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PREDICTIONS OF VEHICLE ENCOUNTERED ELECTRON AND PROTON FLUXES FOR THE UK-4 SPACECRAFT

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GSFC

GODDARD SPACE FLIGHT CENTER
GREENBELT, MARYLAND

Predictions of Vehicle Encountered Electron and Proton Fluxes for The UK-4 Spacecraft

A special study to determine the trapped particle radiation intensities expected in a nominal UK-4 orbit with addendum on "Environment Models and Orbital Flux Calculations"

by

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Foreword

Updated radiation data were obtained for the UK-4 satellite by performing orbital flux integrations for protons and electrons along a specified flight path, using current field and environment models. In this process, adjustments were made to the electron data to account for temporal variations. The final results are presented in tabular and graphical form; they are analysed, explained, and discussed.

Introduction

High inclination circular and elliptical trajectories ($i>55°$) or low inclination elliptical orbits of large eccentricity traverse the terrestrial radiation belts twice during each revolution. The vehicle thus executes a transverse motion in L-space, passing successively through a region of low L-values ($1.0 \leq L \leq 2.0$) and of high L-values ($2.0 \leq L \leq 6.6$), commonly referred to as the inner zone and the outer zone. The specified UK-4 trajectory performs in a very similar way.

Launch date for the UK-4 mission is given as late 1971, which places the epoch close to the last solar maximum of 1969-1970. Since the electron fluxes are calculated with Vette's AE2 model (Vette, Lucero and Wright, 1966) which describes the environment as it actually existed back in 1964 (at solar minimum), the electron predictions had to be adjusted in two ways. Firstly, the artificial "Starfish" electrons that populated the inner zone from July 1962 to about 1969 had to be removed; this was achieved by decaying the fluxes exponentially with experimentally determined decay lifetimes (Stassinopoulos and Verzariu, 1971) up to the time when it was felt that natural background levels had been reached. Secondly, the outer zone experiences lasting solar cycle effects, which tend to increase the population significantly towards solar maximum. These effects are not reflected in the model, which does not consider temporal variations, because conditions prevailing in the radiation belts at solar maximum are still being studied at this time and a complete description of the important phenomena is not yet available. Therefore, in order to partially reflect the solar cycle changes in the outer zone, we increased the uncertainty factor attached to the results. The increase is proportional to the time spent in the outer zone and to the expected variations of intensities, both taken as functions of the parameter L.

Orbital flux integrations for high energy protons were performed with Vette's current models AP1, AP6, AP7 while low energy protons were obtained with King's AP5. All are static models, including the AE2, which do not consider temporal variations. For the protons this is a valid representation because experimental measurements have shown that no significant changes with time have occurred. With the exception of the fringe areas of the proton belt, that is, at very low altitudes and at the outer edges of the trapping region, the possible error introduced by the static approximation lies well within the uncertainty factor of 2, attached to the models. Consequently, the proton models may be applied to any epoch without the need for an updating process.

Occasionally discontinuities appear in the proton spectra. These "breaks" occur because the complete proton environment is being described by three (formerly four) independent maps or grids, each valid only over a limited energy range; for certain critical orbital configurations the discontinuities are then produced when moving from one energy range to another.

They are caused, in part, by the exponential energy parameter of the model which in many instances had to be extrapolated to make up for lacking data and, in part, to insufficient experimental measurements over some areas of B/L-space; furthermore, the discontinuities reflect the fact that the available data cannot be completely matched at their overlap. In order to overcome such spectral breaks, a continuous weighted mean curve is usually drawn, connecting the adjacent segments; it should be regarded as an approximate spectral distribution. In doing this, the AP1 results ($30 < E(Mev) < 50$) have to be totally ignored sometimes. The UK-4 orbit belongs to the affected group.

Classification of orbit integrated spectra as hard or soft is relative; it is based on an overall evaluation of near earth space in terms of circular trajectories between equatorial and polar orbits.

Attachment A contains other pertinent background information with regard to units, field models, trajectory generation and conversion, etc. At this point, we wish to emphasize again that our calculations are only approximations; we strongly recommend that all persons to receive parts of this report be advised about the uncertainty in our data.

Results: Analysis and Discussion

Our calculations for the UK-4 orbit is summarized in Table 1 for electrons and Table 2 for protons. The superimposed spectral distribution of the trajectory is given graphically for both types of particles in Figure 1. Figures 1a and 1b are computer plots of the same data presented separately.

The electron spectrum above E=1 Mev may be classified as "hard" for near earth space mission, while the protons rate a "very hard" classification for energies E>15 Mev. Figures 2 and 3 are computer plots depicting the characteristic electron and proton spectra for the flightpath, separately.

Table 3 indicates what percent of its total lifetime the satellite spends in "flux-free" regions of space, what percent of its total lifetime in "high intensity" regions, and while in the latter, what percent of its total daily flux it accumulates.

In the context of this study, the term "flux-free" applies to all regions of space where trapped-particle fluxes are less than one electron or proton per square centimeter per second, having energies E>.5 Mev and E>5. Mev respectively; this includes regions outside the radiation belts. Similarly, we define as "high tensity" those regions of space, where the instantaneous, integral, omnidirectional, trapped-particle flux is greater than 10^5 electrons with energies E>.5 Mev, and greater than 10^3 protons with energies E>5. Mev. The values given in Table 3 are statistical averages, obtained over extended intervals of mission time. However, they may vary significantly from one orbit to the next, when individual orbits are considered.

Predictably, the high energy proton population, which occupies a smaller volume of the radiation belt, affords a larger flux-free time than the electrons. It should be noted that at the indicated height, a small change in altitude does not alter significantly the flux-free time afforded the satellite, in either the electron or the proton medium.

If the flux-free time is important in mission planning, it is advisable, before decisions are made, to evaluate and compare the radiation hazards or effects due to the predicted electron and proton fluxes, either in regard to the entire mission or in regard to specific mission functions or requirements. For, while the proton intensities are on the average about two orders of magnitude smaller than the electrons, and while they apparently do afford more flux-free time, their greater mass and harder spectra may prove more damaging to the mission than the more numerous electrons with their lesser flux-free time.

In Table 4 the percentage of total lifetime T spent by the vehicle in the inner zone (T^i) and in the outer zone (T^o) is given, with the percent duration spent outside the trapped particle radiation belt (L>6.6), denoted by T^e (T-external).

For any mission then:

$$T = T^i + T^o + T^e = 100\%$$

Evidently, the high inclination UK-4 spends almost equal amounts of its entire lifetime in the actual trapping regions of the inner and the outer zones, for the selected altitude. It only briefly visits regions of space outside the Van Allen belts (about 15% of T). The satellite thus performs a complete sweep through magnetic L-space, which constitutes the transverse motion mentioned in the first paragraph, executed twice during each revolution (orbit). This information is used to evaluate the possible contribution of the outer zone solar cycle dependence to the uncertainty factor attached to the results.

The following related points are submitted for consideration in connection with the lifetime distribution over distinct regions of space:

a. Lasting solar cycle effects are more severely experienced in the <u>outer zone</u> (significant changes in the trapped electron population from solar minimum to solar maximum).

b. Energetic artificial electrons from high altitude nuclear explosions (Starfish) have displayed a remarkable longevity, but only in the inner zone; there they contaminated the environment for over 8 years, while they rapidly decayed to background levels in the outer zone (within weeks to months). A planned or accidental explosion of another atomic device with the appropriate yield and at the right latitude and altitude may, very likely, produce conditions similar to those experienced with "Starfish", transforming the inner zone again into a radiation hotbed.

c. Transient solar flare effects (high energy solar proton fluxes) may be especially hazardous and damaging in regions external to the trapped particle belts.

Figures 2 and 3 are additional computer plots for the UK-4 trajectory showing the vehicle encountered instantaneous peak electron (E>.5 Mev) and proton (E>5 Mev) intensities per orbit for a sequence of about 30 revolutions. On all graphs a periodic pattern emerges that indicates a daily cycle of about 15 orbits which may shift slightly in the plotting. This is due to the relative orbit period, which determines the precession of the trajectory.

In regards to the displayed data, it is noteworthy to point out the fact that the UK-4 trajectory offers some virtually flux-free revolutions per day in the proton medium. This is not observed in the electron medium. The described phenomenom is a special feature of this particular flight path. A change in inclination or altitude will affect the radiation free period.

Finally, for the investigated flight path, two more computer plots are included, Figures 4 and 5, one for protons and one for electrons, depicting time and flux histograms as functions of the magnetic parameter L. The unmarked contours show the characteristic averaged instantaneous intensities of the trajectory in terms of constant L-bands of .1 earth radius width; the percent of total lifetime spent in each L-interval is shown on the same graphs by the contours marked with x's.

ATTACHMENT A

General Background Information

For the specified UK-4 trajectory, an orbit tape was generated with an integration stepsize of one minute and for sufficiently long flighttime, so as to insure an adequate sampling of the ambient environment; on account of its period, which determines the rate of orbit-precession, the following circular flight path of 48-hour duration was produced:

Inclination	Perigee	Apogee
80°	550km	550km

The orbit was subsequently converted from geocentric polar into magnetic B-L coordinates with McIlwain's INVAR program of 1965 and the field routine ALLMAG by Stassinopoulos and Mead, (1972), utilizing the POGO (10/68) geomagnetic field model by Cain and Langel, (1968), calculated for the epoch 1971.11 (B is the field strength at a given point and L is the geocentric distance to the intersect of the field line, through that point, with the geomagnetic equator).

Orbital flux integrations were performed with Vette's current models of the environment, the AE-2 for electrons and the AP1, AP6, AP7 for high energy protons and King's AP5 for low energy protons. All are static models which do not consider temporal variations. See the text of the report for further details on this matter.

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The results, relating to omnidirectional, vehicle encountered, integral, trapped particle fluxes, are presented in graphical and tabular form with the following unit convention:

1. Daily averages: total trajectory integrated flux averaged into particles/cm^2 day,
2. Totals per orbit: non-averaged, single-orbit integrated flux in particles/cm^2 orbit,
3. Peaks per orbit: highest orbit-encountered instantaneous flux in particles/cm^2 sec,

where 1 orbit = 1 revolution.

Please note: we wish to emphasize the fact that the data presented in this report are only approximations. We do not believe the results to be any better than a factor of 2 for the protons and a factor of 4 for the electrons. It is advisable to inform all potential users about this uncertainty in the data.

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3. J. H. King (AP5) NASA SP-3024, Vol. IV, 1967.
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ADDENDUM

Environment Models and Orbital Flux Calculations

In response to frequent inquiries about the models employed in orbital flux calculations, their proper use, the interpretation or accuracy of the obtained values, and the correct application of the results, we have attempted in the following paragraphs to answer some of these querries, especially those in regards to validity, terminology, and usage.

From the time of its discovery in 1959 - 1960, the trapped radiation environment has consistently been described and modelled separately for electrons and for protons. Initially, this distinction was probably made out of necessity. At that time, the sheer magnitude and complexity of the modelling task favored this solution; that is, it became necessary to break the whole problem up into smaller manageable pieces and treat them independently.

Several years and many satellites later, as magnetospheric physics grew to a full fledged member of the scientific disciplines and a deeper understanding developed for the causality of the observed physical phenomena, it became apparent that the initial distinction was a fortuitous design of great merit. By then it had also become evident that the real high energy proton environment could most appropriately be approximated by static models (four initially, three now), while the electrons posed severe problems, displaying strong temporal variations throughout their entire trapping region, partially due to the vast deposition of artificial electrons from the STARFISH nuclear explosion in 1962, and partially due to solar cycle and magnetic storm effects.

Thus, it has long been customary to construct separate models for the two types of particles, a distinction which is now well accepted and established. Vette's "Models of the Trapped Radiation Environment" were designed along these lines. Today widely acclaimed, they have become standards and they are extensively used throughout the entire western world.

These models are periodically updated or revised to reflect changes or improvements in their data base. Up to this time they have always been static models but Dr. Vette and his group are presently working on a dynamic electron model which should be published soon. Currently the following models are in valid use: AE2 of 1964 (subsynchronous electrons), AE3 of 1967 (synchronous electrons), AP5 of 1967 (low energy protons), AP6 of 1964, AP1 of 1963, and AP7 of 1969 (high energy protons).

All models are by necessity approximations. The extent to which they predict correctly the real environment in intensity and energy distribution is given by an error- or uncertainty-factor, inseparably attached to each model. It is applied both as a multiplier and as divisor; if for example, for a flux-value of 10^5 (particles per square centimeter per second) a factor 2 is given, then the upper and lower estimates for the intensity are 2×10^5 and 5×10^4.

Obviously, every calculation performed with any one of these models will inherently contain at least this uncertainty factor. Furthermore, it is evident that in electron calculations the final uncertainty factor may be significantly greater than the model factor, as long as a static model is being used. There can be no question or doubt as to the applicability of the uncertainty factor. Results obtained in any way or form from these models should be bracketed by an error bar determined by the uncertainty factor. This implies of course, that actual measurements are expected (to a high degree of probability) to fall within the given error bar.

As to prevailing terminology, a profusion of too-general or of ill-defined terms has at times inordinately complicated communications by perpetuating ambiguity and fostering confusion, especially in the application oriented field of the aerospace community, where terms like: model, radiation model, model radiation environment etc., may mean many different things to many different people.

It is felt that this bewilderment would be significantly reduced if the terms "model radiation environment" or "radiation model" were selectively used only in connection with descriptions of the Van Allen Belts, such as Vette's AE2, AP6, etc. Such trapped particle models, in conjunction with dated magnetic field models and the orbit of a spacecraft, can then be utilized to determine the fluxes encountered by that satellite at a specified epoch.

But unfortunately, the term "model radiation environment" is still being used frequently in reference to calculated flux predictions. That is to say, special radiation data obtained exclusively from specific orbital flux integrations (i.e. total electron and proton intensities, characteristic of a unique trajectory), are being referred to as "A Model Radiation Environment" for a particular satellite.

This is a very unfortunate choice of nomenclature because it may convey the wrong impression about the nature of the data and it may lead to misunderstanding or confusion. Generally, in the context of orbital flux studies, "models of the environment" are only those constructed and published by Dr. Vette and his group at the National Space Science Data Center-GSFC (Formerly of Aerospace). Once issued they are standard, static and unchanging with regards not only to time but also with regards to application, at least until new ones appear. Subsequently, every single orbital flux calculation performed for any project office or for any mission requirement uses the same identical models, current at that time. To attach the term "model" to the end products of their use would imply that for the specific flightpath the results could in turn be used to again predict fluxes, when given different parameters or conditions, which of course is not the case.

But sometimes the misleading effect of such a misnomer is further compounded when electrons and protons are summarily lumped together under the same deceptive heading. This last practice may be particularly confusing. Mainly because it may produce several of the so-called "models" for a given satellite in a fixed year, if during that year more than two true environment models happened to be published. For example:

let us assume that whenever improved, real models do become available, the older ones are immediately replaced and new calculations are invariably performed; but since new proton and electron models are not published simultaneously, it may happen that revised data are issued to a project office several times during a particular year, some reflecting changes in the flux values of one type of particles only. The lumped together affair would then be different each time, adding to the proliferation of the so-called "models".

Furthermore, for a given trajectory, in addition to the electron and proton flux variations due to a routine model replacement, different electron fluxes may also be obtained from the <u>same</u> model by altering either the decay date or the decay process of the artificials, increasing even more the abundance of pseudo- "models"; a still further cause of variability of the computed electron intensities may be the inclusion of some modifying factor to account for long range solar cycle effects.

Finally, another source that may contribute to the proliferation of such "model radiation environments" is the selection of a different geomagnetic field model for the flux calculations or the recalculation of the expansion coefficients of a given field model for a later date. In every instance, this could produce a variation of the vehicle encountered fluxes.

All of the aforementioned causes may affect, individually or jointly, periodically released orbital-flux results, in a number of combinations.

But in every case are the later results preferable and superior to the older ones. This not only because each time they most probably are obtained with improved calculational methods, from better field and environment models, but also because progressively an expanded knowledge and understanding of the physical processes involved has been utilized.

It is therefore, advisable to discontinue the use of obsolete data as soon as possible, and caution should be exercised when comparing new with older data sets because a superficial comparison of numbers only would not always serve a useful or practicle purpose. In fact, sometimes it may lead to the fallacious conclusion that the older values were "better", meaning in essence either "less severe" or "more convenient", while the "best" estimates in the sense of "closest to the real thing" (really needed for satellite design and operating cirteria) are those later, updated fluxes.

Table 1

ORBITAL FLUX STUDY WITH COMPOSITE ELECTRON ENVIRONMENT* (VETTES AE2) * DATE OF RUN = YEAR 1971, DAY 0285
FLUXES EXPONENTIALLY DECAYED WITH DECAY-FACTOR D1 = VETTE TBLE *** DECAY DATE = YEAR 1967. , MONTH 6. , DAY 0.

AVERAGED FLUXES ON THIS TABLE ARE IN UNITS OF PARTICLES/CM**2/DAY *** NON-AVERAGED FLUXES ARE IN UNITS OF PARTICLES/CM**2/SEC
ALL FLUXES ON THIS TABLE ARE FOR ENERGIES E>.5MEV (EXCEPT WHERE ENERGY IS SPECIFIED, AS IN SPECTRUM)

INCLINAT.= 80 * PERIG.= 550 * APOG.= 550 KM * B&L ORBIT TAPE TD 6969 * PERIOD = 1.594 * VEHICLE = UK-4

SPECTRUM IN % OF

ENERGY RANGES (MEV)	AVERAGED TOTAL FLUX (PER DAY)	SPECTRUM (PER CENT)
0-.5	5.721E 09	82.90
.5-1	7.299E 08	10.58
1-2	3.502E 08	5.07
2-3	7.229E 07	1.05
3-4	1.878E 07	0.27
4-5	5.759E 06	0.08
5-6	1.914E 06	0.03
6-7	6.526E 05	0.01
GT.7	3.487E 05	0.01
TOTAL =	6.901E 09	100.00

COMPOSITE ORBIT SPECTRUM

ENERGY GRTR.THAN (MEV)	AVERAGED INTEG.FLUX (PER DAY)
0.0	6.901E 09
0.25	2.350E 09
0.50	1.180E 09
0.75	7.055E 08
1.00	4.499E 08
1.25	3.000E 08
1.50	2.049E 08
1.75	1.415E 08
2.00	9.974E 07
2.25	7.033E 07
2.50	5.047E 07
2.75	3.697E 07
3.00	2.745E 07
3.25	2.040E 07
3.50	1.528E 07
3.75	1.152E 07
4.00	8.670E 06
4.25	6.635E 06
4.50	5.051E 06
4.75	3.774E 06
5.00	2.916E 06
5.25	2.227E 06
5.50	1.691E 06
5.75	1.305E 06
6.00	1.001E 06
6.25	7.724E 05
6.50	5.933E 05
6.75	4.449E 05
7.00	3.487E 05

EXPOSURE INDEX

INTENSITY RANGES (EL/CM**2/SEC)	DURATION OF EXPOSURE (HRS)	TOTAL NO. OF ACCUMULATED PARTICLES (E>.5)
ZERO FLUX	33.7	6.272E 03
1.E0-1.E2	2.42	1.686E 05
1.E2-1.E3	1.82	2.500E 06
1.E3-1.E4	2.37	3.488E 07
1.E4-1.E5	5.78	8.939E 08
1.E5-1.E6	1.90	1.428E 09
1.E6-1.E7	0.0	0.0
1.E7-1.E8	0.0	0.0
1.E8-INFIN	0.0	0.0
TOTAL =	48.017	2.360E 09

AVERAGED FLUXES ON THIS TABLE ARE IN UNITS OF PARTICLES/CM**2/DAY *** NON-AVERAGED FLUXES ARE IN UNITS OF PARTICLES/CM**2/SEC
ALL FLUXES ON THIS TABLE ARE FOR ENERGIES E>5 MEV (EXCEPT WHERE ENERGY IS SPECIFIED, AS IN SPECTRUM)

ORBITAL FLUX STUDY FOR COMPOSITE PROTON ENVIRONMENT * GRIDS AP1,AP7,AP6,AP5 * DATE OF RUN = YEAR 1971, DAY 0285
INCLINAT.= 80 * PERIG.= 550 * APOG.= 550 KM * REL ORBIT TAPE TO 6969 * PERIOD = 1.594 * VEHICLE =.UK-4

HIGH ENERGY

SPECTRUM IN % OF

ENERGY RANGES (MEV)	AVERAGED TOTAL FLUX (PER DAY)	SPECTRUM (PER CENT)
3-5	1.581E 07	53.176
5-15	9.141E 06	30.741
15-30	1.785E 06	6.002
30-50	2.324E 05	0.781
50-100	1.225E 06	4.121
>100	1.540E 06	5.179
TOTAL =	2.974E 07	100.00

COMPOSITE ORBIT SPECTRUM

ENERGY GRTR.THAN (MEV)	AVERAGED INTEG.FLUX (PER DAY)
1	NOT VALID
3	2.974E 07
5	1.392E 07
7	9.398E 06
9	7.318E 06
11	6.122E 06
13	5.339E 06
15	4.782E 06
18	4.190E 06
21	3.768E 06
24	3.451E 06
27	3.201E 06
30	2.998E 06
35	2.865E 06
40	2.630E 06
45	2.437E 06
50	2.765E 06
60	2.443E 06
70	2.168E 06
80	1.930E 06
90	1.722E 06
100	1.540E 06

EXPOSURE INDEX

INTENSITY RANGES (PT/CM**2/SEC)	DURATION OF EXPOSURE (HRS)	TOTAL NO. OF ACCUMULATED PARTICLES (E>5)
0.E0-1.E0	42.300	7.475E 04
1.E0-1.E1	1.133	1.279E 04
1.E1-1.E2	0.850	1.177E 05
1.E2-1.E3	1.383	2.468E 06
1.E3-1.E4	2.350	2.518E 07
1.E4-1.E5	0.0	0.0
1.E5-OVER	0.0	0.0
TOTAL =	48.000	2.785E 07

UK-4

Circular

Inclination 80°

Altitude 550 km

Decay Date: 1967.6

	Electrons (E>.5 Mev)	Protons (E>5. Mev)
1. Fraction of total life-time spent in flux-free regions* of space:	70.2%	88.1%
2. Fraction of total life-time spent in high-intensity regions* of Van Allen Belts:	4.0%	4.9%
3. Fraction of total daily flux accumulated during (2):	60.5%	90.4%

*See text for definition

UK-4

Circular

Inclination 80°

Altitude 550 km

Percent of total lifetime spent inside and outside the Trapped Particle Radiation Belt

1.	Inner Zone (T^i)*	48.2%
2.	Outer Zone (T^o)	36.6%
3.	External (T^e)	15.2%
		100.0%

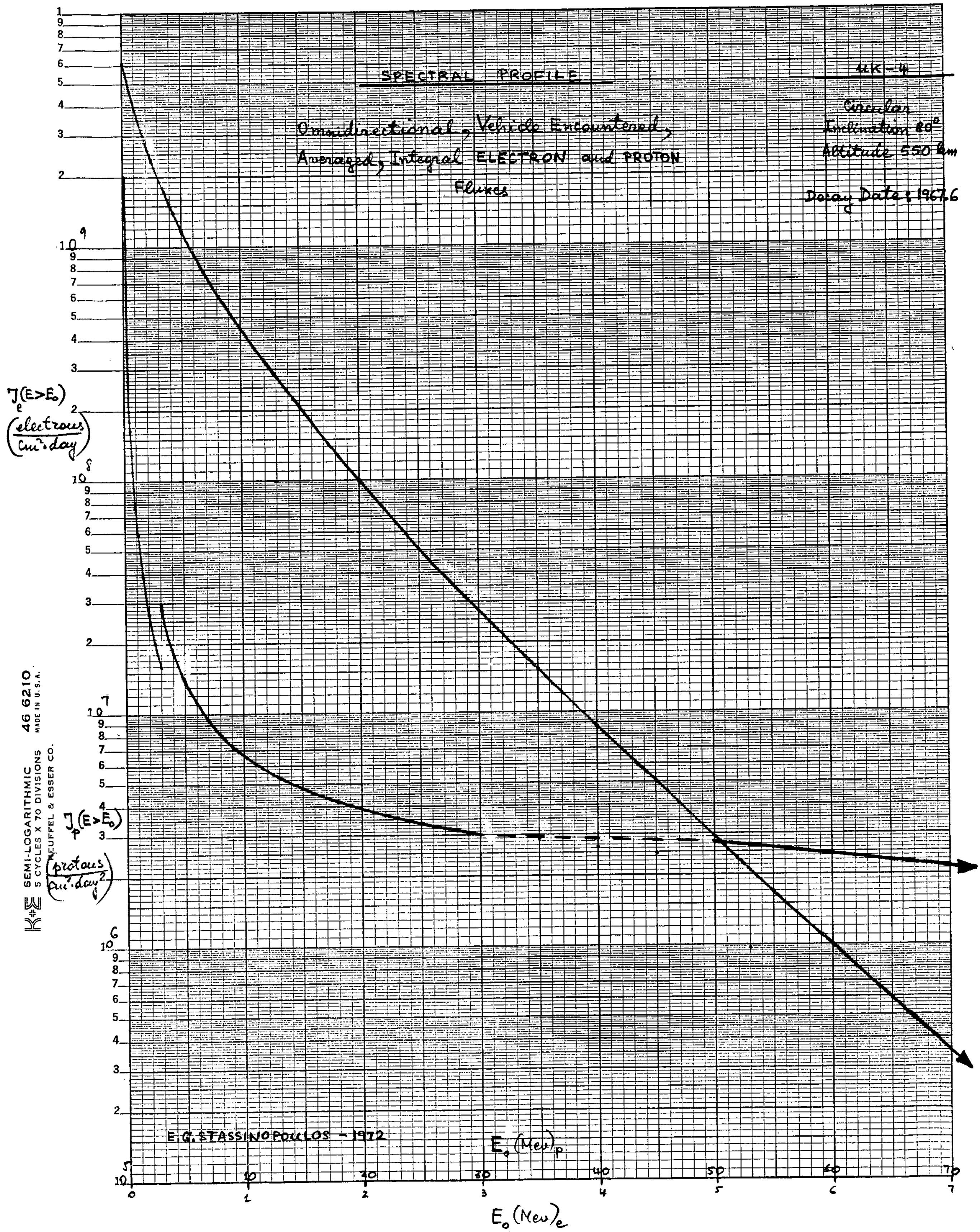
*This time may be subdivided into two parts:

38.9% in the L-interval $1.1 \leq L < 2.0$

9.3% in the L-interval $1.0 \leq L < 1.1$

where the T^i $(1.0 \leq L < 1.1)$ lies outside the actual trapping region.

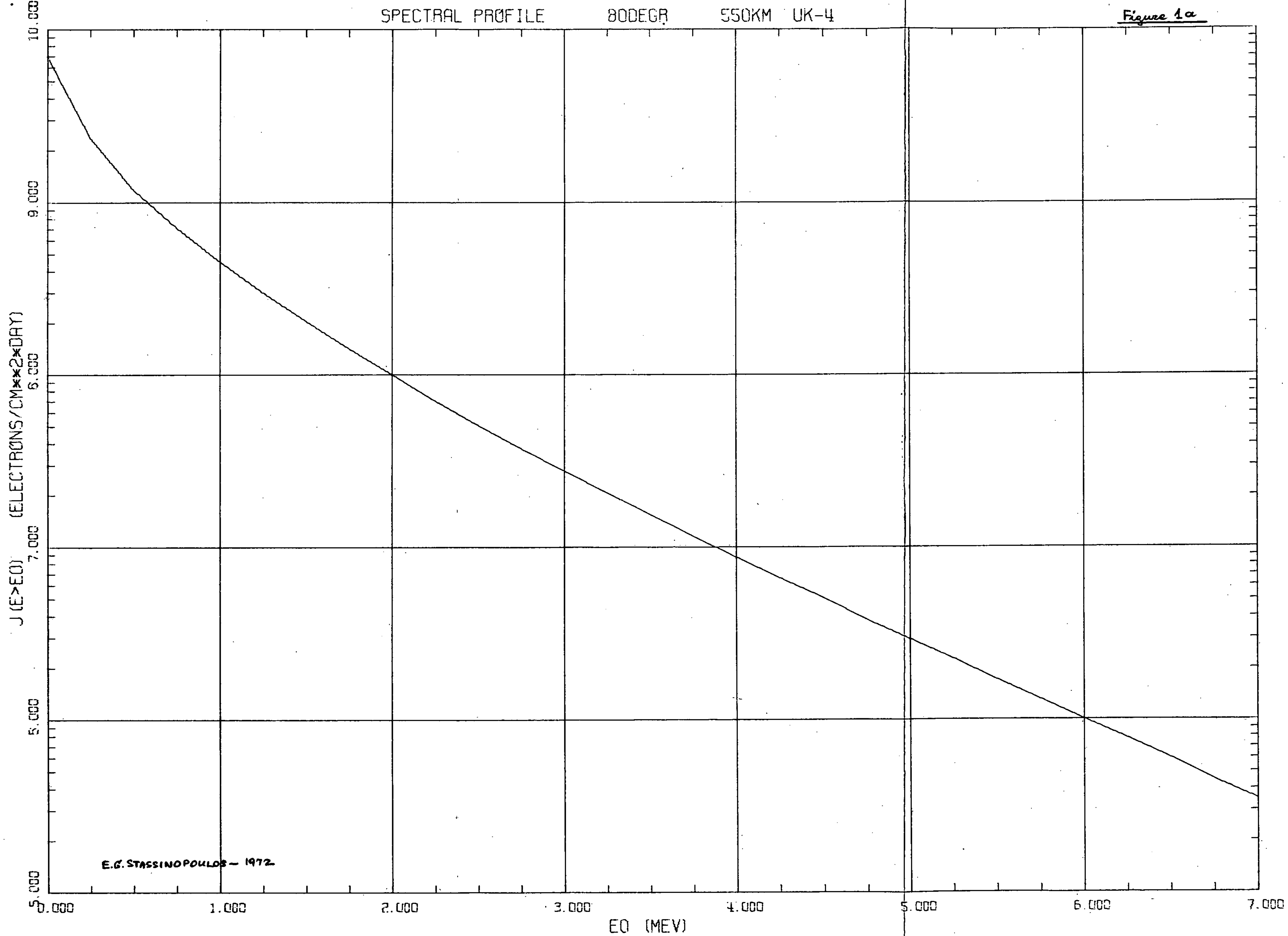
Figure 1


SPECTRAL PROFILE
Omnidirectional, Vehicle Encountered, Averaged, Integral ELECTRON and PROTON Fluxes
UK-4
Circular
Inclination 80°
Altitude 550 km
Decay Date: 1967.6
$J_e(E>E_o)$ (electrons / cm²·day)
$J_p(E>E_o)$ (protons / cm²·day)
E.G. STASSINOPOULOS - 1972
E_o (Mev)$_p$
E_o (Mev)$_e$
SEMI-LOGARITHMIC
5 CYCLES X 70 DIVISIONS
KEUFFEL & ESSER CO.
46 6210
MADE IN U.S.A.

FOLDOUT FRAME 1

FOLDOUT FRAME 2

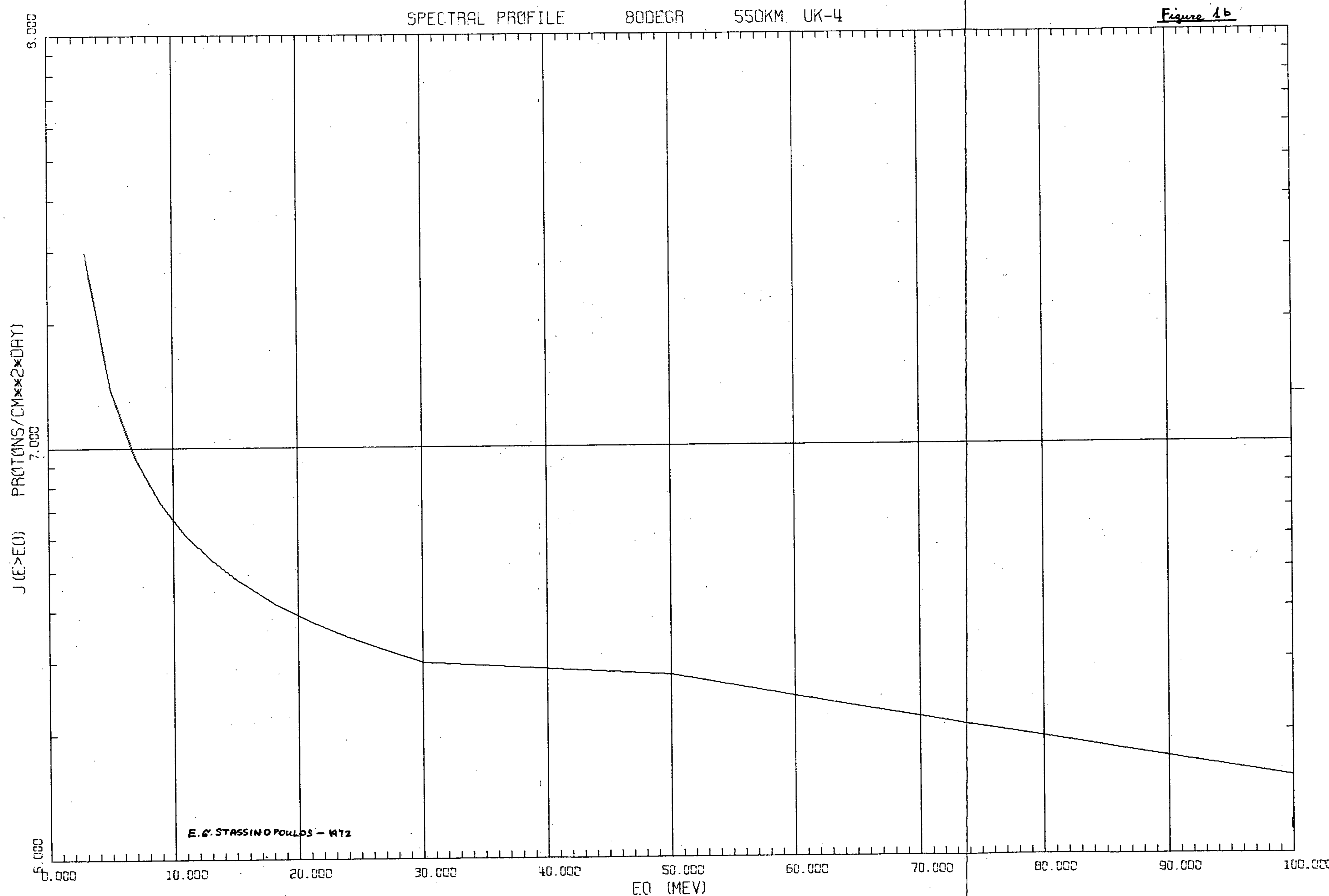
Figure 1a



FOLDOUT FRAME 1

FOLDOUT FRAME 2

Figure 1b



25

25A

FOLDOUT FRAME 1

FOLDOUT FRAME 2

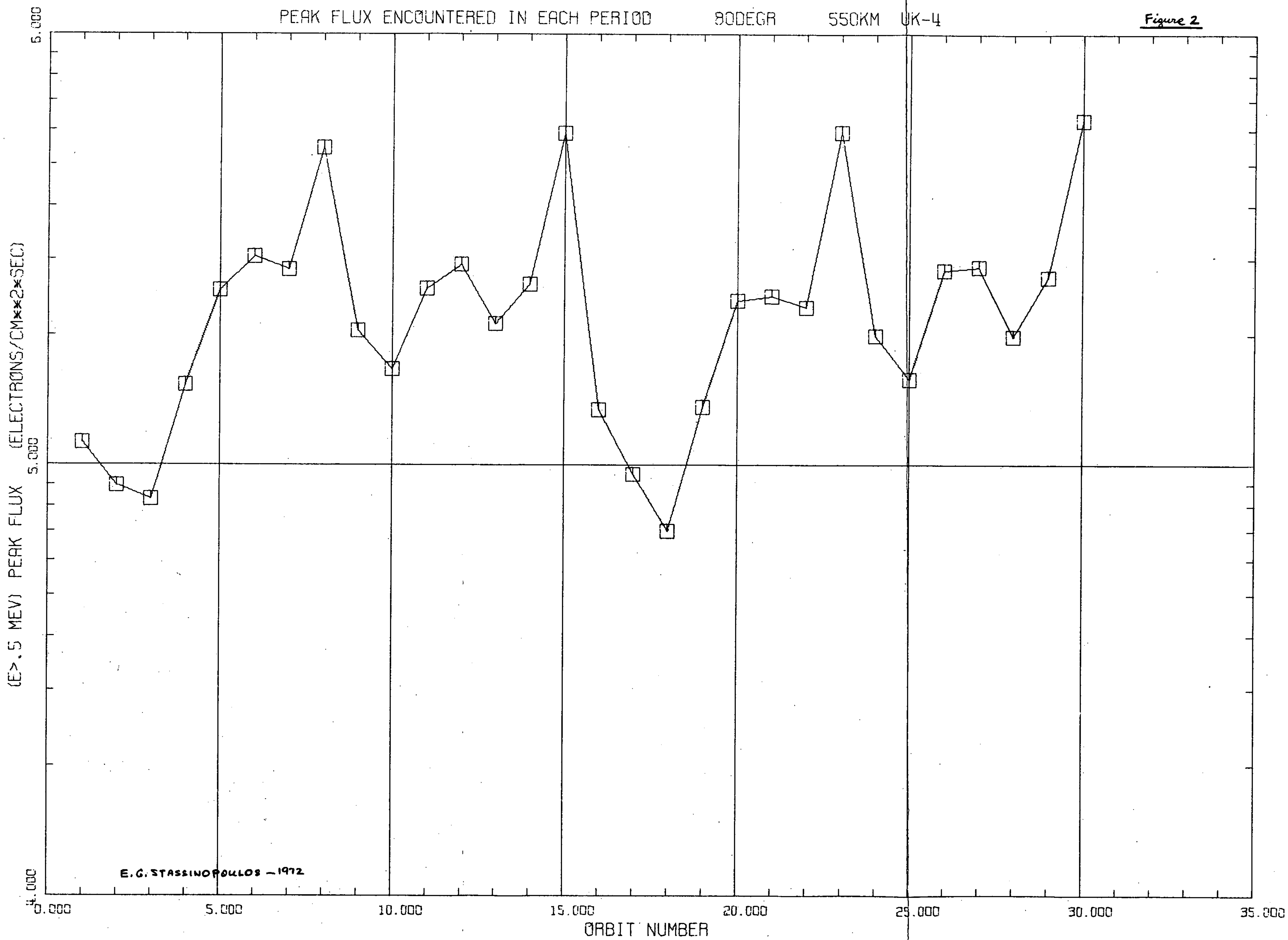


Figure 2

26 26A

Figure 3

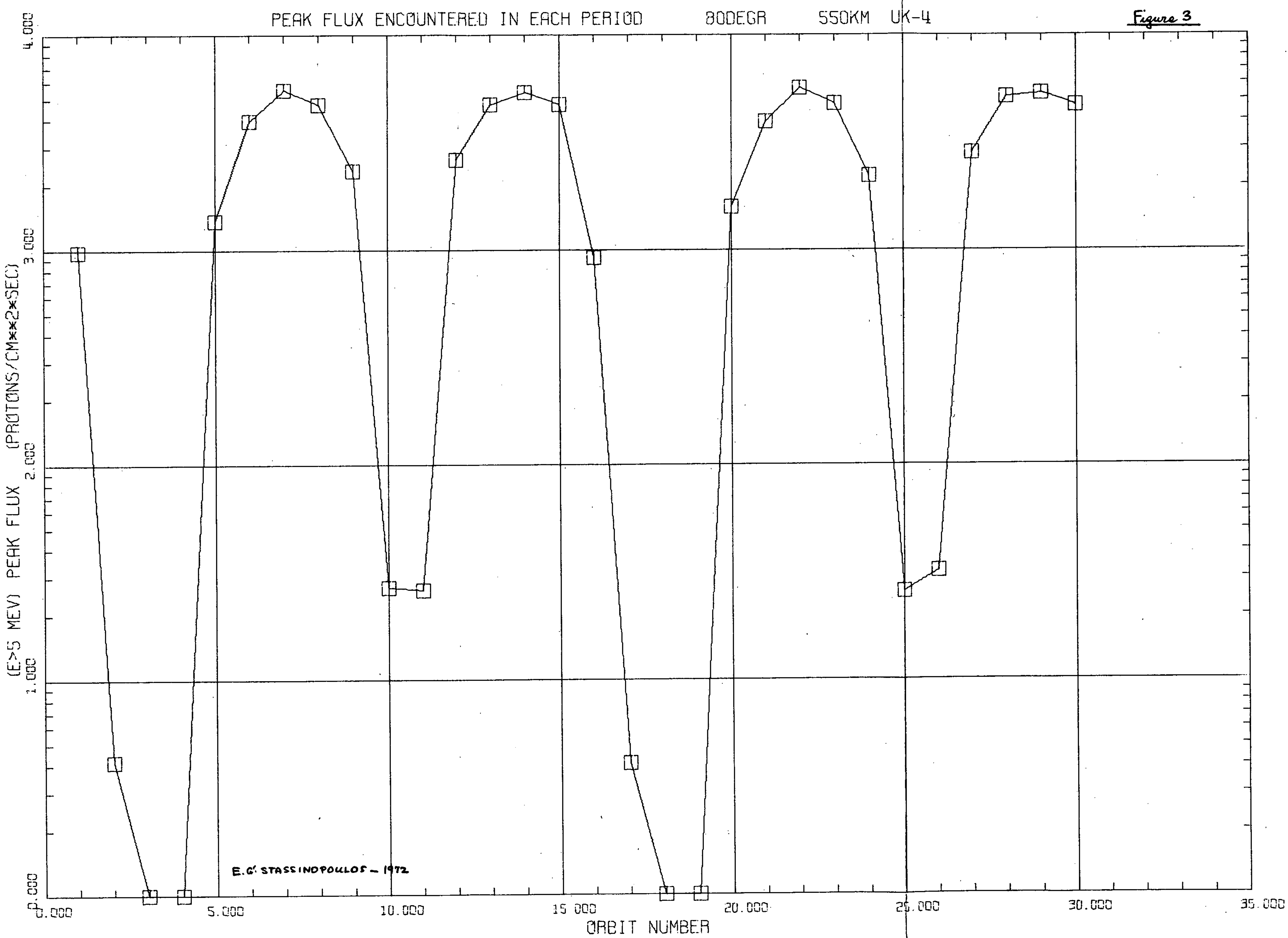
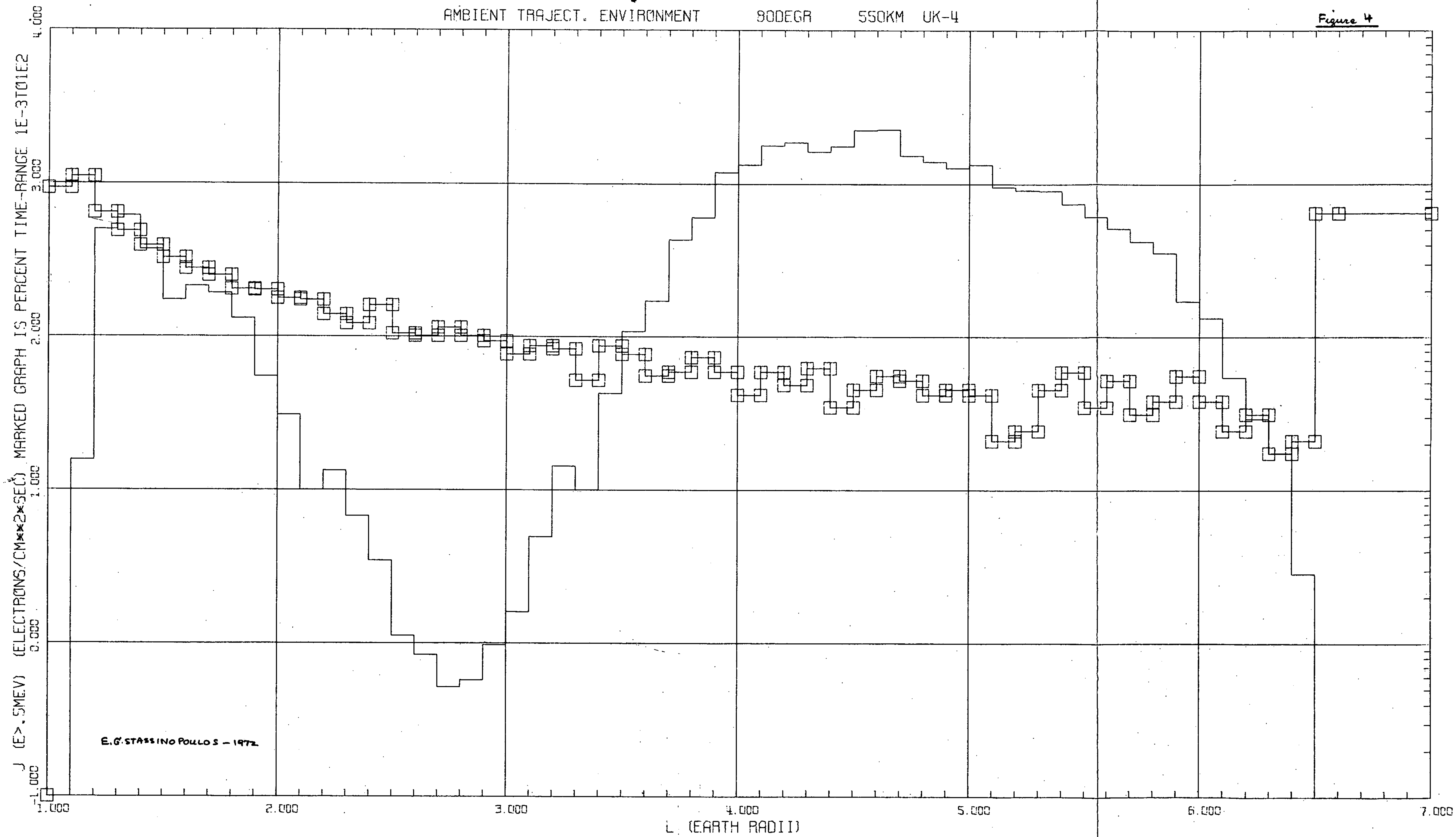
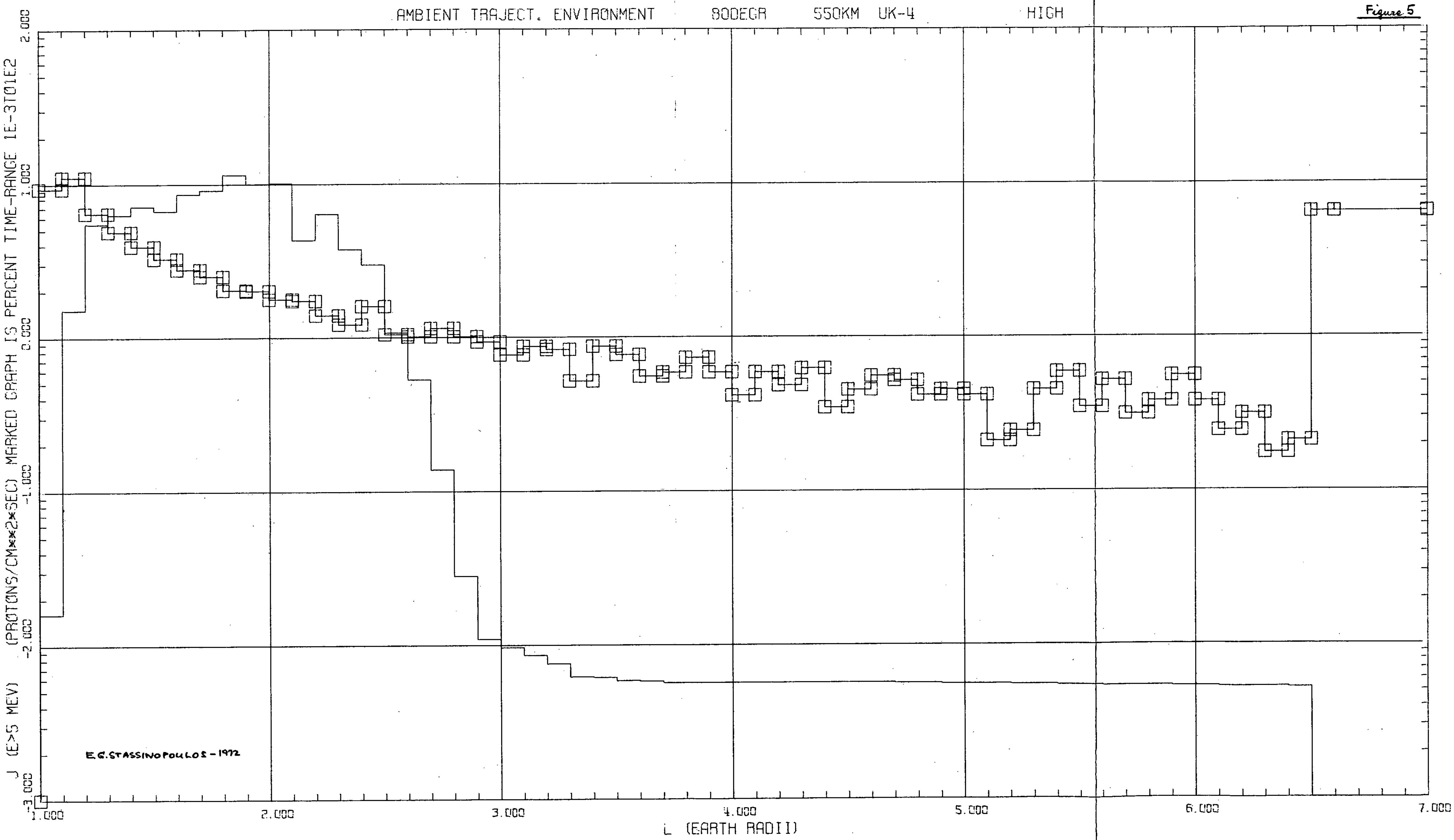

PEAK FLUX ENCOUNTERED IN EACH PERIOD 80DEGR 550KM UK-4
(E>5 MEV) PEAK FLUX (PROTONS/CM**2*SEC)
ORBIT NUMBER
0.000
1.000
2.000
3.000
4.000
5.000
10.000
15.000
20.000
25.000
30.000
35.000
E.G. STASSINOPOULOS – 1972

Figure 4


AMBIENT TRAJECT. ENVIRONMENT 80DEGR 550KM UK-4
J (E>.5MEV) (ELECTRONS/CM**2*SEC) MARKED GRAPH IS PERCENT TIME-RANGE 1E-3TO1E2
4.000
3.000
2.000
1.000
0.000
-1.000
1.000
2.000
3.000
4.000
5.000
6.000
7.000
L (EARTH RADII)
E.G. STASSINOPOULOS – 1972

FOLDOUT FRAME 1

FOLDOUT FRAME 2



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