MATERIALS TECHNOLOGY DEVELOPMENT FOR
LONG LIFE LARGE SPACE SYSTEMS

DATE:

TOPICS

- MATERIALS REQUIREMENTS FOR LARGE SPACE SYSTEM (LSS)
- TYPICAL LSS MATERIALS, APPLICATION, AND CONTROLLING PROPERTIES
- ENVIRONMENTAL CONSIDERATIONS
  - LEO
  - GEO
- MATERIALS TECHNOLOGY DEVELOPMENT FOR LSS

Figure 1

(Figure 2)

IT IS OBVIOUS THAT ONE OF THE PRIME REQUIREMENTS FOR LSS MATERIALS IS THAT THEY BE LIGHTWEIGHT WHICH ALSO IMPLIES A HIGH STRENGTH TO WEIGHT RATIO. LOW COST IS IMPORTANT WHEN CONSIDERING THE SHEER SIZE OF THE STRUCTURES AND THE AMOUNT OF MATERIAL THAT WILL BE REQUIRED. IN ADDITION, THE MATERIALS SHOULD BE EASILY PROCESSED. THIS MEANS NOT ONLY MINIMIZING LABOR AND TIME BUT ALSO THE TOOLING AND POWER REQUIRED FOR PROCESSING. THE LAST REQUIREMENT LISTED PERTAINS TO THE SPACE DURABILITY OF THE LSS MATERIALS AND IS THE MOST SIGNIFICANT AS FAR AS MATERIALS TECHNOLOGY IS CONCERNED. NO LONG TERM ENVIRONMENTAL DATA ARE AVAILABLE WITH WHICH TO ASSESS MATERIALS PERFORMANCE. SINCE MAINTENANCE AND REPAIR OF THESE STRUCTURES AND SYSTEMS WILL BE DIFFICULT AND EXPENSIVE, IT IS IMPERATIVE THAT THE BASIC MATERIALS USED MAINTAIN THEIR CRITICAL PROPERTIES WITHIN SPECIFIED LIMITS FOR THE BASELINED LIFETIME OF 20 TO 30 YEARS.

MATERIALS REQUIREMENTS

- LIGHT WEIGHT
- LOW COST
- EASILY PROCESSED
- LONG TERM RETENTION OF PROPERTIES IN SPACE ENVIRONMENT (20 TO 30 YEARS)

Figure 2

(Figure 3)

BASED ON A REVIEW OF THE LSS FOCUS MISSIONS AND ASSOCIATED HARDWARE, GENERAL MATERIALS CATEGORIES, TYPICAL APPLICATIONS, AND CONTROLLING PROPERTIES FOR THESE APPLICATIONS HAVE BEEN DEFINED AS SHOWN IN THIS CHART. IT IS NOT INTENDED THAT THIS CHART BE ALL INCLUSIVE BUT THAT IT BE ILLUSTRATIVE OF THE BREADTH OF THE MATERIALS DATA BASE THAT WILL BE NEEDED TO SUPPORT THE LSS.

ORGANIZATION:	MARSHALL SPACE FLIGHT CENTER MATERIALS TECHNOLOGY DEVELOPMENT FOR LONG LIFE LARGE SPACE SYSTEMS	NAME: DATE:

		CONTROLLING PROPERTIES				
MATERIAL TYPE	TYPICAL LSS APPLICATION	MECH	OPTICAL	ELECT	CoTE	OUTGASSING
COMPOSITES	STRUCTURAL MEMBERS	X			X	X
THIN GAUGE METALS	STRUCTURAL MEMBERS	X			X	
ADHESIVES	JOINTS	X				X
DIELECTRICS	ELECTRICAL/ELECTRONIC SYSTEMS	X		X		X
COATINGS	THERMAL CONTROL REFLECTORS	X	X			X
THIN FILMS	THERMAL BLANKETS MIRRORS	X	X		X	X
WIRE MESHES	ANTENNAE	X			X	
SEMICONDUCTORS	ELECTRONICS, SOLAR CELLS			X		
GLASSES	SOLAR CELL COVERS		X			

Figure 3

(Figure 4)

THE ELECTRON ENVIRONMENT FOR GEOSYNCHRONOUS ORBIT IS GIVEN BY VETTE'S MODEL AE4. THE INTEGRAL ELECTRON SPECTRA FOR L = 6.6 AT SOLAR MINIMUM IN EPOCH 1964 IS SHOWN WITH TIME AVERAGED VALUES USED TO AVERAGE OUT THE EFFECTS OF MAGNETIC STORMS.[1,2] THE ION ACCELERATOR FACILITY AT MSFC CAN PROVIDE ELECTRON IRRADIATIONS OVER THE ENERGY RANGE OF 0.35 MEV TO 2.5 MEV TO SIMULATE THIS ENVIRONMENT.

(1) SINGLEY, G.W. AND VETTE, J.I., THE AE4 MODEL OF THE OUTER RADIATION ZONE ELECTRON ENVIRONMENT. NSS DC 72-06, AUGUST 1972.

(2) THE EARTH'S TRAPPED RADIATION BELTS. NASA SP-8116, MARCH 1975.

INTEGRAL ELECTRON SPECTRA, GEOSYNCHRONOUS ORBIT

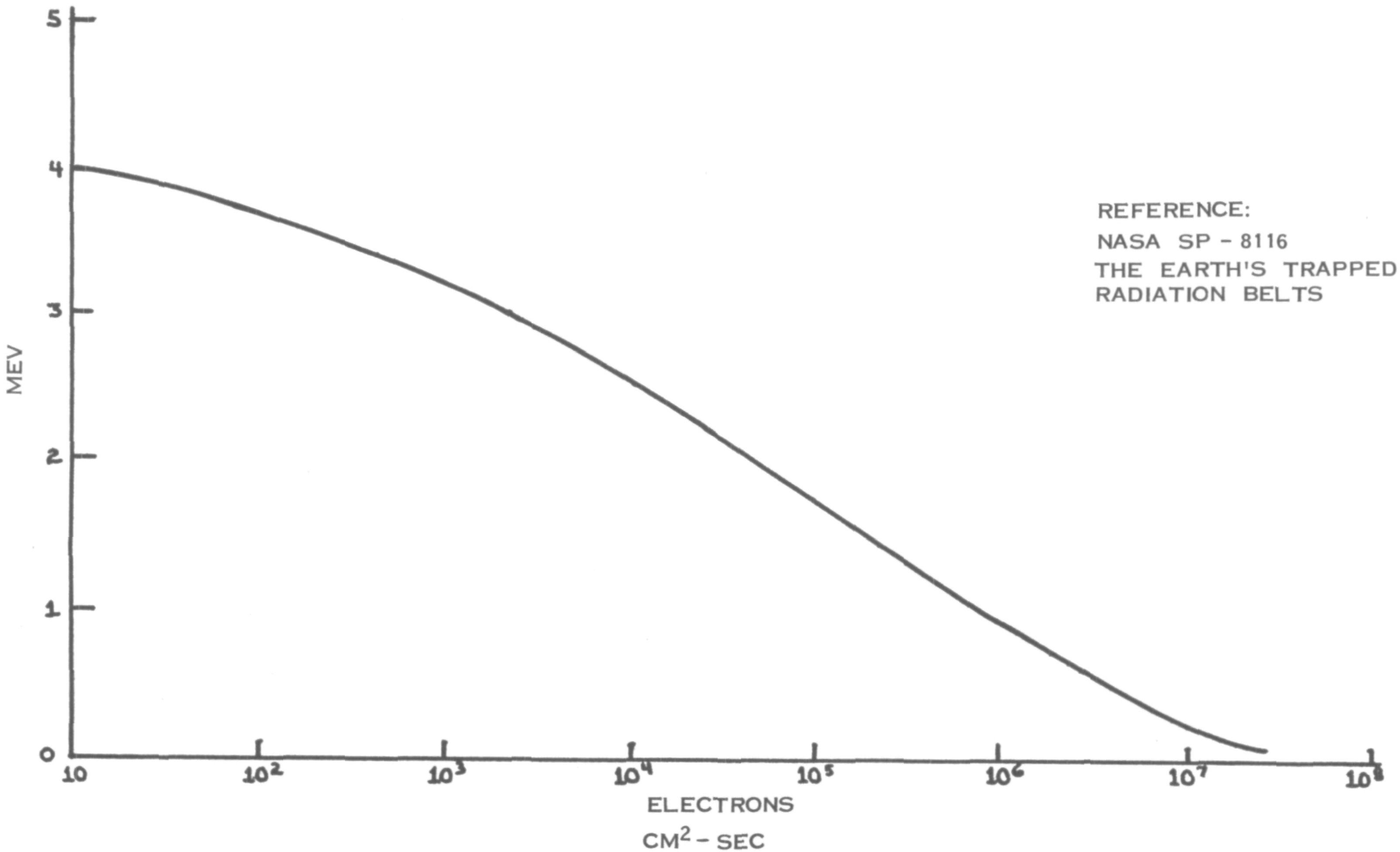


Figure 4

(Figure 5)

THE CUMULATIVE ELECTRON EXPOSURE IN GEOSYNCHRONOUS ORBIT IS SHOWN AS DERIVED FROM THE FIGURE FOR L = 6.6 FOR ELECTRONS WITH ENERGIES GREATER THAN 0.5 MEV. FOR SURFACE RADIATION DAMAGE EFFECTS, THE LOWER ENERGY ELECTRONS MUST BE INCLUDED AND THE TOTAL FLUENCE WOULD BE HIGHER THAN SHOWN. FOR A 20 TO 30 YEAR STAY TIME IN GEO, THE PREDICTED FLUENCE IS ON THE ORDER OF 3×10^{15} e/cm^2. THIS ELECTRON EXPOSURE CAN INDUCE SIGNIFICANT PROPERTY CHANGES IN MANY TYPES OF MATERIALS.

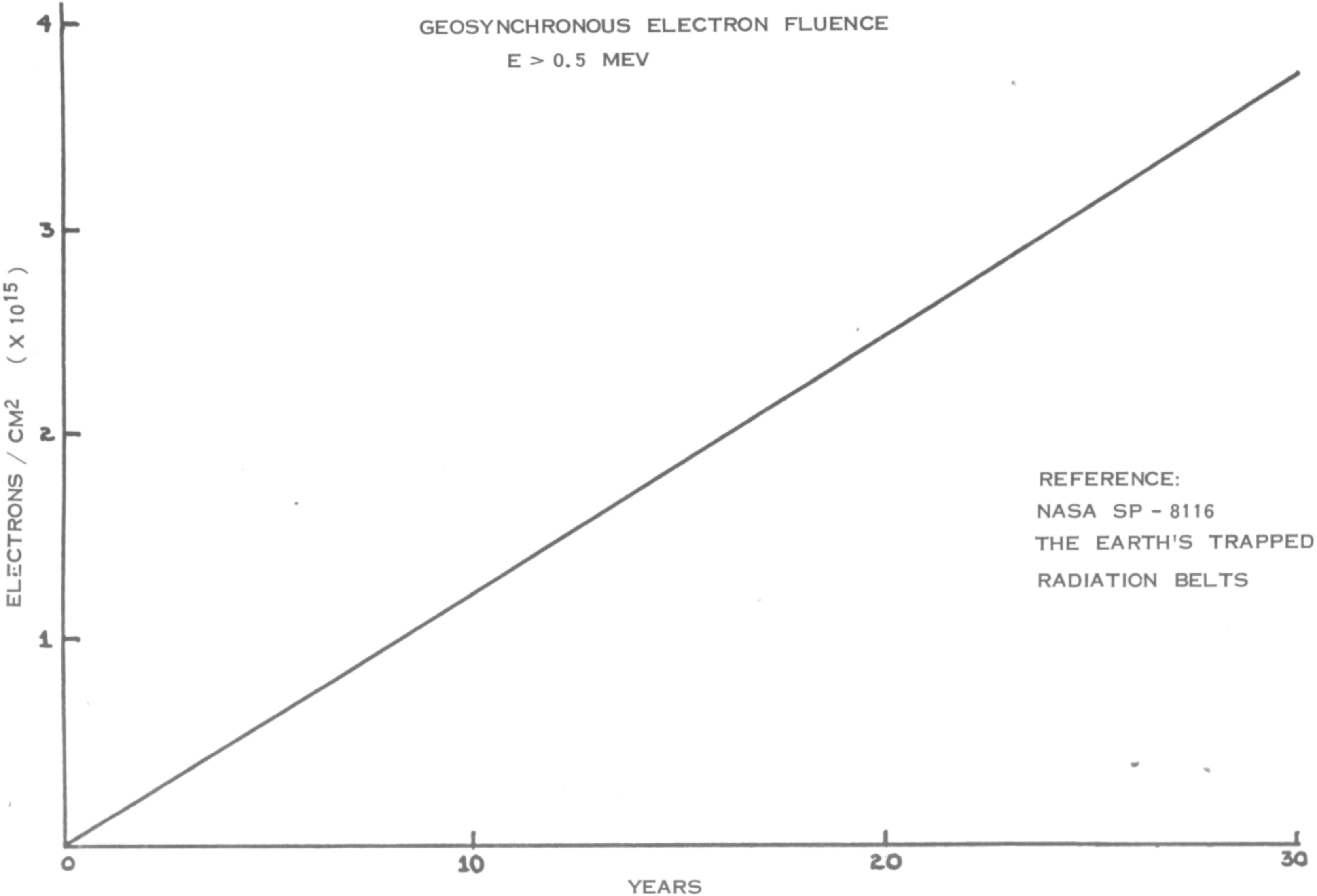
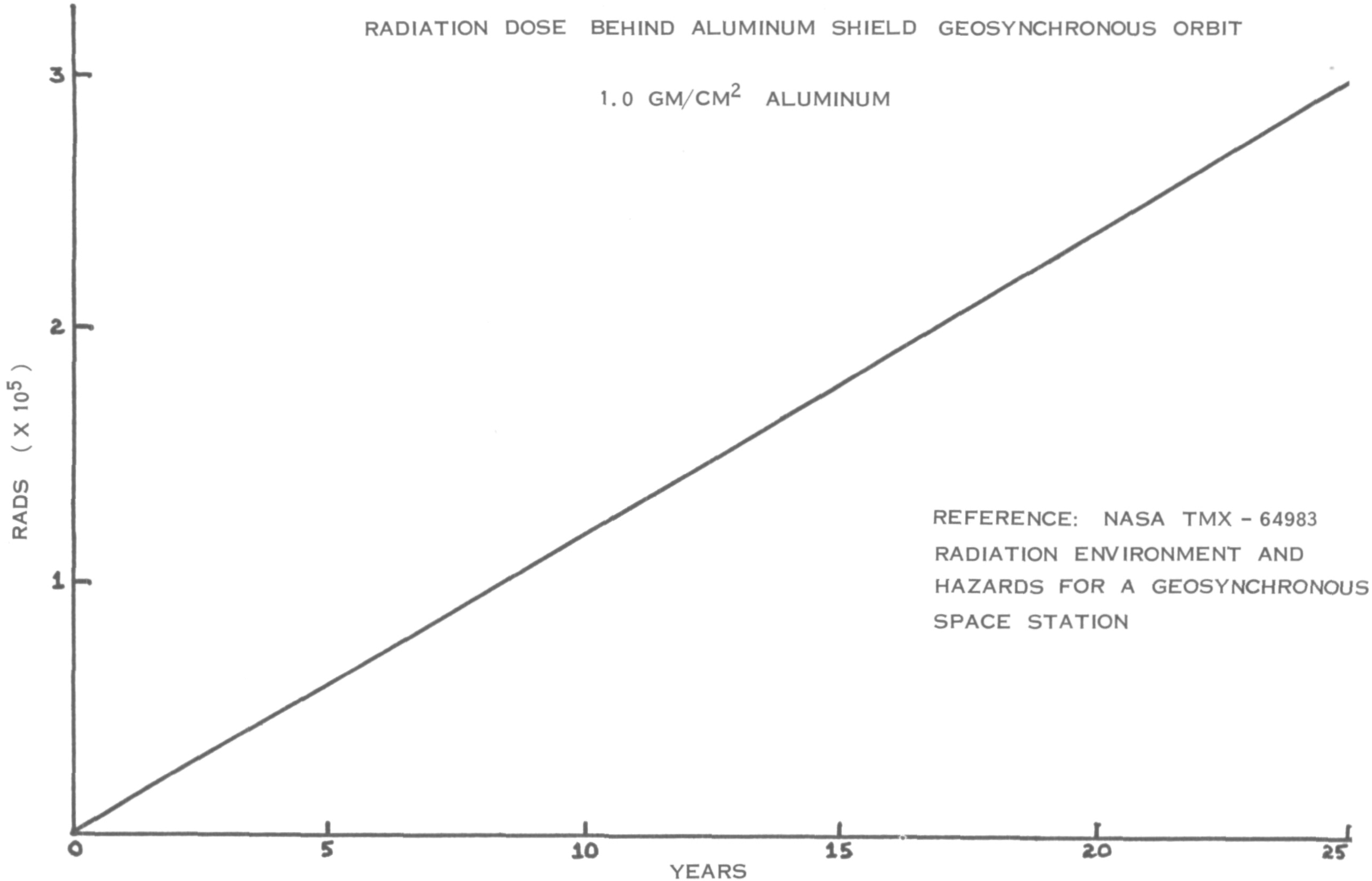

GEOSYNCHRONOUS ELECTRON FLUENCE
E > 0.5 MEV
ELECTRONS / CM2 (X 1015)
4
3
2
1
0
10
20
30
YEARS
REFERENCE:
NASA SP - 8116
THE EARTH'S TRAPPED
RADIATION BELTS

Figure 5

(Figure 6)

THE TOTAL RADIATION DOSE RECEIVED BEHIND A 1 g/cm^2 THICK ALUMINUM SHIELD IS SHOWN.[1] FOR THIS THICKNESS,THE PRIMARY SOURCE OF RADIATION IS THE ELECTRON FLUENCE. FOR THICKNESSES OF MORE THAN 1.8 g/cm^2 OF ALUMINUM, THE PRIMARY RADIATION SOURCE WOULD BE BREMSSTRAHLUNG PHOTONS GENERATED BY THE ELECTRON FLUENCE'S INTERACTIONS WITH THE ALUMINUM ATOMS. SINCE THE BREMSSTRAHLUNG FLUX IS A FUNCTION OF THE ATOMIC NUMBER OF THE TARGET MATERIAL, THE RADIATION DOSE WITHIN A GEOSYNCHRONOUS SPACE STRUCTURE WOULD BE HIGHLY VARIABLE AND THEREFORE MUST BE CAREFULLY CALCULATED FOR EACH SPACE STRUCTURE AND/OR COMPONENT. FOR ILLUSTRATIVE PURPOSES, HOWEVER, USING THIS GRAPH, AN ELECTRONIC COMPONENT IN A 1 g/cm^2 ENCLOSURE WOULD RECEIVE A DOSE ON THE ORDER OF 2×10^5 RADS IN 20 YEARS. THIS DOSE IS SUFFICIENT TO SERIOUSLY DEGRADE THE PERFORMANCE OF SOME ELECTRONIC DEVICES.

(1) WRIGHT, J.J. AND FISHMAN, G.J., RADIATION ENVIRONMENT AND HAZARDS FOR A GEOSYNCHRONOUS SPACE STATION. NASA TMX-64983, FEBRUARY 1976



RADIATION DOSE BEHIND ALUMINUM SHIELD GEOSYNCHRONOUS ORBIT
1.0 GM/CM^2 ALUMINUM
REFERENCE: NASA TMX - 64983
RADIATION ENVIRONMENT AND
HAZARDS FOR A GEOSYNCHRONOUS
SPACE STATION
RADS (X 10^5)
3
2
1
0
5
10
15
20
25
YEARS

Figure 6

(Figure 7)

THE TOTAL ELECTRON FLUENCE AT 800 KM ORBIT AND 28.5° INCLINATION IS SHOWN.[1] THESE FLUENCES ARE ABOUT AN ORDER OF MAGNITUDE LESS THAN THOSE AT GEOSYNCHRONOUS ORBIT; HOWEVER, IT IS TO BE NOTED THAT THE PEAK FLUENCES LIE BETWEEN THESE TWO ORBITS AT ABOUT L = 4 TO L = 5.

(1) WATTS, J.W., JR., AND WRIGHT, J.J., CHARGED PARTICLE RADIATION ENVIRONMENT FOR THE SPACELAB AND OTHER MISSIONS IN LOW EARTH ORBIT, REVISION A. NOVEMBER 1976. NASA TMX-73358, NOVEMBER 1976.

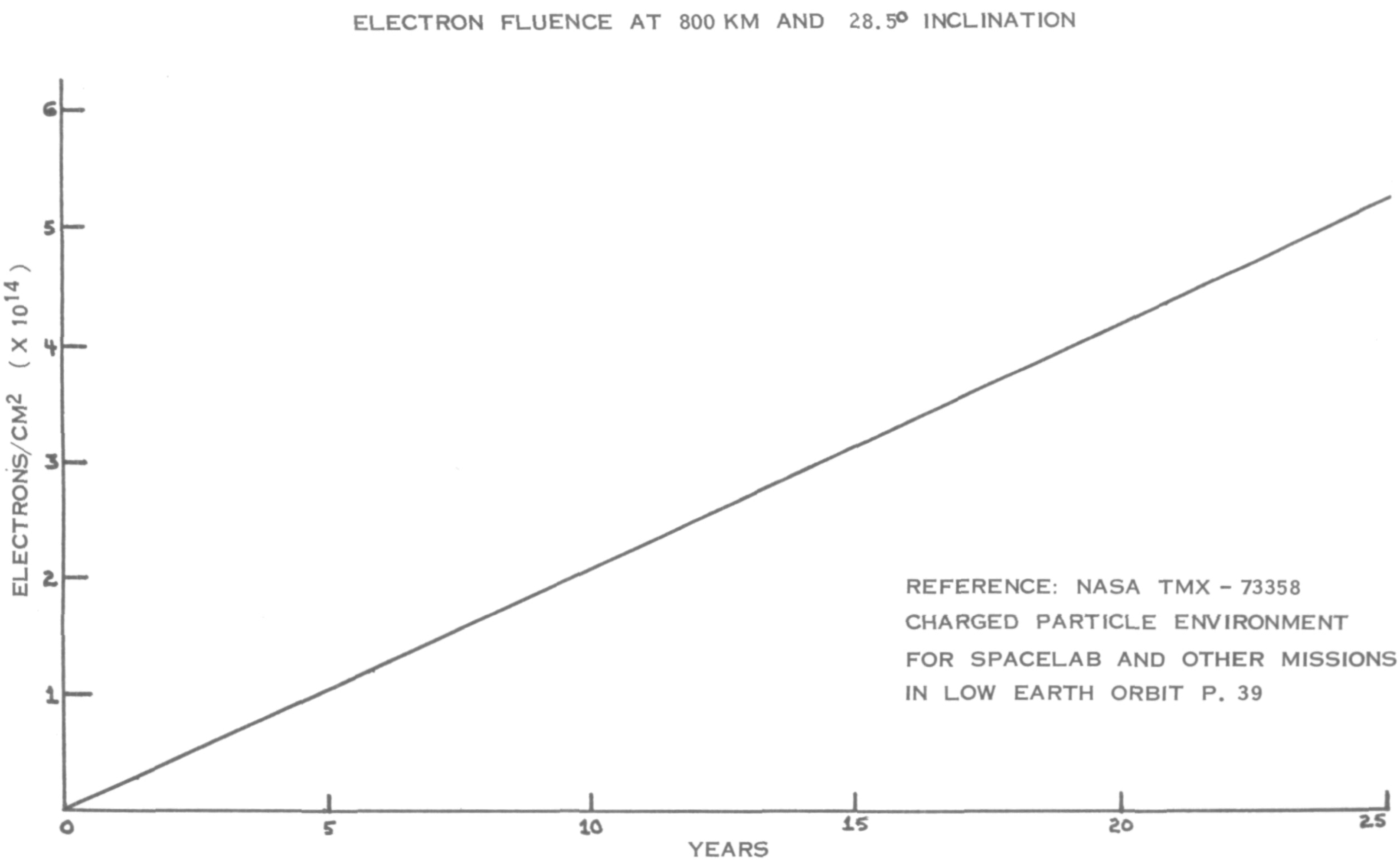

ELECTRON FLUENCE AT 800 KM AND 28.5° INCLINATION
ELECTRONS/CM2 (X 10^14)
6
5
4
3
2
1
0
5
10
15
20
25
YEARS
REFERENCE: NASA TMX - 73358
CHARGED PARTICLE ENVIRONMENT
FOR SPACELAB AND OTHER MISSIONS
IN LOW EARTH ORBIT P. 39

Figure 7

(Figure 8)

THE TOTAL ELECTRON FLUENCE AT A 200 KM ORBIT AND 28.5° INCLINATION IS SHOWN. THIS FLUENCE IS ABOUT 4-1/2 ORDERS OF MAGNITUDE LESS THAN THAT AT THE PREVIOUS 800 KM ORBIT. AT THIS ALTITUDE, THE PROTON FLUENCE IN THE SOUTH ATLANTIC ANOMALY IS THE PRIMARY RADIATION SOURCE.

ELECTRON FLUENCE AT 200 KM AND 28.5° INCLINATION

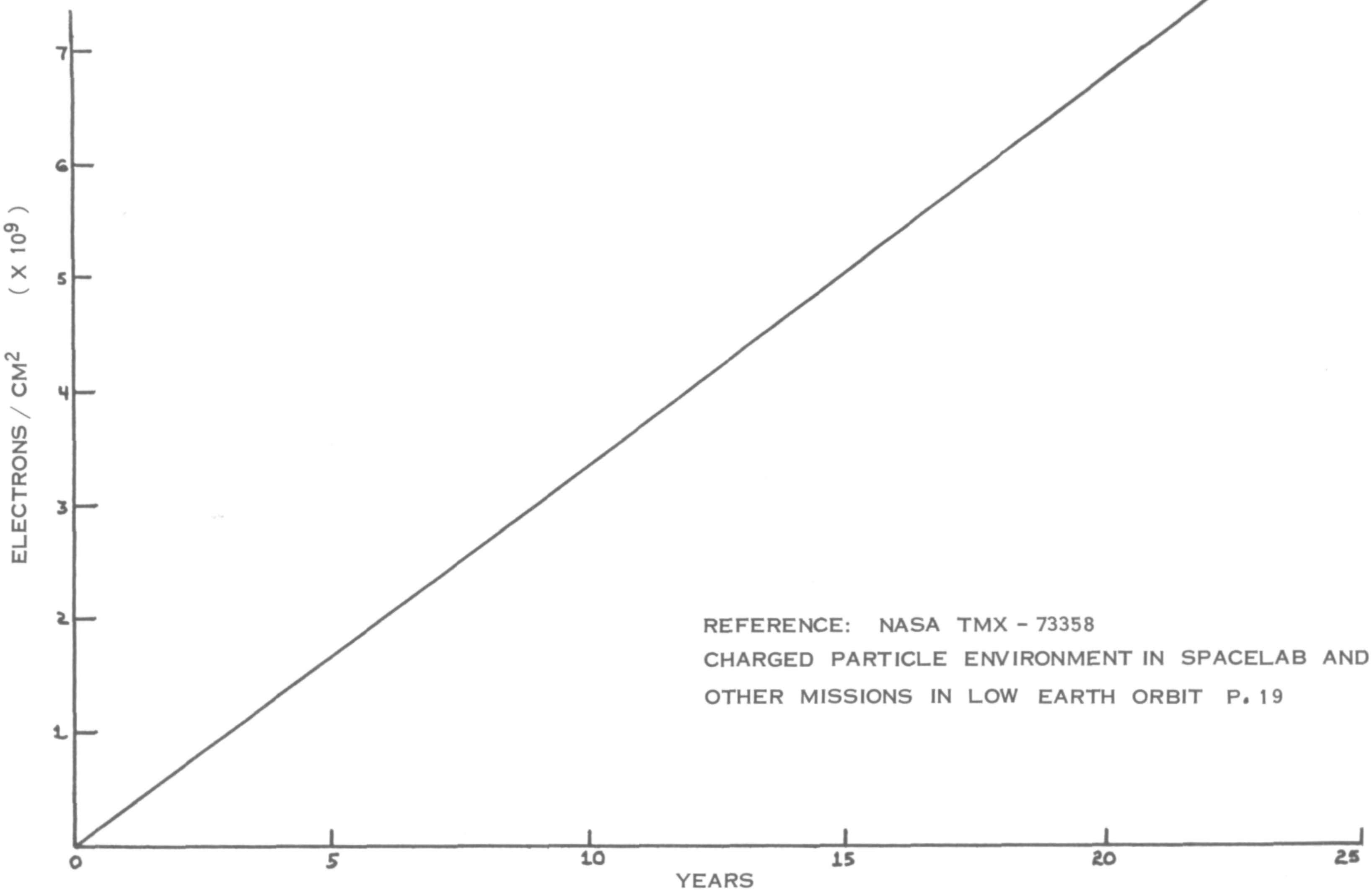


Figure 8

(Figure 9)

THE THICKNESS OF ALUMINUM AND NON-METALLIC COMPOSITE MATERIALS FOR LSS STRUCTURAL MEMBERS WILL RANGE FROM 0.010 TO 0.050 INCH. AS CAN BE SEEN FROM THIS CHART, ELECTRONS WITH AN ENERGY GREATER THAN APPROXIMATELY 0.3 MEV WILL HAVE SUFFICIENT RANGE IN THESE MATERIALS TO AFFECT THE BULK PROPERTIES, WHEREAS LOWER ENERGY ELECTRONS WILL PRIMARILY AFFECT SURFACE PROPERTIES. SINCE THE GEO ENVIRONMENT HAS A SIGNIFICANT FLUX OF ELECTRONS IN THIS ENERGY RANGE, BOTH THE SURFACE AND BULK PROPERTIES OF MATERIALS CAN BE EXPECTED TO BE AFFECTED IN GEO.

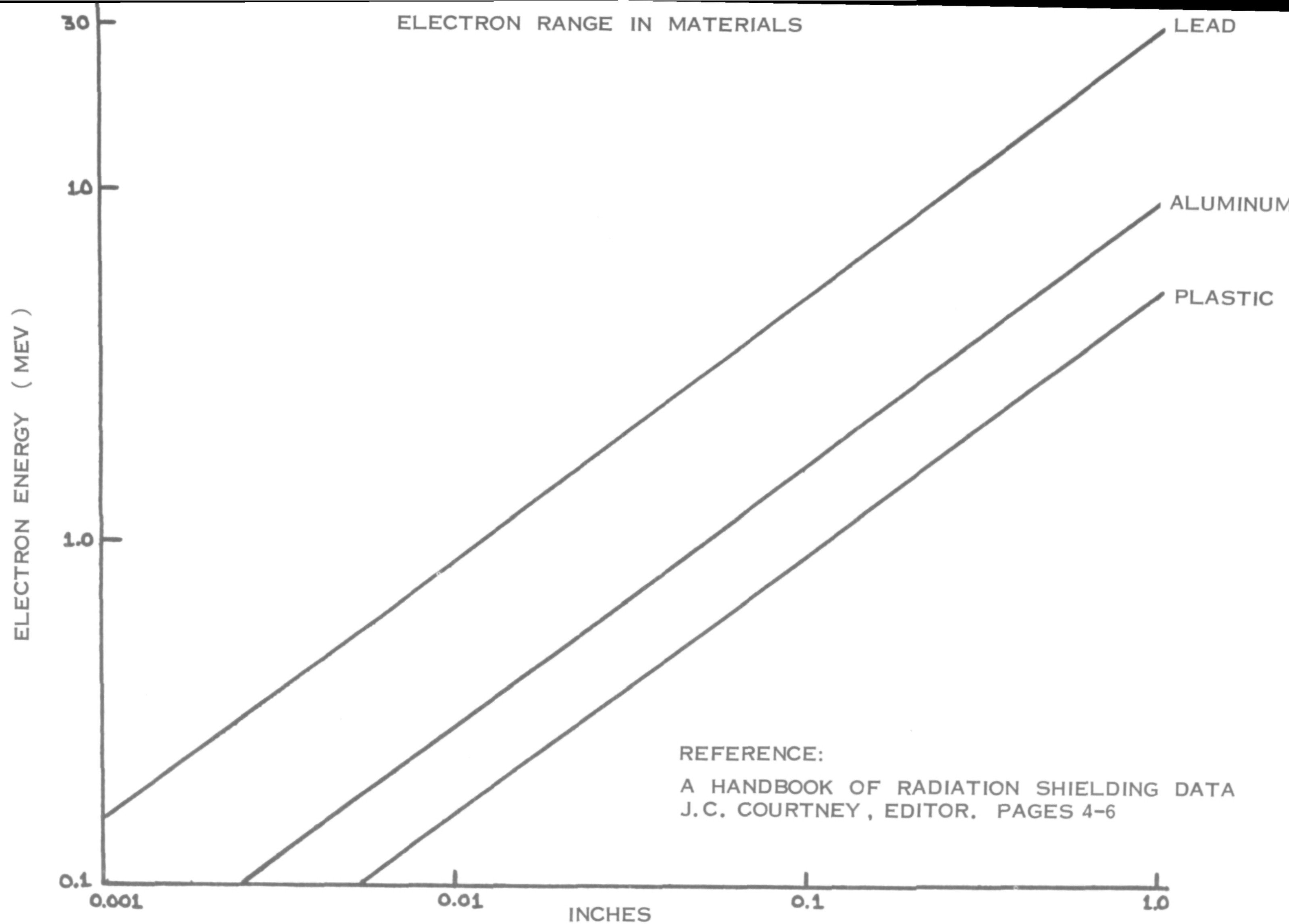
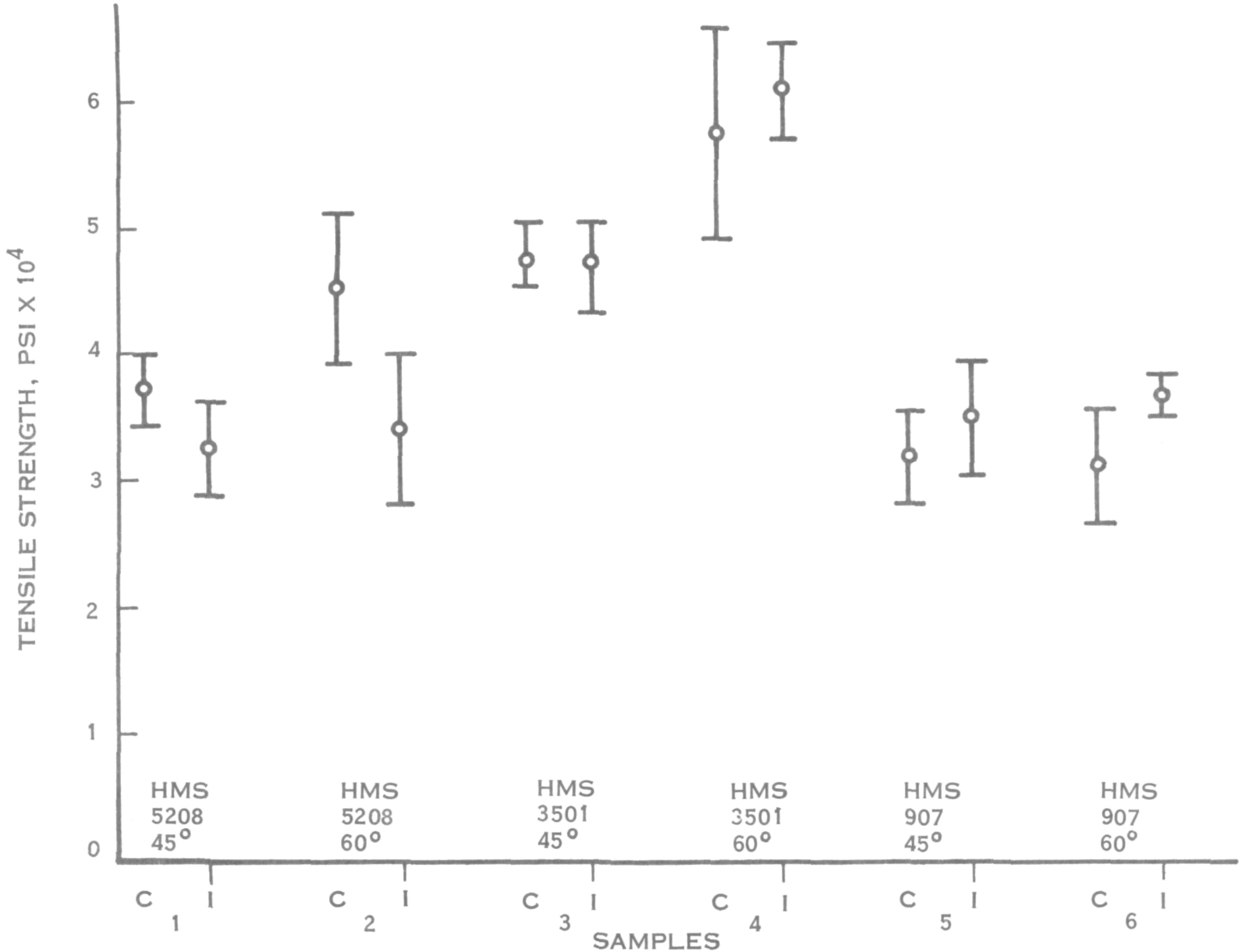

ELECTRON RANGE IN MATERIALS
ELECTRON ENERGY (MEV)
30
10
1.0
0.1
0.001
0.01
0.1
1.0
INCHES
LEAD
ALUMINUM
PLASTIC
REFERENCE:
A HANDBOOK OF RADIATION SHIELDING DATA
J.C. COURTNEY, EDITOR. PAGES 4-6

Figure 9

(Figure 10; Figure 11)

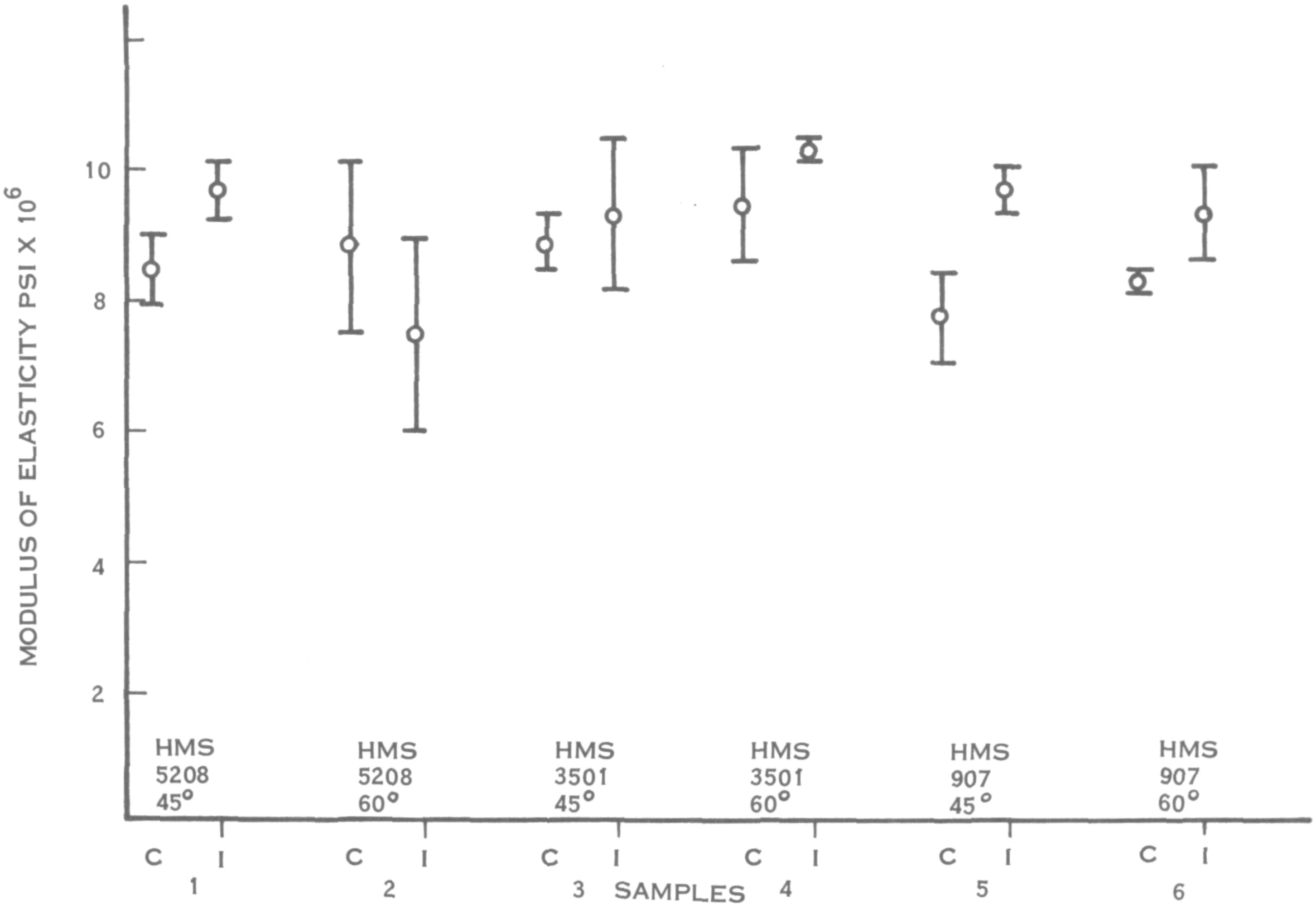
SINCE NON-METALLIC COMPOSITES ARE PRIME CANDIDATES FOR THE FABRICATION OF LSS STRUCTURAL MEMBERS, IT IS IMPORTANT TO ESTABLISH THE ENVIRONMENTAL STABILITY OF THE VARIOUS COMPOSITE FIBER/RESIN SYSTEMS IN ORDER TO ASSURE THE SELECTION OF MATERIALS THAT WILL PROVIDE THE PRESCRIBED LIFETIME IN ORBIT. THIS CHART, AND THE ONE FOLLOWING, PRESENT THE RESULTS OF SOME MSFC IN-HOUSE TESTS THAT WERE MADE USING A 2.5 MEV VAN DE GRAAFF ACCELERATOR. THREE SETS OF COMPOSITE SPECIMENS WERE PREPARED USING THE SAME TYPE OF GRAPHITE FIBER, BUT THREE DIFFERENT EPOXY RESIN SYSTEMS. THE THICKNESS OF THE SPECIMENS RANGED FROM 0.030 TO 0.040 INCH. SOME SPECIMENS WERE USED TO OBTAIN CONTROL PROPERTY DATA, AND THE OTHERS WERE IRRADIATED IN VACUUM WITH 2 MEV ELECTRONS TO A FLUENCE OF 2.6×10^{12} ELECTRONS/cm^2. THIS FLUENCE REPRESENTS THE PREDICTED ELECTRON RADIATION EXPOSURE THAT WOULD BE ENCOUNTERED IN 7 YEARS IN LEO (300 NM 30° INCLINATION) OR IN 7.5 DAYS IN GEO WHICH VIVIDLY DEMONSTRATES THE MORE HOSTILE ENVIRONMENT ASSOCIATED WITH GEO OPERATIONS. THE DATA SHOWS THAT THERE WAS A SIGNIFICANT DEGRADATION IN BOTH THE TENSILE STRENGTH AND THE MODULUS OF THE HMS/5208 FIBER/RESIN SYSTEM. THIS, OF COURSE, REPRESENTS UNACCEPTABLE PERFORMANCE AND ELIMINATES THIS MATERIAL SYSTEM FOR LSS APPLICATION IN EITHER LEO OR GEO. THE PROPERTIES OF THE HMS/3501 AND HMS/907 MATERIAL SYSTEMS WERE IMPROVED BY THIS EXPOSURE. HOWEVER, BEFORE EITHER COULD BE DESIGNATED AS CANDIDATE LSS MATERIALS, TESTS WOULD HAVE TO BE MADE AT HIGHER FLUENCES (TO $\sim 5 \times 10^{15}$ ELECTRONS/cm^2) TO VERIFY STABILITY.



C - CONTROL
I - IRRADIATED

EXPOSURE; 2.6 X 10^{12} ELECTRONS/CM^2, EQUIVALENT TO:
7 YEARS IN A 300 NAUTICAL MILE 30° ORBIT OR,
7.5 DAYS IN GEOSYNCHRONOUS ORBIT

Figure 10



C - CONTROL
I - IRRADIATED

EXPOSURE; 2.6 X 10^{12} ELECTONS/CM^2, EQUIVALENT TO:
7 YEARS IN A 300 NAUTICAL MILE 30° ORBIT OR,
7.5 DAYS IN GEOSYNCHRONOUS ORBIT

Figure 11

(Figure 12)

THIS CHART SHOWS THE EFFECTS OF THERMALLY CYCLING IN VACUUM FROM -100°F TO +300°F ON THE MECHANICAL PROPERTIES OF THIN GAUGE (.031 INCH) ALUMINUM. AFTER 1000 CYCLES, THE MOST SIGNIFICANT CHANGE WAS A 44% DECREASE IN ELONGATION. THESE TESTS ARE BEING MADE IN-HOUSE AT MSFC TO EVALUATE THE SPACE PERFORMANCE OF THIN ALUMINUM SUCH AS IS BEING CONSIDERED FOR USE AS LSS STRUCTURAL MEMBERS. DATA WILL BE OBTAINED FOR 5000 THERMAL CYCLES FOLLOWED BY ELECTRON IRRADIATION TO 5 x 10^{15} ELECTRONS/CM^2.

ORGANIZATION:	MARSHALL SPACE FLIGHT CENTER MATERIALS TECHNOLOGY DEVELOPMENT FOR LONG LIFE LARGE SPACE SYSTEMS	NAME: DATE:

MECHANICAL PROPERTIES OF THERMALLY CYCLED 6061-T6 THIN GAUGE ALUMINUM[1]

CONDITION	UTS (KSI)	YS (KSI)	ELONG. (% IN 2.0 IN.)
UNCOATED	46.9	42.9	12.9
COATED (BAKED)[2]	44.7	41.3	12.1
COATED (BAKED), THERMALLY CYCLED[3]	40.9	38.4	6.8

NOTES:
1. THICKNESS OF AL, 0.03125 INCHES.
2. COATING, KEM LUSTRAL S-65B2 BAKED AT 200°F FOR 4 HOURS.
3. THERMAL CYCLING BETWEEN -100°F AND +300°F FOR 1000 CYCLES AT 1 HOUR PER CYCLE.

Figure 12

ORGANIZATION:	MARSHALL SPACE FLIGHT CENTER REFLECTOR MATERIALS TESTS	NAME: DATE:

MATERIAL: 4 MIL ACRYLIC SILVERED POLYESTER

TEST ENVIRONMENT: 10^{-6} TORR, 100 °C, OUTGASSING

RESULTS: MATERIAL SEPARATION AT SILVER/POLYESTER BOUNDARY

MATERIAL: ALUMINIZED 1 MIL MYLAR

TEST ENVIRONMENT: 10^{-6} TORR, PROTON IRRADIATION OF 10^{12} TO 10^{16} PROTONS/CM^2

RESULTS: FAILURE OF MYLAR AT ALL PROTON FLUENCES

MATERIAL: ALUMINIZED 2 MIL KAPTON

TEST ENVIRONMENT: 10^{-6} TORR, PROTON IRRADIATION OF 10^{12} TO 10^{16} PROTONS/CM^2

RESULTS:

PROTONS/CM^2	REFLECTANCE
10^{12}	0.89
10^{13}	0.89
10^{14}	0.89
10^{15}	0.87
10^{16}	0.84
CONTROL	0.87

Figure 13

(Figure 14; Figure 15)

THIS CHART, AND THE ONE FOLLOWING, SUMMARIZE THE MATERIALS AREAS FOR WHICH FURTHER TECHNOLOGY DEVELOPMENT IS NEEDED TO MEET LSS REQUIREMENTS. A PROGRAM ENCOMPASSING THESE AREAS WAS FORMULATED BY A NASA INTERCENTER WORKING GROUP AND SUBMITTED TO THE LSS PROGRAM OFFICE FOR INCORPORATION IN THE LSS PROGRAM PLAN.

ORGANIZATION:	MARSHALL SPACE FLIGHT CENTER MATERIALS TECHNOLOGY DEVELOPMENT FOR LONG LIFE LARGE SPACE SYSTEMS	NAME: DATE:

LSS MATERIALS TECHNOLOGY DEVELOPMENT

- COMPOSITES
  - THERMOPLASTIC AND THERMOSETTING
  - LOW THERMAL EXPANSION/DIMENSIONALLY STABLE
  - RADIATION RESISTANT
  - ULTRA THIN
- METALS
  - THIN GAUGE SHEET
  - WIRE MESH
  - CONDUCTIVE MEMBRANES
- POLYMERS
  - ADHESIVES
  - DIELECTRICS
  - RIGIDIZING
  - THIN FILMS (COATED AND UNCOATED)

Figure 14

ORGANIZATION:	MARSHALL SPACE FLIGHT CENTER MATERIALS TECHNOLOGY DEVELOPMENT FOR LONG LIFE LARGE SPACE SYSTEMS	NAME: DATE:

LSS MATERIALS TECHNOLOGY DEVELOPMENT (CONTINUED)

- COATINGS
  - REFLECTOR
  - THERMAL CONTROL AND UV PROTECTIVE (INTEGRAL AND APPLIED)
- SPACE ENVIRONMENTAL EFFECTS
  - EVALUATE MATERIALS
    - SCREENING
    - IN-SITU
    - SYNERGISTIC
    - LONG TERM
  - DEVELOP PREDICTIVE MODELS
  - DEFINE FLIGHT EXPERIMENTS
  - PROVIDE DATA BASE FOR DESIGN

Figure 15

(Figure 16)

IN SUMMARY, IT HAS BEEN DEMONSTRATED BY EXAMPLE THAT THE PERFORMANCE AND RELIABILITY OF LARGE SPACE SYSTEMS WILL BE CRITICALLY DEPENDENT ON THE SELECTION OF MATERIALS WHICH WILL EXHIBIT STABILITY IN FUNCTIONAL PROPERTIES IN THE LSS ORBITAL ENVIRONMENT. IN THIS REGARD, THE DEVELOPMENT OF MATERIALS WHICH WILL HAVE A 20 TO 30 YEAR LIFE IS THE MOST SIGNIFICANT PROBLEM FACING THE MATERIALS COMMUNITY. TO PROVIDE THE TECHNOLOGY TO MEET THIS REQUIREMENT REQUIRES AN INTENSIVE EFFORT IN SEVERAL MATERIALS AREAS. THESE AREAS HAVE BEEN DEFINED AND A TECHNOLOGY PLAN PREPARED. TIMELY IMPLEMENTATION OF THIS PLAN IS NECESSARY TO INSURE THE AVAILABILITY OF THE LONG LIFE HIGH PERFORMANCE MATERIALS THAT WILL BE REQUIRED FOR THE LSS PROGRAM.

006

ORGANIZATION:	MARSHALL SPACE FLIGHT CENTER MATERIALS TECHNOLOGY DEVELOPMENT FOR LONG LIFE LARGE SPACE SYSTEMS	NAME: DATE:

SUMMARY

- LSS PERFORMANCE CRITICALLY DEPENDENT ON MATERIALS SELECTION
- MOST SIGNIFICANT PROBLEM IS 20-30 YEAR LIFE REQUIREMENT
- MATERIALS TECHNOLOGY DEVELOPMENT REQUIRED
    - NEEDS DEFINED
    - PLAN PREPARED
    - TIMELY IMPLEMENTATION NECESSARY

Figure 16

COMMENTS OF GENERAL INTEREST FROM QUESTIONS AND ANSWERS

Materials Technology Development for Long Life Large Space Systems

Approach to Test Planning for Materials

The reusability of the shuttle opens up the potential for satellites with lives beyond the 10 years experienced to date. While needs can be established for exposures ranging from 20 to 30 years, the materials testing effort should be approached as a series of 4 to 5 year programs in which each can be realistically defined, costed and implemented.