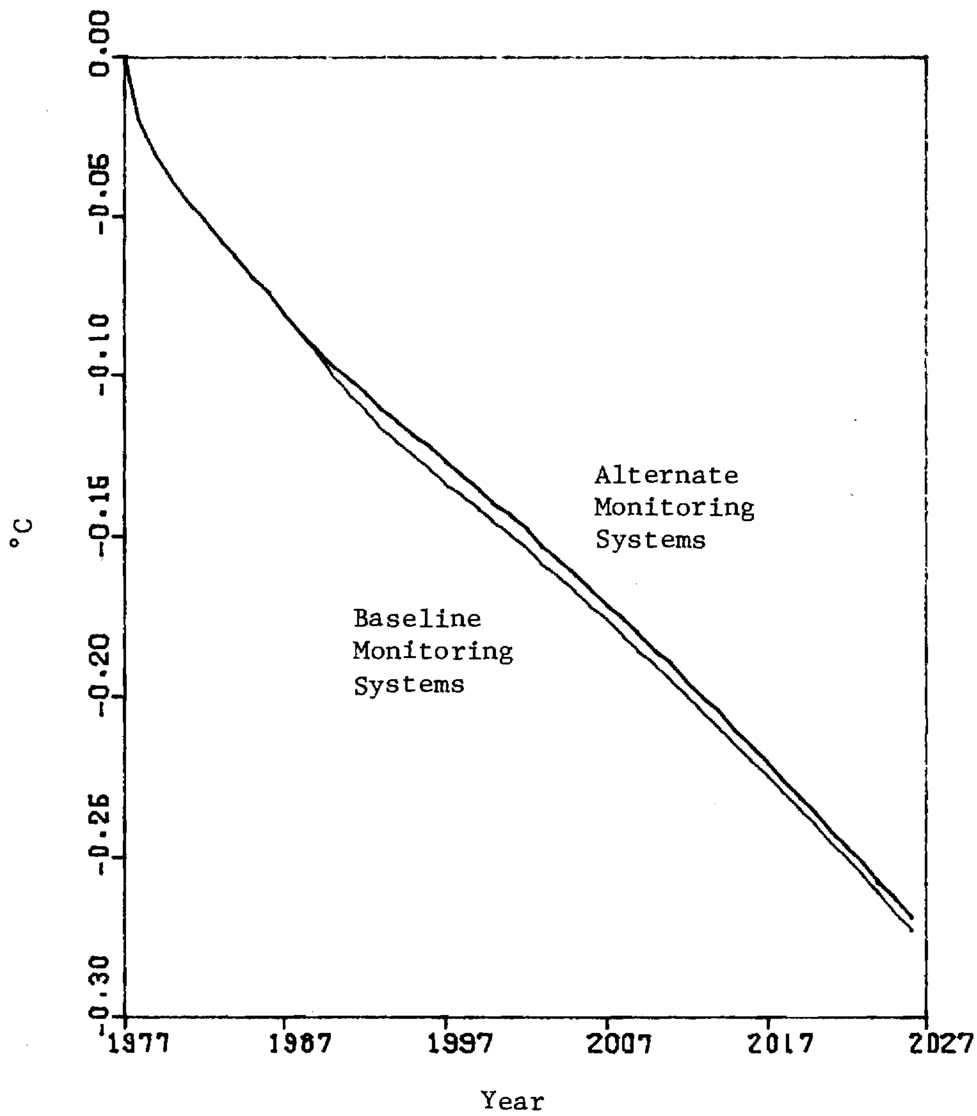

Figure C.22 Global Average Temperature Change Due to Ozone Reduction

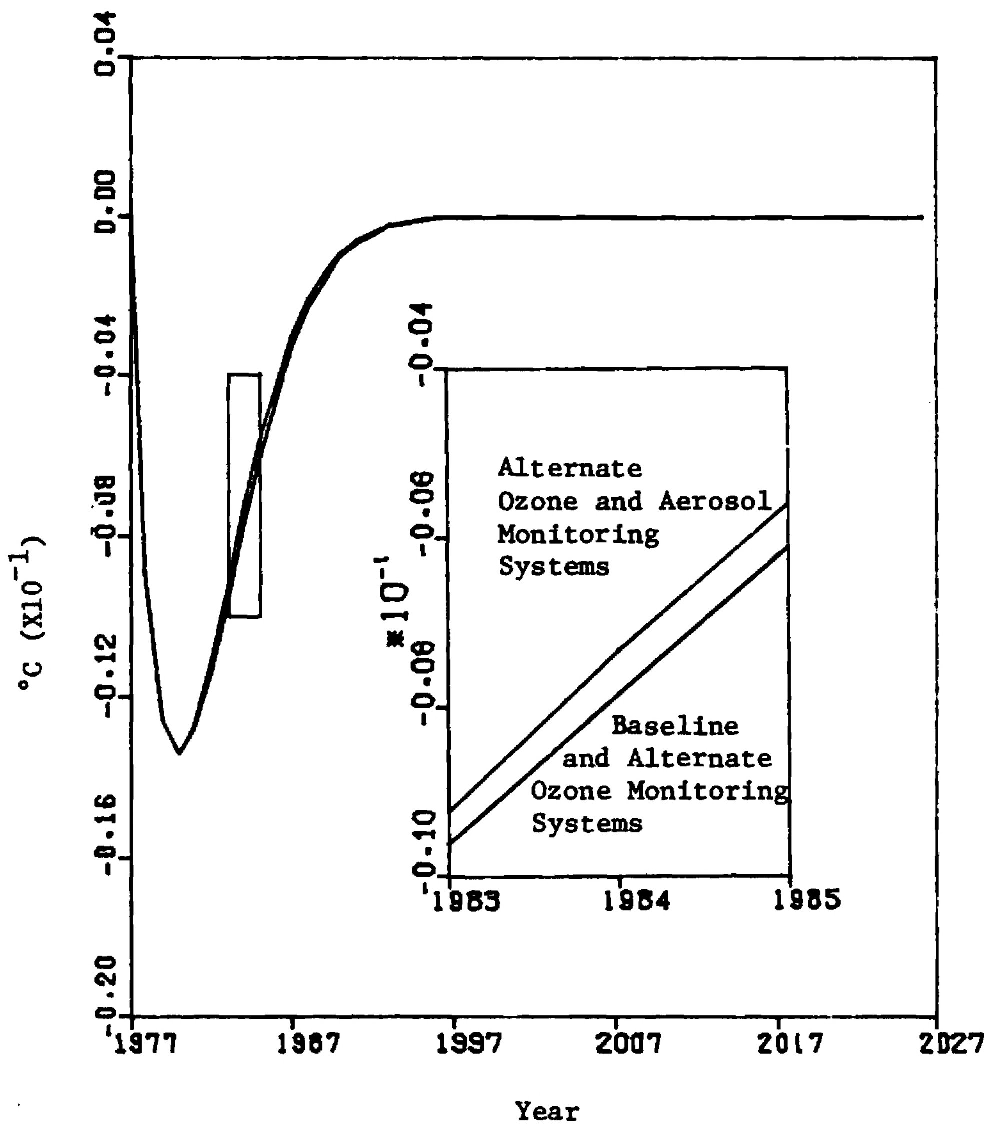

Figure G.23 Global Average Temperature Change
Due to Aerosols

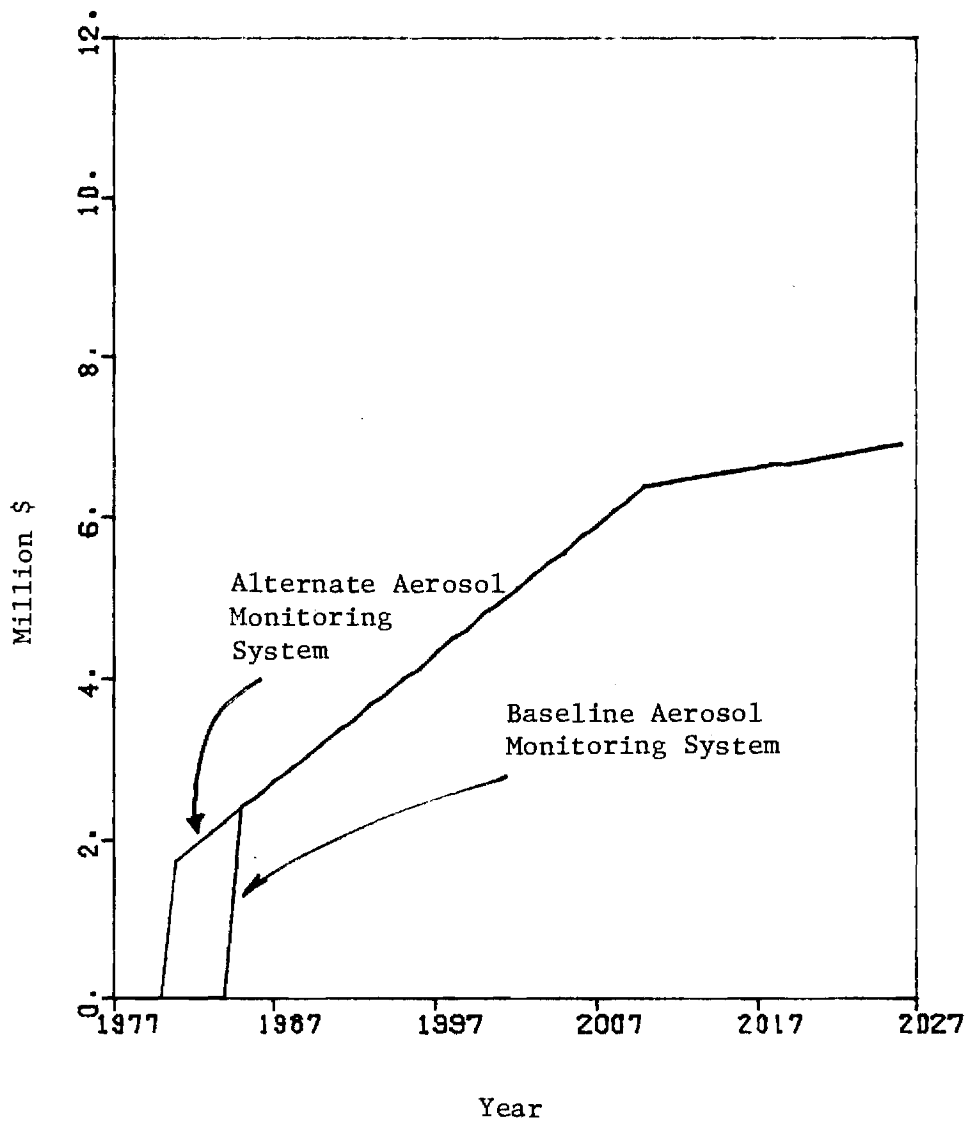

Figure C.24 Costs of Fuel Desulfurization

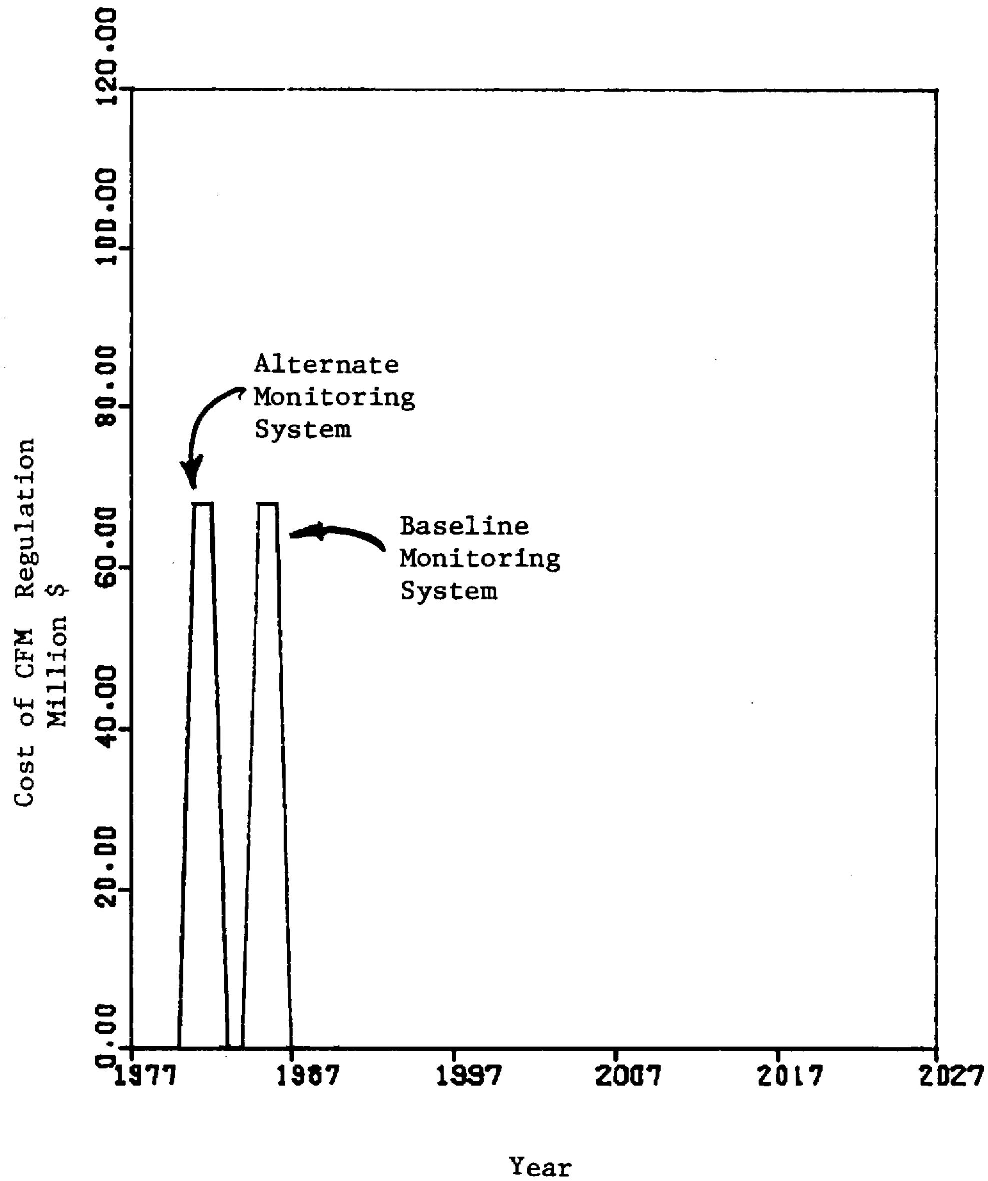

Figure C.25 Cost of CFM Regulation

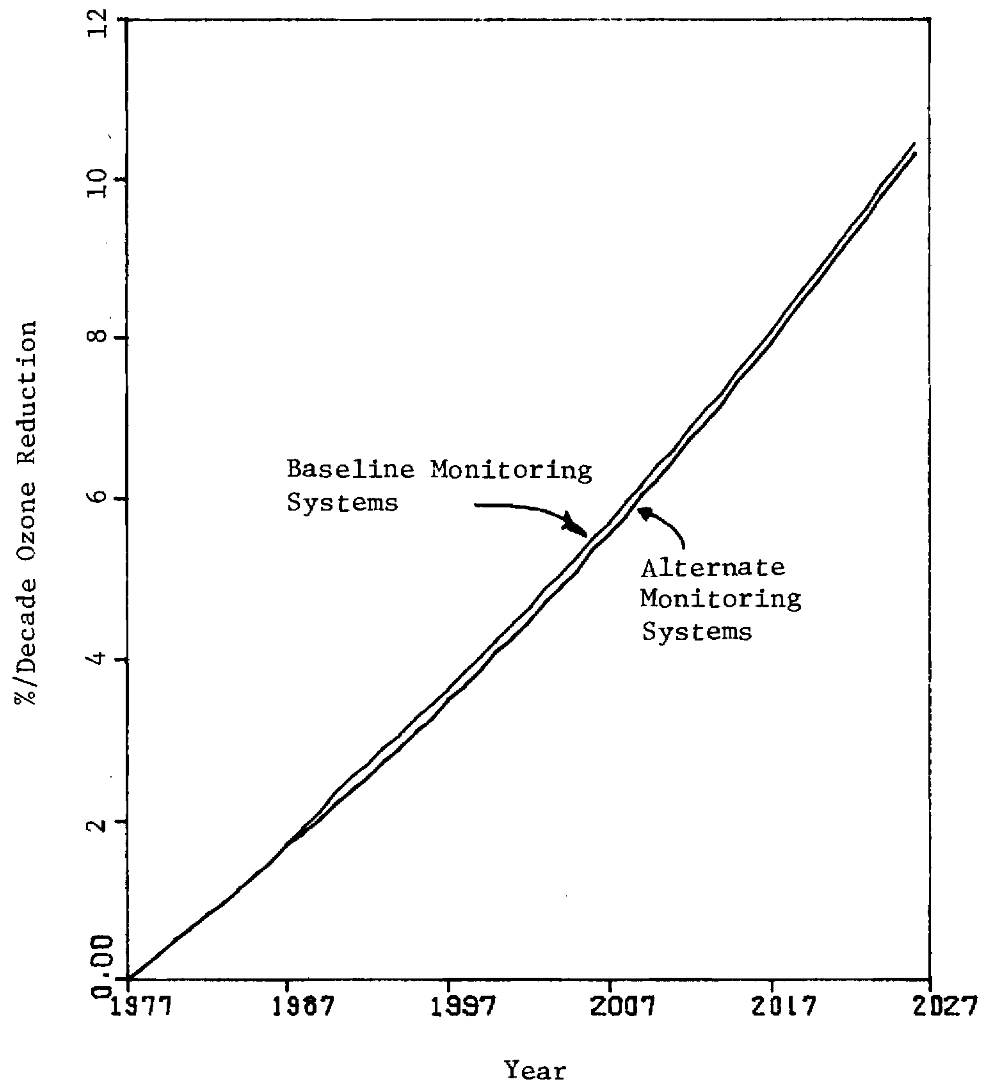

Figure C.26 Ozone Reduction Due to CFMS

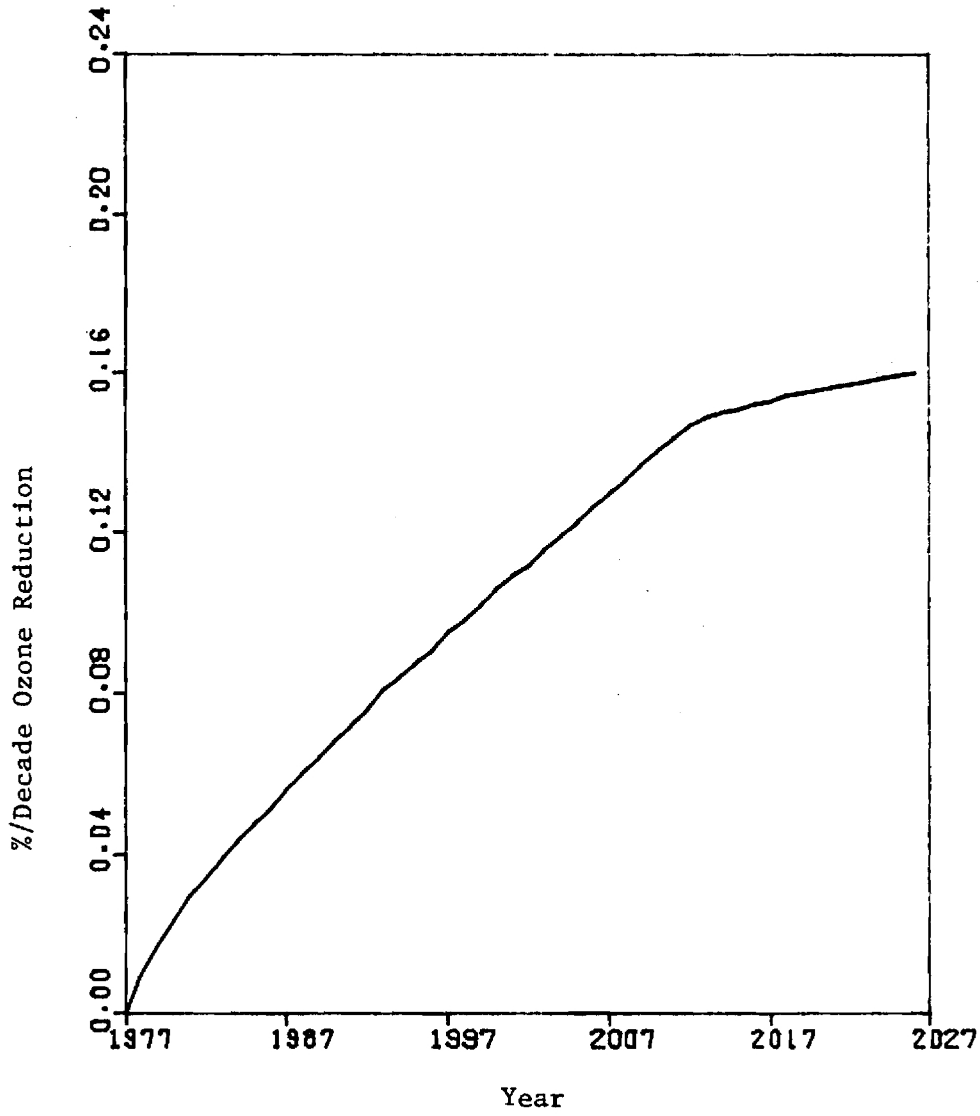

Figure C.27 Ozone Reduction Due to NO_Xs

Figure C.28 and C.29 give the cost due to skin cancer and temperature change. Figure C.30 compares the net present cost, over time of each of the scenarios. Note that at first the baseline case is lower in cost. Later however, the pollution reduction policies become cheaper. Thus, the length of time which the simulation is run must be long enough for the reduced costs due to pollution damage.

Table C.21summarizes the calculation of benefits. These benefits correspond to one combination of a trend in ozone reduction and a trend in aerosol increase. In the section which follows trend combinations covering the range of 1 to 10 percent per decade are assumed. Calculations similar to the ones illustrated here are repeated for each of the combinations.

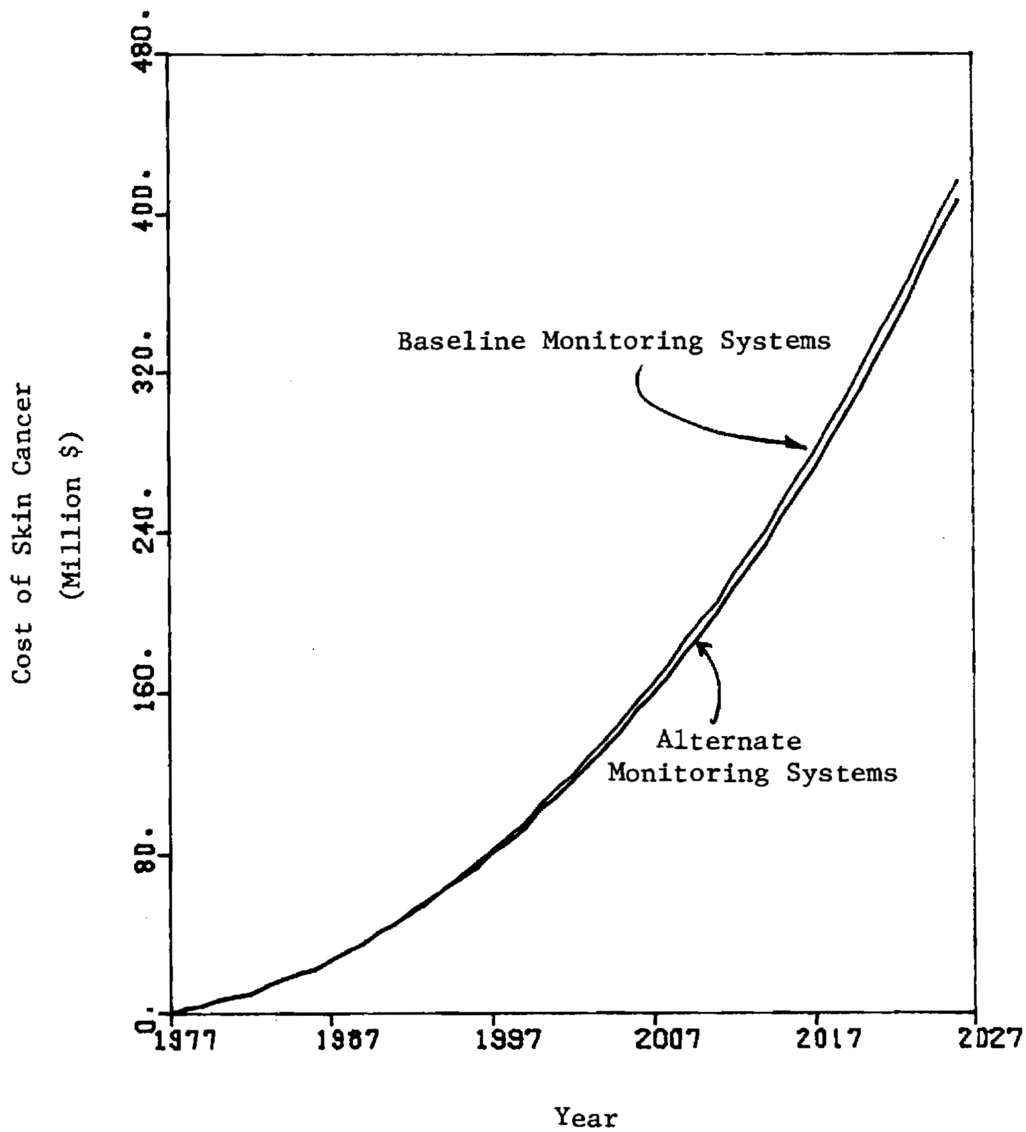

Figure C.28 Cost of Skin Cancer

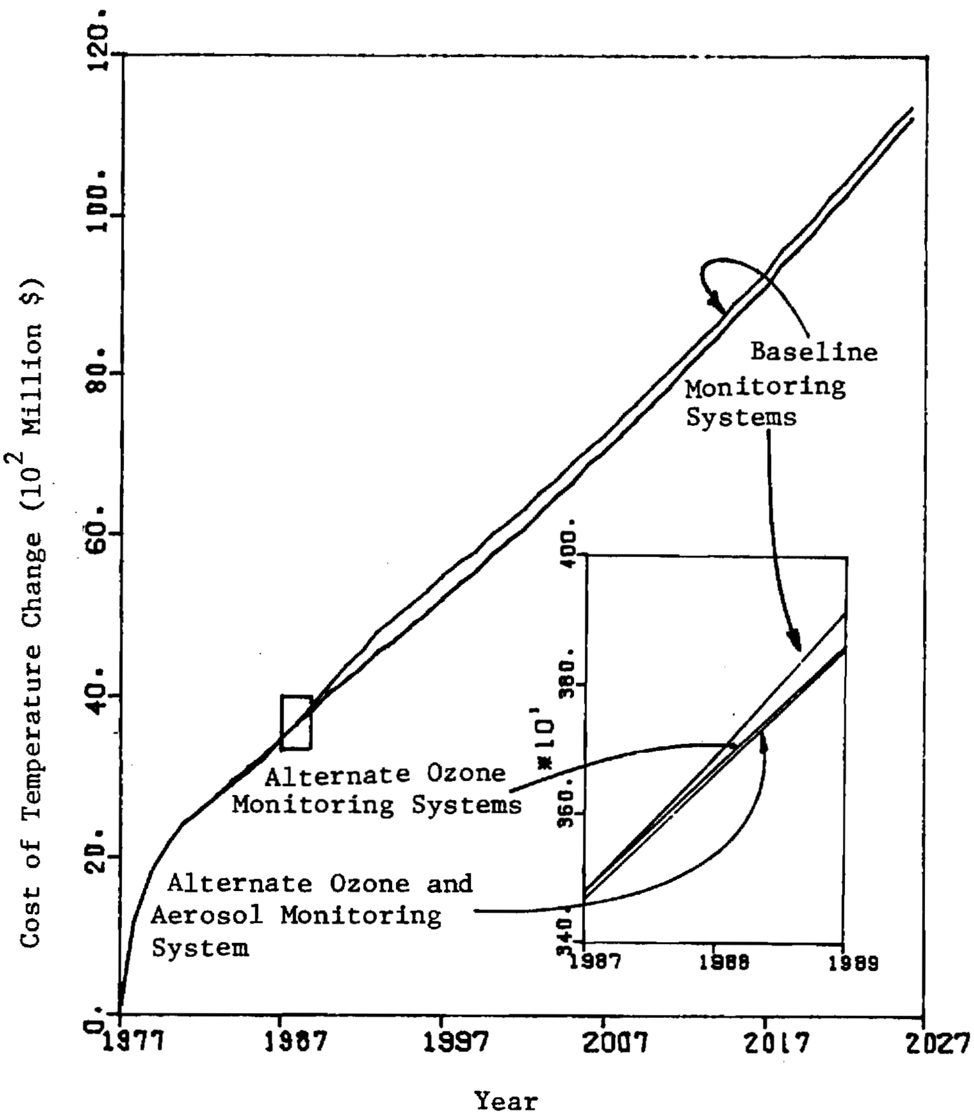

Figure G.29 Cost of Temperature Change

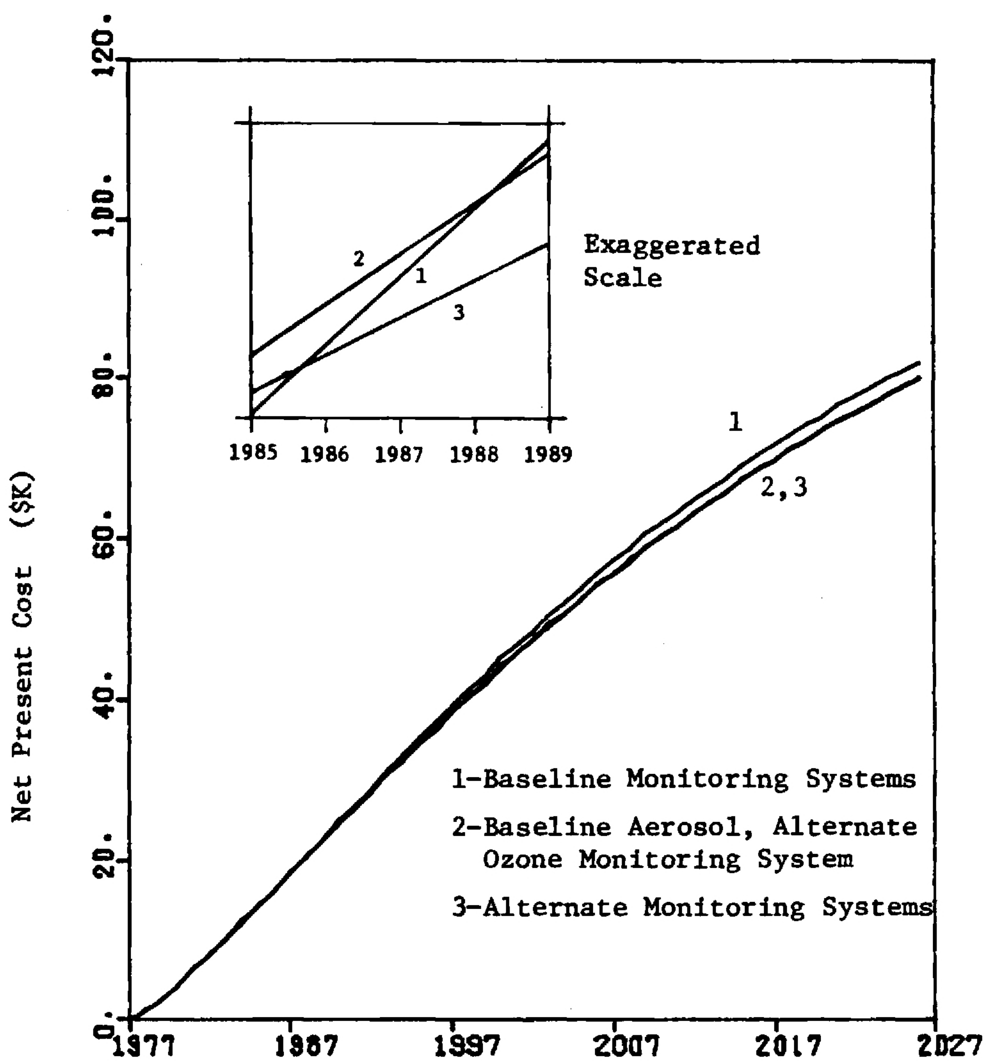

Figure C.30 Net Present Cost Time History

TABLE C.21 ILLUSTRATION OF BENEFIT CALCULATIONS FOR AN OZONE TREND OF 1%/DECADE (REDUCTION) AND AN AEROSOL TREND OF 1%/DECADE (INCREASE)

	Ozone Monitoring System		Aerosol Monitoring System		Cost (Million $)	Benefits (Million $)	Marginal Benefit (Million $)
	Baseline	Alternate	Baseline	Alternate			
1	X		X		82292		
2		X	X		80253	Cost(1)-Cost(2) 2039	
3		X		X	80174	Cost(1)-Cost(3) 2118	Cost(2)-Cost(3) 79

APPENDIX D

Benefits of Monitoring: Mathematical Development

D.1 Introduction

In this appendix, a mathematical model of the monitoring process is developed. The model is then used to consider issues of trend detection, cost effectiveness of monitoring systems, policy choices, and finally the value of a monitoring system. This section is included for those readers interested in the mathematical development. A summary of this material is included in the main body of the report.

D.2 Model of the Monitoring Process

In this section a very simple model of the monitoring process is developed which illustrates some of the key issues. As mentioned above, the goal of an environment monitoring system is to establish the causal relationship between terrestrial activity (typically the economic activities of production, distribution, and consumption) and ambient pollution concentrations. Once the causal relations are known, the offending activities can be controlled in an efficient manner, and standards for ambient pollution concentrations achieved at minimal cost.

A one dimensional world is assumed, in which only a single observation can be made at any time. In the real world, of course, many spacially separate observations can be taken at once. The assumption above is tantamount to having an implicit aggregating scheme which reduces all cotemporal observations to a single summary statistic (such as an average), which is then used in the model. Indeed, a series of mean global or regional averages is often the raw data for pollution trend analyses. Table D.1

summarizes the notation used for the model. Y is a specific atmospheric constituent. The constituent may be naturally present in the atmosphere, as are CO, CO_2, O_3, NO_X, and SO_X; or it may be present due solely to anthropogenic causes, as are chlorofluoromethanes. In general, its concentration may be due to both natural and anthropogenic forces, as are the first five mentioned compounds.

The observation recorded by the monitoring system is assumed to be the true concentration plus the independent error term U_t^M, which is assumed to be distributed $N(0, \sigma_M^2)$. The true concentration can be considered the sum of two terms, that due to natural forces and that due to anthropogenic forces. The natural concentration may follow complex daily, seasonal, annual and/or multi-year cycles. These cycles are assumed to be known from prior observations in a period characterized by the absence of anthropogenic perturbations. The true natural concentration is the sum of an explained term - the known cyclical concentration - plus an independent error term, U_t^N. We assume U_t^N is distributed $N(0, \sigma_N^2)$. Equations D.1, D.2, and D.3 represent the model as described thus far. f(t) represents the known cyclical component of $\tilde{Y}_{Nt}$.

$$Y_t = \tilde{Y}_t + U_t^M \qquad \text{D.1}$$

$$\tilde{Y}_t = \tilde{Y}_{Nt} + \tilde{Y}_{At} \qquad \text{D.2}$$

$$\tilde{Y}_{Nt} = f(t) + U_t^N \qquad \text{D.3}$$

Table D.1 Summary of Notation

Y_t	Observed concentration of Y at time t, observation generated by monitoring system.
$\tilde{Y}_t$	Actual concentration of Y at time t.
$\tilde{Y}_{Nt}$	Actual concentration of Y at time t due to natural forces.
$\tilde{Y}_{At}$	Actual concentration of Y at time t due to anthropogenic sources.
P_{it}	Emission of the i^{th} pollutant (affecting the concentration of Y) at time t.
X_{ikt}	The quantity of the k^{th} good produced at time t with which P_i is associated.
W_t	Index of Social Wellbeing at time t.
U_t^M, U_t^N	Disturbance terms, independent of each other, each normally distributed, and each serially uncorrelated.

The anthropogenic concentration can be assumed to be determined by a "partial adjustment" model, as in D.4. The first term in the RHS represents the partial adjustment to the equilibrium state of $\tilde{Y}_{At} = 0$ in the absence of anthropogenic disruption. The second term in the RHS represents the disruption - a very simple transport/reaction model which transforms the pollutants emitted at t-1 into contributions to $\tilde{Y}_{At}$.

$$\tilde{Y}_{At} = \alpha\tilde{Y}_{A,\ t-1} + \sum_{i=1}^{I} \gamma_i P_{i,\ t-1}, \quad 0 < \alpha < 1 \qquad \text{D.4}$$

The pollutants P_i may be of many types and from many sources. The P_i are byproducts of production processes - processes producing goods X_k. X_{ik} is the k^{th} good whose production contributes to pollutant i. We assume a linear homogeneous relation between the X_{ik} and the P_i, as represented in D.5.

$$P_{it} = \sum_{k=1}^{K} \lambda_k X_{ikt} \qquad \text{D.5}$$

The reason for concern about anthropogenic environmental changes is, of course, the suspicion that any perturbations of the natural balances of the ecosystem can be deleterious to man. A common theme [as such concerns are voiced] is that there is likely to be a substantial time lag between the pollution emission and the ultimate social impact of its physical consequences. Thus, waiting for impacts to occur, and then reacting to their causes, is not seen as a viable strategy. For, once the initial impacts are felt, possibly decades more of increasing impacts may be suffered even if the causes are stopped at once. The nature of the time lag is that many years of impacts are irreversibly built into the system at any one time. Ultimately, social wellbeing at t depends on the history of ambient Y concentrations. For concreteness suppose the history of Y, an atmospheric constituent, affects climate. Climate can be considered as a vector of variables $(R_1, R_2, \ldots, R_j, \ldots, R_J)$ where R_1 might be mean annual temperature, R_2 mean annual precipitation, R_3 mean annual number of days temperature drops below 0^oC, R_4 mean quantity of ultraviolet radiation reaching the ground, etc. Assume climate affects the availability of a number of goods and services consumed by the members of society.* Let these goods and services be denoted as $Q_1, Q_2, \ldots, Q_\ell, \ldots, Q_L$. Finally, let W be an index of social welfare. From the foregoing remarks :

$$\left.\begin{aligned} R_{1t} &= R^1(Y_t, Y_{t-1}, \ldots) \\ R_{2t} &= R^2(Y_t, Y_{t-1}, \ldots) \\ &\cdots\cdots\cdots\cdots \\ R_{Jt} &= R^J(Y_t, Y_{t-1}, \ldots) \end{aligned}\right\} \qquad \text{D.6}$$

and

$$\left.\begin{aligned} Q_{1t} &= Q^1(R_{1t}, R_{1,\,t-1}, R_{1,\,t-2}, \ldots; R_{2t}, R_{2,\,t-1}, R_{2,\,t-2}, \ldots; \ldots) \\ Q_{2t} &= Q^2(R_{1t}, R_{1,\,t-1}, R_{1,\,t-2}, \ldots; R_{2t}, R_{2,\,t-1}, R_{2,\,t-2}, \ldots; \ldots) \\ &\cdots\cdots\cdots\cdots \\ Q_{Lt} &= Q^L(R_{1t}, R_{1,\,t-1}, R_{1,\,t-2}, \ldots; R_{2t}, R_{2,\,t-1}, R_{2,\,t-2}, \ldots; \ldots) \end{aligned}\right\} \qquad \text{D.7}$$

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*Without loss of generality, we can include health as a "service consumed by society.

and

$$W_t = W(Q_{1t}, Q_{2t}, \ldots, Q_{Lt}) \quad \text{D.8}$$

In recent years, much effort has been expended investigating the empirical form of relations like D.6 and D.7. For example, the Climatic Impact Assessment Program [1] attempted to determine the impact of the SST by linking its projected pollution emissions to potential climate change to the economic effects of such change. The types of economic costs considered included impacts on agriculture, marine life, human health, aesthetics, and physical and urban resources.

If the λ_k, the γ_i, α, and the forms of D.6, D.7, and D.8 were known or could be readily estimated, environmental management decisions could be made with complete information and the most efficient economic policies adopted. For example, if $\tilde{Y}_A$ is approaching non-zero equilibrium value, the costs of various levels of corrective action could be weighed against one another and against the "do nothing" alternative, and an optimal decision achieved. Complete knowledge of parameter values and functional forms is clearly the ideal state of affairs.

The role of a monitoring system is to collect data from which information can be inferred. In the context of our model, the data are observations on the Y_t, P_{it}, X_{ikt}, R_{jt}, and $Q_{\ell t}$. (The W_t are constructed from the $Q_{\ell t}$'s, using the principles of welfare economics, they are not actually observed.) Thus, a monitoring system whose goal is the optimization (or even improvement) of environmental management decisions is not one monitoring system, but very many. For the five variables mentioned above, there are $1 + I + \Sigma + J + L$ series of interest, where Σ is the number of X_{ikt} variables. In addition, there is the issue of simply properly specifying the relations D.4 and D.5. While we may now have available many X_k series, we don't usually know which P_i the X_k affect, nor which P_i affect Y.

The upshot of all this is that comprehensive monitoring systems which provide data for the estimation of D.1 - D.8, thereby permitting optimization of environmental management decisions are not now available, and are not likely to be available in the near future. Instead, we have a number of disparate data collection efforts, run by various private and public agencies, for reasons not all necessarily related to environmental quality. One might easily speculate that the lack of comprehensive monitoring systems is due to the lack of a demonstrated need, coupled with the confidence that should a non-zero, non-natural trend in an atmospheric constituent be detected, enough would be known or could be quickly learned about the underlying causes that the trend could be reversed, albeit through inefficient policies, before serious damage is experienced. The recent ozone depletion issue, for example, is being attacked with policies based on some small amount of data coupled with educated guesses, all in a state of substantial uncertainty about the true transport/reaction properties of chloro-fluoromethanes.

One could easily argue that because of the great cost of establishing and operating a comprehensive monitoring system for any atmospheric constituent, and because of the large number of atmospheric constitutents which are potentially of interest, the establishment of comprehensive systems is not a desirable, or even politically feasible, strategy.

The economic desirability of such systems is an empirical issue, but insufficient data are now available to resolve it.

It appears that, at least for the near future, environmental monitoring developments will be mainly in the realm of technology and hardware for the monitoring of atmospheric constituents, the Y_t. In defense of this strategy, it should be pointed out that this is the most difficult part of developing a possible future comprehensive monitoring system, and until the comprehensive system exists, the ability to monitor Y_t is the most useful component of that ultimate system to have on hand. The use of the limited system would be to detect unexplained, and presumably anthropogenic, trends in Y. When such a trend is detected, the alarm goes out, bits and pieces of the rest of a comprehensive system are assembled, and (admittedly inefficient) stopgap policies are developed and implemented. Then, the need having been established, the comprehensive monitoring system for that constituent can be developed over time. Ultimately, but not immediately, efficient policies can be expected to prevail.

This approach (monitoring only Y for the purpose of trend detection) can be accomodated within the model developed thus far if we assume that the production of the "problem" goods and services, the X_{ikt}'s, all follow a linear trend over time. Specifically, if :

$$X_{ikt} = a_{ik} + b_{ik} \cdot t \,, \qquad \text{D.9}$$

then the anthropogenic part of $\tilde{Y}_t$, namely $\tilde{Y}_{At}$, becomes a linear function of time. In this context, Y can be monitored for any unexplained linear trend. If a non-zero trend is detected, the alarm is raised, the comprehensive monitoring system begins to develop, and ultimately the specific causes of the trend can be detected and remedied.* In the meantime, however, sub-optimal policies are likely to be promulgated.

The equation to be estimated is :

$$Y_t - f(t) = B_0 + B_1 t + U_t \qquad \text{D.10}$$

where Y_t is observed by the monitoring system, f(t) is the known natural component of Y_t, t is the index of time, U_t is the disturbance term, and B_0, B_1 the parameters to be estimated. If $B_1 \neq 0$, a trend exists. Thus, B_1 is the parameter of interest. To see how D.10 is derived from the model, and therefore why D.10 is the appropriate equation for estimation, start with D.1, D.2, D.3. Substituting D.2 and D.3 into D.1 yields:

$$Y_t - f(t) = \tilde{Y}_{At} + U_t \quad , \qquad \text{D.11}$$

where

$$U_t = U_t^M + U_t^N \quad ,$$

and

$$U_t \sim N(0, \sigma_M^2 + \sigma_N^2).$$

Substituting D.4 and D.5 into D.11 yields:

$$Y_t - f(t) = \alpha\tilde{Y}_{A,\ t-1} + \sum_{i=1}^{I} \gamma_i \left\{ \sum_{k=1}^{K} \lambda_k X_{ik,\ t-1} \right\} + U_t. \qquad \text{D.12}$$

---

*Note the implicit assumption that a non-natural trend is necessarily bad. This is the pessimistic, but presumably risk-minimizing, assumption adopted in the absence of complete information on the trend's ultimate impact on social well-being.

Substituting with D.9 into D.12 leaves :

$$Y_t - f(t) = \alpha\tilde{Y}_{A,\ t-1} + \sum_{i=1}^{I} \gamma_i \left[\sum_{k=1}^{K} \lambda_k \left(a_{ik} + b_{ik}(t-1) \right) \right] + U_t$$

or

$$Y_t - f(t) = \alpha\tilde{Y}_{A,\ t-1} + \sum_i \sum_k \gamma_i \lambda_k a_{ik} + \sum_i \sum_k \gamma_i \lambda_k b_{ik} t - \sum_i \sum_k \gamma_i \lambda_k b_{ik} + U_t \quad . \qquad \text{D.13}$$

Iterating through the substitution process to eliminate $\tilde{Y}_{A,\ t-1}$ yields :

$$Y_t - f(t) = \alpha \left\{ \alpha\tilde{Y}_{A,t-2} + \sum_i \sum_k \gamma_i \lambda_k a_{ik} + \sum_i \sum_k \gamma_i \lambda_k b_{ik} t - 2 \sum_i \sum_k \gamma_i \lambda_k b_{ik} \right\}$$

$$+ \sum_i \sum_k \gamma_i \lambda_k a_{ik} + \sum_i \sum_k \gamma_i \lambda_k b_{ik} t - \sum_i \sum_k \gamma_i \lambda_k b_{ik} + U_t \quad .$$

Continual substitution back to t=0 finally yields :

$$Y_t - f(t) = \alpha^t \tilde{Y}_{A,0} + \left(\sum_i \sum_k \gamma_i \lambda_k a_{ik}\right) \left(\sum_{s=0}^{t-1} \alpha^s\right)$$

$$+ \left(\sum_i \sum_k \gamma_i \lambda_k b_{ik} t\right) \left(\sum_{s=0}^{t-1} \alpha^s\right)$$

$$- \sum_i \sum_k \gamma_i \lambda_k b_{ik} \left(\sum_{s=0}^{t-1} (s+1)\ \alpha^s \right) + U_t$$

which can be expressed as

$$Y_t - f(t) = B_0 + B_1 t + U_t \qquad \text{D.10}$$

where

$$\left.\begin{aligned} B_0 &= \alpha^t \tilde{Y}_{A,0} + (\sum_i \sum_k \gamma_i \lambda_k a_{ik})(\sum_{s=0}^{t-1} \alpha^s) - \sum_i \sum_k \gamma_i \lambda_k b_{ik} (\sum_{s=0}^{t-1} (s+1)\alpha^s) \\ B_1 &= (\sum_i \sum_k \gamma_i \lambda_k b_{ik}) (\sum_{s=0}^{t-1} \alpha^s) \end{aligned}\right\} \quad D.14$$

$$U_t = U_M^t + U_N^t \quad .$$

B_0 and B_1 are the constants to be estimated. t, the time index, is nonstochastic. U_t is independent of t and independent of its own past values. The conditions are satisfied for the ordinary least squares (OLS) estimators of B_0 and B_1 to be best linear unbiased estimators. D.10 is the reduced form of D.1, D.2, D.3, D.4, D.5, and D.9. The parameters within those equations cannot be identified,* however, from the OLS estimators, B_0 and B_1. As is evident from D.14, the right hand side of B_0 and B_1 contain too many variables for any information to be inferred about their values from estimates of $\hat{B}_0$ and $\hat{B}_1$.

D.3 Trend Detection

Given that the role of the monitoring system is to detect the existence of any anthropogenic trend in Y, the next step is to investigate how well a specified system can accomplish that task. To reiterate our point of view, the natural seasonal patterns of Y are assumed to be known from past observations on an unperturbed environment. Each current observation on Y, therefore, is the sum of

1) the known seasonal variation, f(t)
2) any anthropogenic contribution to Y concentration, $\tilde{Y}_{At}$

*For a discussion of the identification problem, see Chapter 10 of Intriligator, Econometric Models, Techniques, and Applications, Englewood Cliffs, N.J.: Prentice Hall, 1978.

3) the random monitoring system error, U_t^M

4) and the random unexplained component of the natural concentration, U_t^N.

The key issue in the evaluation of any monitoring system is how quickly it can detect any given trend, and with what degree of confidence. The characteristics of the monitoring system germane to the issue are its rate of observation (number of observations per time period), and the nature of the monitoring system error term. By assumption, the error term U_t^M is normally distributed with mean zero and variance σ_M^2. It is the variance, then, which describes the "accuracy" of the system. The smaller the variance, the closer to the true concentration each reported observation is likely to be.

In using the monitoring system data to estimate the parameters of D.10, the null hypothesis that the trend, B_1, $\neq 0$. For any true non-zero B_1, how long would it take to be detected? Figure D.2 illustrates the meaning of the question. Clearly, the null hypothesis would not be rejected if the estimated trend were not <u>exactly</u> 0. After all, the random process (the U_t's) may not average out to 0 in any given sample. Thus, there would be some range around 0 that, should the estimated trend fall into it, the observations could be judged consistent with the null hypothesis. By chance, the estimated trend could fall outside the range even if the trend were truly 0. This would cause rejection of the true hypothesis - a Type I or Alpha error. This error can be controlled by adjusting the size of the range of trend values which we deem consistent with a 0 trend. The larger the range, the smaller the chance of committing this

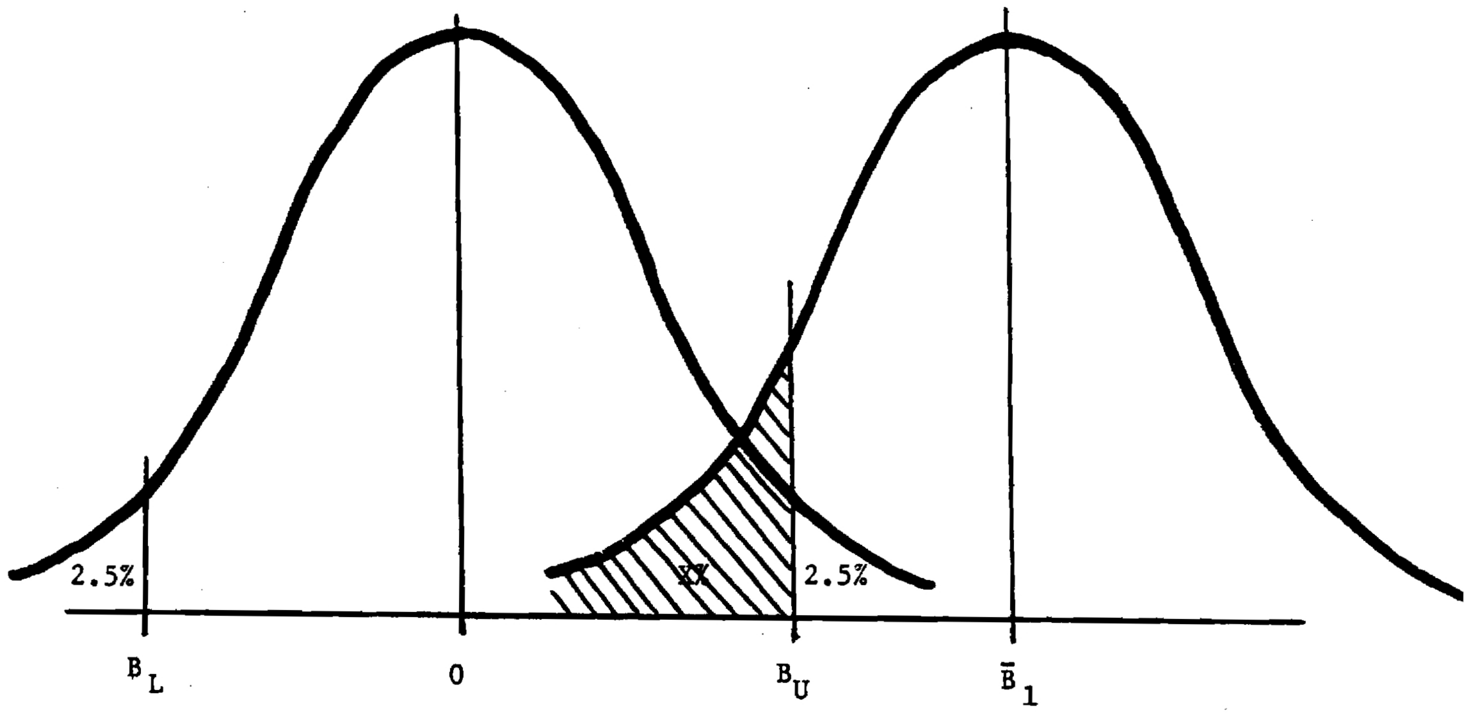

Figure D.2 Hypothesis Testing on Trends in Environmental Constituents.

type of error. Typically, the acceptable chance of committing a Type I error might be set at 5%. In Figure D.2 the acceptable range for accepting a 0 trend is for the estimate of B_1, $\hat{B}_1$, to fall between B_L and B_U (given a 5% chance of a Type I error is acceptable). But now suppose that the true trend is $\bar{B}_1$. Again, because of the random disturbance term, the estimated trend will likely not be exactly $\bar{B}_1$. There would be a range around $\bar{B}_1$ into which $\hat{B}_1$ should fall. If $\bar{B}_1$ is "close" to 0, there is the possibility that the estimated trend, even if $\bar{B}_1$ is true, falls in the B_L to B_U range. This is the chance of accepting a false hypothesis - that the trend is 0 when it is truly $\bar{B}_1$, and is indicated by the shaded area in Figure D.2. Accepting a false hypothesis is known as a Type II, or Beta error. If the shaded area is X% of the area under the curve, then there is a (100-X)% chance of detecting a trend of $\bar{B}_1$ against a null hypothesis of 0 trend tested at a .05 significance level with a two tailed test. In general X should be as small as possible. X can be reduced by simply shifting B_U to the left. However, this results in a corresponding increase in the chance of a Type I error which is unacceptable if the chance of that error is to be maintained at 5%. X can also be reduced by increasing the number of observations on which the trend estimate is based. This, of course, does <u>not</u> cause a corresponding increase in the probability of a Type I error. The larger the number of observations, the tighter the bell curves fit around 0 and $\bar{B}_1$. The idea would be to increase the number of observations until some B_U can be found so that 2.5% of the area under the curve centered at 0 lies to the right of that B_U, and just some minimal acceptable amount, say 5%, of the area under the curve centered at $\overline{B}_1$ lies to the left of B_U. Using these ideas, we recognize the existence of a relationship of the form :

$$\overline{B}_1 = F(n, \sigma_u^2, H_0, \alpha, B) \quad , \qquad \text{D.15}$$

where n is the number of observations, σ_u^2 is the variance of the disturbance term, H_0 the trend value under the null hypothesis, α is the chance of a Type I error, and B the chance of a Type II error. The interpretation of D.15 is that $\overline{B}_1$ is the smallest trend that can be expected to be detected with 100(1-B)% confidence with n observations against a null hypothesis trend of H_0 tested with a 100 α % significance level, given the variance of the error term is σ_u^2.

The explicit form of D.15 , for some given values of H_0, α, and B can be constructed as follows:

$$\overline{B}_1 = F(n, \hat{\sigma}_u \mid H_0 = 0, \alpha = .05, B = .05) \qquad \text{D.16}$$

where $\hat{\sigma}_u$ is the estimate of σ_u from the observations. That is, D.16 is to be derived using the properties of the OLS estimates of D.10.

If $\hat{B}_1$ is the OLS trend estimate for D.10, and if B_1 is the true trend, then

$$V = \frac{(\hat{B}_1 - B)\sqrt{\Sigma(t-\bar{t})^2}}{\hat{\sigma}_u} \qquad \text{D.17}$$

has the Student's t distribution with (n-2) degrees of freedom. From the arguments surrounding Figure D.2, we can state our problem as finding a value of n so that there exists some B_U (the critical value of B_1) such that

$$\text{Prob}\ (-B_U < \hat{B}_1 < B_U \mid B_1 = 0) = .95 \qquad \text{D.18}$$

and

$$\text{Prob}\ (\hat{B}_1 < B_U \mid B_1 = \bar{B}_1) = .05\ . \qquad \text{D.19}$$

Equation D.18 can be transformed to

$$\text{Prob}\left[\frac{(-B_U - 0)\sqrt{\Sigma(t-\bar{t})^2}}{\hat{\sigma}_u} < \frac{(\hat{B}_1 - 0)\sqrt{\Sigma(t-\bar{t})^2}}{\hat{\sigma}_u} < \frac{(B_U - 0)\sqrt{\Sigma(t-\bar{t})^2}}{\hat{\sigma}_u}\right] = .95 \qquad \text{D.20}$$

which, using D.17, is the same as

$$\text{Prob}\left[-t_c^{.025}\ (n-2) < V < t_c^{.025}\ (n-2)\right] = .95 \qquad \text{D.21}$$

where $t_c^{.025}$ (n-2) is the critical value of the Student's t statistic at the .05 significance level with a two tailed test, and where the value of the statistic is explicitly recognized as depending on the degrees of freedom, n-2. In similar manner, D.19 can be expressed as

$$\text{Prob}\left[\frac{(\hat{B}_l - \bar{B}_1)\sqrt{\Sigma(t-\bar{t})^2}}{\hat{\sigma}_u} < \frac{(B_U - \bar{B}_1)\sqrt{\Sigma(t-\bar{t})^2}}{\hat{\sigma}_u}\right] = .05 \qquad \text{D.22}$$

and then as

$$\text{Prob}\,[V < -\,t_c^{.05}\,(n-2)] = .05. \qquad \text{D.23}$$

From D.20 and D.21, we have :

$$\frac{(B_U - 0)\sqrt{\Sigma(t-\bar{t})^2}}{\hat{\sigma}_u} = t_c^{.025}\,(n-2) \qquad \text{D.24}$$

and from D.22 and D.23 :

$$\frac{(B_U - \bar{B}_l)\sqrt{\Sigma(t-\bar{t})^2}}{\hat{\sigma}_u} = -t_c^{.05}\,(n-2). \qquad \text{D.25}$$

Solving both D.24 and D.25 for B_U, equating, and solving for $\bar{B}_l$ yields :

$$\bar{B}_l = \frac{\hat{\sigma}_u}{\sqrt{\Sigma(t-\bar{t})^2}}\left[t_c^{.025}(n-2) + t_c^{.05}(n-2)\right]. \qquad \text{D.26}$$

Equation D.26 is the explicit form of equation D.16, and appears to correspond to the relations reported by Pittock [7] and Hill et. al. [18] for ozone monitoring. It is easily verified that :

$$\frac{\partial \bar{B}_l}{\partial n} < 0, \quad \frac{\partial}{\partial n}\left(\frac{\partial \bar{B}_l}{\partial n}\right) > 0 \qquad \text{D.27}$$

and

$$\frac{\partial \overline{B}_1}{\partial \hat{\sigma}_u} > 0, \quad \frac{\partial}{\partial \hat{\sigma}_u}\left(\frac{\partial \overline{B}_1}{\partial \hat{\sigma}_u}\right) = 0 \quad . \qquad \text{D.28}$$

Figure D.3 depicts the general shape of D.26. The greater the number of observations and/or the smaller the estimate of the standard deviation of the disturbance term, the smaller the trend which can be detected at the specified levels of significance. Put another way, for given $\hat{\sigma}_u$, it takes a greater number of observations to detect a smaller trend. In general, there is a trade-off between gaining more observations through more monitoring "stations" over less chronological time and through fewer monitoring stations over more chronological time. The former entails greater investment cost but poses less risk of letting a deleterious environmental trend go undetected. We will return to the point below.

Consider again the distrubance term U_t. Recall it is the sum of two unrelated errors, namely, the natural unexplained distrubance U_t^N and the monitoring system detection error U_t^M. Since both components of U_t are assumed normally distributed, it follows :

$$U_t d\ N(0,\ \sigma_M^2 + \sigma_N^2). \qquad \text{D.29}$$

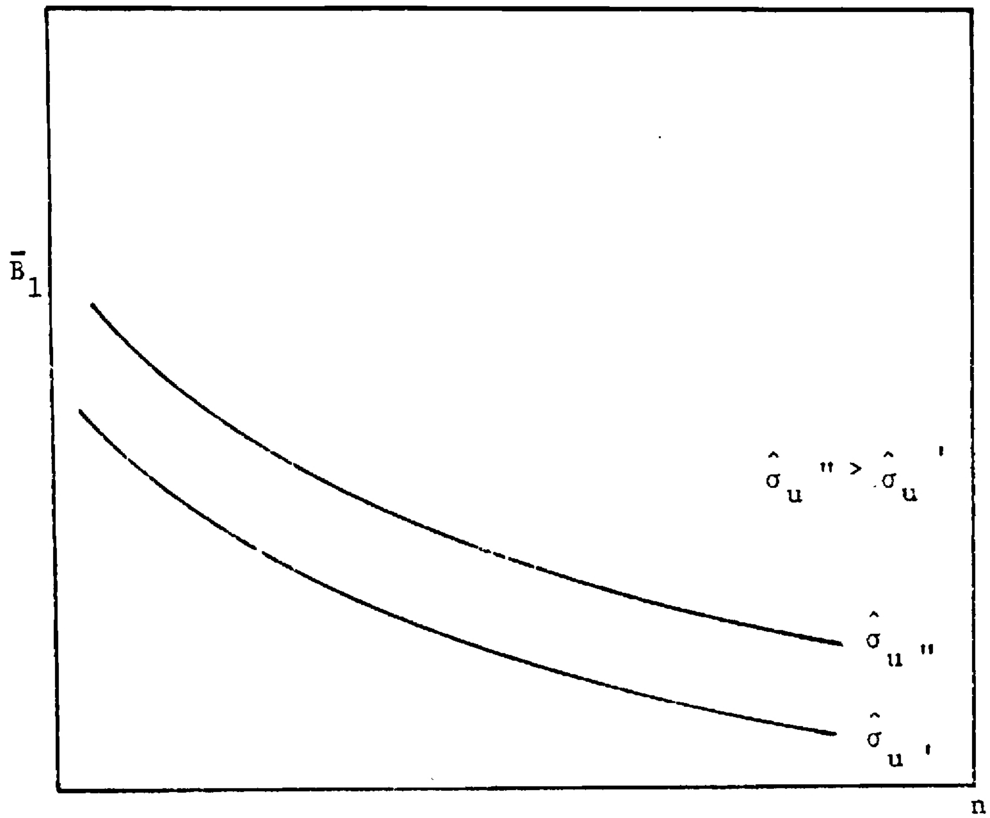

Figure D.3 General Relation Among $\bar{B}_1$, n, and $\hat{\sigma}_u$.

It is convenient to think of the variance of the monitoring system error term as a percentage of the natural variance. We define :

$$\rho \equiv \frac{\sigma_M^2}{\sigma_N^2} \quad , \qquad \text{D.30}$$

from which it follows :

$$\sigma_u = \sigma_N \sqrt{1 + \rho}$$

and substituting into D.26 yields

$$\bar{B}_1 = \frac{\bar{\sigma}_N \sqrt{1 + \hat{\rho}}}{\sqrt{\Sigma (t - \bar{t})^2}} \; [t_c^{.025}(n-2) + t_c^{.05}(n-2)] \qquad \text{D.31}$$

assuming $\bar{\sigma}_n$, the value of σ_n, is known from previous experimentation, and

$$\hat{\rho} = \frac{\hat{\sigma}_M^2}{\bar{\sigma}_N^2} \text{ where } \hat{\sigma}_M^2 = \hat{\sigma}_U^2 - \bar{\sigma}_N^2 .$$

D.4 Cost-Effectiveness Analysis of Environment Monitoring Systems

As mentioned above, the model of monitoring systems performance developed above can be used to perform trade-off, or cost-effectiveness, analyses among alternative methods of achieving given trend detection capability. Our purpose here is to briefly sketch the construction of such a model.

In general, the costs of an environment monitoring system will consist of development, procurement, installation, operation, and maintenance costs. These costs, in turn, depend on

- ρ the ratio of the monitoring system error variance to the variance of the natural disturbance term, i.e., $\rho = \sigma^M_2/\sigma^N_2$ as in D.30.
- I the number of monitoring "stations" or instruments.
- s the rate of instrument observation, i.e., number of observations per instrument per year.
- $\bar{t}$ the maximum number of years allowed for the monitoring system to detect the trend.

Typically, there is some maximum number of observations per year which are usefully effected. Observations beyond the number add no new information.*

Let T represent this maximum number of annual observations. The cost-effectiveness problem can be stated as :

$$\text{MINIMIZE} \quad \text{Cost}(\rho, I, s, \bar{t}) \qquad \text{D.32}$$

$$\text{S.T.} \quad \bar{\bar{B}}_1 = \frac{\bar{\sigma}_N \sqrt{1+\rho}}{\sqrt{\Sigma(t-\bar{t})^2}} \left[t_c^{.025}(n-2) + t_c^{.05}(n-2)\right] \qquad \text{D.33}$$

$$t = \bar{t} \qquad \text{D.34}$$

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*For example, in the case of ozone it is thought that approximately 120 observations per year (properly spacially and temporally distributed) exhaust all useful information [7].

$$n = \bar{t} \cdot I \cdot s \tag{D.35}$$

$$T \geq I \cdot s \tag{D.36}$$

$$\rho, I, s, \bar{t} \geq 0 \tag{D.37}$$

Expression D.32 is the objective function. Equations D.33 and D.34 are constraints defining the requisite performance of the monitoring system - a trend as small as $\bar{\bar{B}}_1$, must be detectable within time period $\bar{t}$. D.35 is merely a definition. D.36 constrains the number of annual observations to no more than the maximum useful observations. D.37 simply states that the policy variables must be non-negative. Note that only the explicit form of D.32, and specified values for $\bar{\bar{B}}_1$, $\bar{y}$, T, are needed for implementation of the model.

D.5 A Policy Choice Model

Ultimately, the social value of an environment monitoring system depends on what difference that system makes, which in turn depends on the policy choices which would be made with and without the monitoring system in question. "Policy choices" refer to government actions like banning the use of fluorocarbons as spray can propellents, or banning stratospheric (mainly SST) flight; and, in general, banning, controlling, limiting, or mandating modification of any product or production process.

The *a priori* determination of the value of an EMS is necessarily based on predictions of policy choices which will be adopted with and without the subject EMS, and is based on the conditionally forecasted environmental trends which the monitoring system is predicted to detect. Regarding the former basis, it is obvious that the most sophisticated monitoring system is worth little or nothing if the information gained from that EMS is not made available to policy makers or not used by them in formulating policy. If the policy makers' choices are essentially independent of the EMS information, there is no reason to implement that EMS - it would have no social value.* Regarding the latter basis, some reflection will suggest that the social value realized from an EMS depends, but in no especially clear cut way, on the true underlying environmental trend being sought out by the EMS. If the true trend were zero, and if policy makers proceeded in the absence of an EMS as though the trend were zero, the presence of an EMS would not (presumably) alter the choices made by policy makers, for the EMS would simply confirm the zero trend which had been accepted anyway.** If there is truly a "small" trend, the value of an EMS can be great if one assumes that trend would go otherwise undetected for a long period of time and the cumulative effects of the environmental disturbance are substantial. The value can be small in that case if even long term cumulative effects are small. If there is a "large" trend, the value of an EMS can be large if substantial damage would be suffered because of the delay in detecting the trend, or the value of the EMS could be small if the trend would be detected quickly anyway because

*One might argue that knowledge for its own sake has social value. Even if policy makers do not respond to the information, science would progress using that information. This line of thought leads directly to debating the social value of science, and we could not hope to resolve such an issue here.

**Let us suppress the perverse case wherein the EMS gives faulty information, and indicates a trend where none is truly present.

of its significant magnitude. In sum, the value of an EMS can reasonably be supposed to depend on the true state of nature (true trend), but whether that value is an increasing or decreasing function of trend is an empirical issue.

Besides depending on the true trend, the value of an EMS depends on the difference in policy which it induces. Suppose consideration is given to the implementation of a specific EMS, called System A; and the alternative course of action is to simply maintain whatever present system exists, call that system System B. Both Systems A and B can be assumed to eventually detect the true trend, and that policies are adopted based on those findings. Assume System A is the more advanced system (lower ρ), so its time to detection is shorter. To simplify matters substantially, the assumption will be temporarily adopted that the same policy is implemented under both A and B, except it is implemented sooner in the case of A. Also, assume that the costs and benefits of the policy depend only on the elapsed time from policy initiation, not also on calendar time. Table D.2, as an example representation of this policy choice model depicts the case where the time to detection - point of policy implementation - for System A is 3 years and for System B is 7 years. V_i represents the value to society (costs or benefits) in year i after policy initiation. C_A and C_B represent the investment costs in Systems A and B, respectively.

In order to generalize the discussion, let t_A represent the calendar time when the policy is implemented under System A, and t_B likewise for System

Table D.2 Illustration of Policy Choice Model

Calendar Time	0	1	2	3	4	5	6	7	8	9	10 ...
System A	C_A	-	-	V_1	V_2	V_3	V_4	V_5	V_6	V_7	V_8...
System B	C_B	-	-	-	-	-	-	V_1	V_2	V_3	V_4...

B. Letting r represent the discount rate, the Net Present Value of the decision to implement System A rather than System B, $NPV_{A/B}$, is the present value of the annual differences in the investment costs and V_i's, i.e.,

$$\left.\begin{array}{l} NPV_{A/B} = (C_A - C_B) + \dfrac{V_1 - 0}{(1+r)^{t_A}} + \dfrac{V_2 - 0}{(1+r)^{t_A+1}} + \ldots \\ \\ + \dfrac{V_{t_B-t_A+1} - V_1}{(1+r)^{t_B}} + \dfrac{V_{t_B-t_A+2} - V_2}{(1+r)^{t_B+1}} + \ldots \end{array}\right\} \qquad \text{D.38}$$

In terms of the example of Table 2, D.38 is simply

$$NPV_{A/B} = (C_A - C_B) + \frac{V_1 - 0}{(1+r)^3} + \frac{V_2 - 0}{(1+r)^4} + \ldots + \frac{V_5 - V_1}{(1+r)^7} + \frac{V_6 - V_2}{(1+r)^8} + \ldots \qquad \text{D.39}$$

Equation D.38 can be rewritten as

$$NPV_{A/B} = (C_A - C_B) + \left\{\frac{V_1}{(1+r)^{t_A}} + \frac{V_2}{(1+r)^{t_A+1}} + \ldots\right\} - \left\{\frac{V_1}{(1+r)^{t_B}} + \frac{V_2}{(1+r)^{t_B+1}} + \ldots\right\}$$

D.40

Multiplying the first bracket through by $\dfrac{(1+r)^{t_A-1}}{(1+r)^{t_A-1}}$ and the second bracket through by $\dfrac{(1+r)^{t_B-1}}{(1+r)^{t_B-1}}$, and collecting terms yields

$$NPV_{A/B} = (C_A - C_B) + \left[\frac{(1+r)^{t_B-t_A}-1}{(1+r)^{t_B-1}}\right] \cdot PV \qquad \text{D.41}$$

where PV is the present value of the effects of the environmental policy as viewed from the time of its initiation, i.e.,

$$PV = \frac{V_1}{(1+r)^1} + \frac{V_2}{(1+r)^2} + \ldots \qquad D.42$$

and where the bracketed term can simply be viewed as a weighting factor which accounts for both the time elapsing between the present and the point of A's implementation and the time saved by implementing A over B. Note that if $t_B = t_A$, i.e., if the time to trend detection and hence time of policy implementation is the same under both Systems A and B, $NPV_{A/B} = C_A - C_B$. That is, the only value of System A (over B) is the difference in costs, which are likely to be negative. Note also that as t_B gets large and t_A small, $NPV_{A/B}$ approaches $C_A - C_B + PV$. But in general, the value of System A is the value of its improvements over System B, not its value over no EMS at all. As will be seen in the following section, D.41 can be used as the basis for deriving a useful explicit expression for the value of an EMS.

D.6 The Value of an Environment Monitoring System

Consider now the time path of the V_i's. A policy implemented in response to information on the existence of a presumably anthropogenically induced environmental trend will, in general, effect some changes in the processes or products of the production sector of the economy. As examples, one might think of a policy banning or curtailing the use of CFMs in the production of foams or a policy banning the use of CFMs in consumer "spray" can products. The former is an example of a policy affecting a production process, the latter an example of a policy affecting a final product. These changes necessarily impose costs on the economy - costs of changing existing production processes and/or costs of consuming inferior products. With time these costs diminish as the production changeover is completed and/or as the modified consumer products are improved up to their previous level of quality and consumer acceptance. Eventually, the policy results in benefits as damages which would have resulted from the unchecked environmental trend are averted. Just as it is usually assumed that damages would ultimately achieve an equilibrium level, so the benefits (of damage averted) can be assumed to ultimately achieve an equilibrium level. Figure D.4 depicts the assumed path in the V_i's. For convenience, the path is modeled as a function of the form :

$$V = k_0 - k_1 e^{-k_2 t}; \; k_0, k_1, k_2 > 0 \qquad \text{D.43}$$

so that the initial cost of the policy is $k_0 - k_1$, the ultimate equilibrium (asymptotic) benefit is k_0, and benefits and costs net to zero at time $t = \frac{\ln k_1 - \ln k_0}{k_2}$. Using the result established in D.41, the value of one EMS over another depends on PV. PV is defined in discrete form in D.42. However, given the continuous form of V in D.43, it is more convenient to express PV as

$$PV = \int_0^{\infty} (k_0 - k_1 e^{-k_2 t}) e^{-rt} dt \qquad \text{D.44}$$

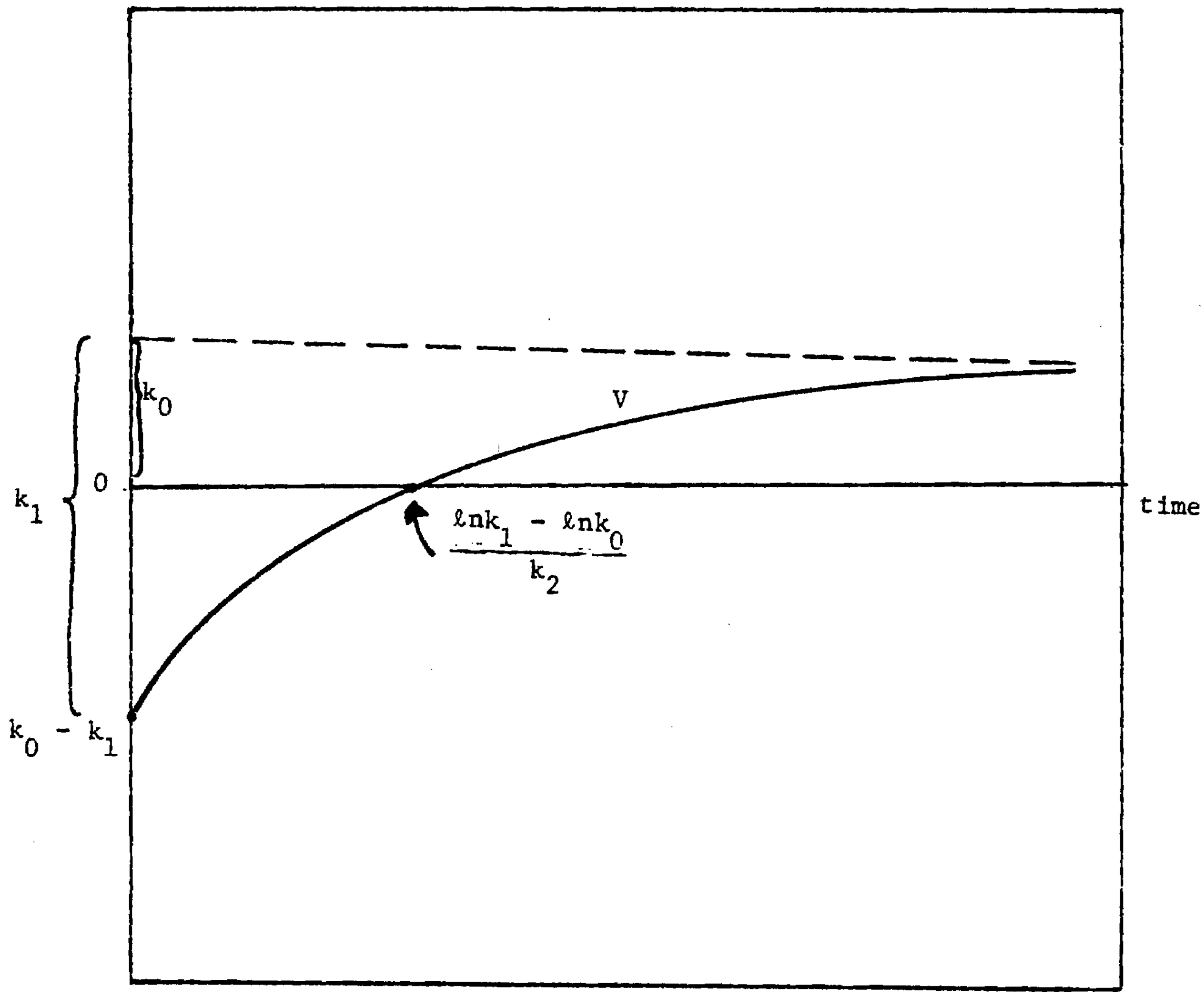

Figure D.4 The Path of Annual Benefits for an Environmental Policy where the term in the parentheses is simply V from (43) and e^{-rt} is the expression permitting continuous discounting. Carrying out the integration results in :

$$PV = \frac{k_0 k_2 + rk_0 - rk_1}{r^2 + rk_2} \quad . \qquad D.45$$

Substituting D.45 into D.41 yields:

$$NPV_{A/B} = (C_A - C_B) + \left[\frac{(1+r)^{t_B - t_A} - 1}{(1+r)^{t_B - 1}}\right] \cdot \left[\frac{k_0 k_2 + rk_0 - rk_1}{r^2 + rk_2}\right] \quad . \qquad D.46$$

The most interesting part of D.46 is $t_B - t_A$, which depends on $\overline{B}_1$, ρ_A, ρ_B, $\overline{\sigma}_N$, $I_A \cdot s_A$, $I_B \cdot s_B$ (the last two terms are the annual number of observations for each EMS). It will be useful to find explicit expressions for t_A and t_B in terms of the aforementioned variables.

Recall from D.31 that :

$$\overline{B}_1 = \frac{\overline{\sigma}_N \sqrt{1+\rho}}{\sqrt{\Sigma(t-\overline{t})^2}} \left[t_c^{.025}(n-2) + t_c^{.05}(n-2)\right] \qquad D.31$$

which gives the minimum detectable trend as a function of the number of observations, among other independent variables. The total number of observations made by a system, say System A, is :

$$n_A = t_A \cdot I_A \cdot s_A \qquad D.47$$

using the same notation as in D.35. The next step is to substitute D.47 into D.31 and solve for t_A. Unfortunately, this is not easily accomplished without resorting to some heuristics. First, it is observed that the term $[t_c^{.025}(n-2) + t_c^{.05}(n-2)]$ ranges between 4 and 3.5 for values of n from 3 to 1000. The bracketed term may be approximated by the constant 3.75. Second, the EMS observations may be assumed to be made one at a time and at uniformly spaced time intervals numbered as 1, 2, 3, 4, ...; then :

$$\sqrt{\sum_{1}^{n} (t-\bar{t})^2} = \sqrt{\frac{n^3-n}{12}} \qquad \text{D.48}$$

which can be approximated as $\sqrt{n^3/12}$. Substituting these approximations and D.47 into D.31 and solving for t_A results in :

$$t_A \cong \frac{5.5\,\bar{\sigma}_N^{2/3}\,(1+\hat{\rho}_A)^{1/3}}{I_A \cdot s_A \cdot \bar{B}_1^{2/3}} . \qquad \text{D.49}$$

In like manner,

$$t_B \cong \frac{5.5\,\bar{\sigma}_N^{2/3}\,(1+\hat{\rho}_B)^{1/3}}{I_B \cdot s_B \cdot \bar{B}_1^{2/3}} . \qquad \text{D.50}$$

Therefore,

$$t_B - t_A \cong 5.5\left(\frac{\bar{\sigma}_n}{\bar{B}_1}\right)^{2/3} \left[\frac{(1+\hat{\rho}_B)^{1/3}}{I_B \cdot s_B} - \frac{(1+\hat{\rho}_A)^{1/3}}{I_A \cdot s_A}\right] \qquad \text{D.51}$$

Returning to (46), both k_0 and k_1 might be expressed as positive functions of $\bar{B}_1$, for both the equilibrium value of averted damage and the initial cost of an environmental policy are likely to be higher for higher $\bar{B}_1$. However, since the present interest is in the qualitative behavior of the NPV of an EMS, that refinement isn't necessary. Rather, the assumption may be adopted that the rightmost bracketed term in D.46, the expression for PV, is positive. This simply means the environmental policy adopted in response to a detected trend has a positive present value as viewed from its point of initiation, excluding the costs of the EMS itself.

Given some proposed EMS, designated as System A; and given an extant (perhaps crude) EMS, designated as System B; our principal concerns are to construct a good estimate of the NPV of System A, and to examine the sensitivity of that estimate to changes (or errors) in the underlying parameter values. Of course, an estimate of NPV must be based on the data, and cannot be inferred from the model. However, the model can be used to predict and explain the sensitivity of NPV to underlying parameters. Specifically, this concern is with the influence on NPV of

- the actual environmental trend, $\bar{B}_1$
- the standard deviation of the natural disturbance term, $\bar{\sigma}_N$
- the accuracy of the observations of the proposed monitoring system as measured by $\hat{\rho} = \hat{\sigma}_M^2 / \hat{\sigma}_N^2$
- the rate of observation of the proposed EMS, $I_A \cdot s_A$
- the discount rate used in the NPV calculation, r.

The investigation is carried out by examining the partial derivaties of D.46, where D.51 is substituted into it for $t_B - t_A$. Since the calculations are tedious, only the results are presented. Our first result is that the direction of the effect of $\overline{B}_1$ on NPV cannot be determined from the model. (This relation was discussed in the previous section.) The issue is strictly empirical, involving the particular parameter values.

The influence of $\overline{\sigma}_N$ on NPV depends on the rates and accuracies of observations of the two systems being compared, and on the discount rate. The sign depends on, and is the same as, the sign of :

$$- \left[\frac{(1+\hat{\rho}_A)^{1/3}}{I_A \cdot s_A} - \frac{(1+\hat{\rho}_B)^{1/3}}{\dfrac{I_B \cdot s_B}{(1+r)^{t_B - t_A}}} \right] . \qquad \text{D.52}$$

If $I_A \cdot s_A$ is greater than $I_B \cdot s_B$, and if $\hat{\rho}_A < \hat{\rho}_B$ (both of which may be expected), then as long as $(1+r)^{t_B - t_A}$ is not too large, the bracketed term is negative and the entire expression D.52 is positive. Generally, then, we expect the NPV of System A to be larger, the larger the standard deviation of the natural disturbance term.

$\hat{\rho}_A$ is a measure of the accuracy of EMS measurements. The smaller $\hat{\rho}_A$, the more accurate the measurements. (See D.30). As would be expected, NPV is inversely related to $\hat{\rho}_A$: the smaller is $\hat{\rho}_A$, the larger is NPV.

$I_A \cdot s_A$ is the number of observations per year made by System A. Not unexpectedly the model's prediction is that larger $I_A \cdot s_A$ results in larger NPV.

The discount rate (more precisely, one plus the discount rate) is the rate at which future and present costs or benefits are traded off. For example, if the discount rate were $r = .10$, then a benefit (or cost) of \$110 next year would be equivalent to a benefit (or cost) of \$100 this year. The parameter r appears in both bracketed terms in D.46. It happens that an increase in r will always decrease the first bracketed term (and vice versa), but the effect of a change in r on the second bracket depends the value of r. At "low" values of r, an increase in r will decrease the value of the second bracket, but at "high" values of r, an increase in r will increase the value of that bracket. The overall effect of the two bracketed terms is that NPV initially decreases with increases in r, but eventually tends to increase as r continues to increase. However, the eventual tendency to increase is not so strong as the initial tendency to decrease, and the tendency to decrease occurs over a fairly broad range.

In sum, the model suggests the value of a proposed EMS, in lieu of an extant EMS, depends on $\bar{B}_1$, $\bar{\sigma}_N$, ρ_A, $I_A \cdot s_A$, and r; as well as on $\hat{\rho}_B$, $I_B \cdot s_B$, C_A, and C_B. Table D.3 summarizes the expected direction of impact of these parameters on the value (as measured by the Net Present Value) of a proposed EMS called System A, when another EMS called System B, is already in place, and where System A is assumed to be the more sophisticated system.

Table D.3 Predicted Sensitivity of Net Present Value of System A to Variance Parameters

$\partial NPV/\partial(1) > 0$ 1	$\partial NPV/\partial(2) < 0$ 2	$\partial NPV/\partial(3) \lesseqgtr 0$ 3
$\hat{\rho}_B$	$\hat{\rho}_A$	$\bar{B}_1$
C_B	C_A	
$I_A \cdot s_A$	$I_B \cdot s_B$	
$\bar{\sigma}_N$	r	

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