A New Solar Flare Heavy Ion Model and Its Implementation Through MACREE, An Improved Modeling Tool to Calculate Single Event Effect Rates in Space

Peter P. Majewski, Eugene Normand, and Dennis L. Oberg[1]
Boeing Defense and Space Group
Seattle WA, 98124-2499

Abstract

A new solar flare heavy ion model has been developed to support Space Station Single Event Effects (SEE) evaluations. It shows good agreement with previous flare data, and is implemented through an improved version of the CREME code.

I. INTRODUCTION

SEE rate predictions have been made by Boeing for the Space Station program. As a part of this effort, we have improved the program set CREME. The main impetus for the changes in CREME [1] was to develop a better solar flare model, which became an important issue when the Space Station orbit was changed from 28.5° to 51.6° inclination. Solar flare protons and heavy ions could now reach the new orbit and thus pose a potential SEE threat that was negligible in the old orbit. In the Boeing version called MACREE ("Modeling and Analysis of Cosmic Ray Effects in Electronics") other improvements besides the new solar flare model were made, including making it faster and easier to use and removing the restrictions imposed by the "weather index" system.

II. DESCRIPTION OF THE COSMIC RAY ENVIRONMENT

The cosmic ray environment in space consists of galactic cosmic rays (GCR), solar cosmic rays (SCR) which are protons and heavy ion emitted during a solar flare, trapped protons, and anomalous cosmic ray heavy ions. We will primarily consider the heavy ion portion of the GCR and SCR in this paper. The intensities of the GCR varies somewhat due to solar modulation. The intensity of the SCR particles, here taken to include all solar activity, varies over many orders of magnitude from normal quiet sun conditions to very large flares such as those of February 23, 1956, August 4, 1972, and October 19, 1989. While the GCR dominate most of the time, most of the fluence for long missions comes from SCR.

III. NEW SOLAR FLARE MODEL

A. General Features

The most distinct aspect of MACREE is the solar flare model. This model has five main features that distinguish it from the solar flare models in CREME [1]:

(1) The October 19, 1989, flare serves as the worst case flare.
(2) Protons and alpha fluences are based on the acceleration model fit to measured data from GOES.
(3) heavy ion abundance consider the high energy fall–off of the abundance
(4) Heavy ion fluences are equal to the alpha fluence multiplied by the ion to alpha abundance ratios.
(5) Account is taken of the reduced charge state of the heavy ions.

These features distinguish this model from CREME and from the newer CHIME model [2] which, like CREME, correlates the solar flare heavy ions with the protons. CREME uses the February 1956 flare for the worst case solar flare proton energy spectrum, the August 1972 flare for the highest total proton fluence, and the composite of the February 1956 and August 1972 flares' extreme features as the overall worst case flare. For purposes of estimating SEE rates, the CREME worst case flare gives rates that are considered too conservative [3].

B. October 1989 as Worst Case Flare

The October 1989 flare was chosen as the worst case flare for several reasons. It has been very well characterized at geosynchronous orbit for both the proton [4] and alpha particle fluences [5]. The JPL solar flare model [6] indicates that this flare is at the 99% level for several proton energies. The JPL solar flare proton model characterizes solar flare proton fluences according to log–normal distributions, one for each of several different proton energies. Upon examination of each of the model's probabilistic distributions, the October 1989 flare emerges as the 99% worst flare for the model's three highest proton energies (10, 30, and 60 MeV). The proton fluence for the August 1972 flare is also at the 99% level for 10 and 30 MeV, but not for 60 MeV [6].

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C. Acceleration Model

Cosmic ray physicists have used a variety of functional forms to represent the solar flare differential proton fluence in both energy and rigidity. A favorite form because of its simplicity is the power law in energy $dJ/dE = AE^{-g}$ where γ is the power law; it yields a straight line in log–log plots. This is the form used in CREME. However, in many cases, the measured differential fluxes when plotted as a function of energy display curvature. We therefore prefer the Ramaty–Lee acceleration model [7, 8] that results in a Bessel function in momentum which simplifies to the following form in energy:

$$dJ/dE = KE^{3/8} \exp\left(-gE^{1/4}\right) \tag{1}$$

where the energy, E, is in MeV per nucleon, K and g are constants, and g is related to the standard acceleration parameters, αT (α is the acceleration efficiency coefficient and T the escape time) by

$$aT = 1/\left(3.26g^4\right). \tag{2}$$

The integral fluence, $J(>E)$, obtained from Eq. 1 is [9]

$$J(>E) = 4Kg^{-5.5}\Gamma\left(5.5, gE^{1/4}\right) \tag{3}$$

where Γ is the incomplete gamma function. This can be approximated by

$$J(>E) = 4\left(K/g\right)E^{9/8} \exp\left(-gE^{1/4}\right). \tag{4}$$

Thus the energy dependence of the fluences in the model is based on the acceleration model as fit to the measured proton [4] and alpha particle fluences [5] for the October 1989 solar flare obtained by the GOES satellite. The Ramaty–Lee acceleration model gives the differential, Eq. 1, and integral, Eq. 4, fluences in terms of the two parameters K and g. Table 1 gives the these model parameters for the proton and alpha particle fluences based on fits to the aforementioned measured data.

Table 1 Parameters for October 1989 Solar Flare

Particle	K, Particle•nucleon/cm^2•MeV	g
Proton	1.53E12	4.0
Alpha	1.11E12	5.7

Mazur [10] also used an acceleration model to fit the heavy ion differential fluxes for the ten solar flares that he analyzed. It is a more generalized form, using additional parameters, compared to our simpler Ramaty–Lee form in Eq. 1, and is expressed in terms of the K_v modified Bessel function. After employing a large argument Bessel function expansion, Mazur's differential flux can be reduced to the following form:

$$dJ/dE = N_0\left(p/b\right)^{0.5} E^{\left(a+0.5-g/2\right)} \exp\left(-bE^g\right) \tag{5}$$

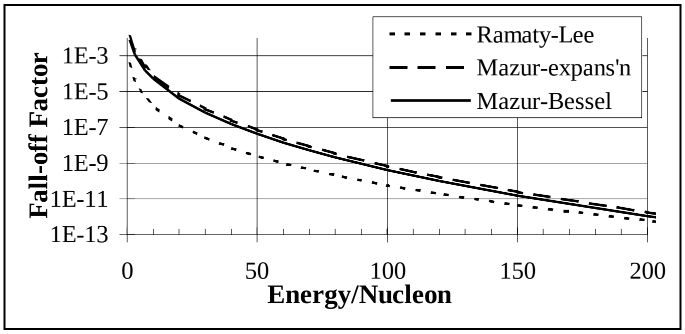

Figure 1 Comparison of Fall–Off Factor in Two Acceleration Models Based on Fits to Alpha Fluence for September 23, 1978 Solar Flare.

where α, β, and γ are defined in terms of several other parameters. Eq. 5 can be generalized into the form

$$dJ/dE = LE^{0.25} \exp\left(-bE^g\right) \tag{6}$$

where L, β, and γ depend on several parameters that vary with each flare and with ion species.

Mazur's generalized differential flux, Eq. 6, is of the same form as the Ramaty–Lee flux in Eq. 1. Three constants can be compared between Eq. 1 and 6, the two exponents of E, 0.25 and γ, against 0.375 and 0.25, and the multiplier within the exponential, β against g. In Table 2 the three constants in the two equations are compared for three of the flares used by Mazur. These comparisons are based on the two acceleration models applied to two sets of alpha particle fluences for these three flares. To carry out the Ramaty–Lee fit, we used the alpha particle fluences listed by Goswami [11] for the three flares, whereas Mazur had available much more detailed measurements of the alpha differential fluxes [10]. Table 2 shows that the factors in the two acceleration models appear to be similar, however a more meaningful assessment can be made by comparing the variation with energy of the two models, i.e., the fall–off with energy. Figure 1 contains such a comparison of the energy fall–off of the Ramaty–Lee and Mazur acceleration models, and also includes use of both forms of Mazur's model, the original one with K_v, and the expansion form of Eq. 6. The figure shows that the fall-off with energy is very similar for the two models, the curves approximately paralleling each other over more than 10 orders of magnitude.

D. Heavy Ion Abundance's

The heavy ion abundances within a solar flare are important parameters. In most cases, a single value of the abundance for each ion is provided. This is how the

Table 2 Comparison of Parameters Used in the Two Acceleration Models

Solar Flare	First E exponent Eq. 1	First E exponent Eq. 6	Second E exponent Eq. 1	Second E exponent Eq. 6	g in Eq. 1	β in Eq. 6
11/27/77	0.375	0.25	0.25	0.21	7.3	10.1
9/23/78	0.375	0.25	0.25	0.35	7.9	4.44
8/19/79	0.375	0.25	0.25	0.24	7.1	7.5

calculation proceeds in the original CREME code, although two sets of abundances, mean and worst case, are actually available in CREME. However, these CREME abundances are based on low energy ion data (~1 MeV per nucleon [1]) whereas the ions of interest for SEE applications are at much higher energies (at and above 100 MeV per nucleon).

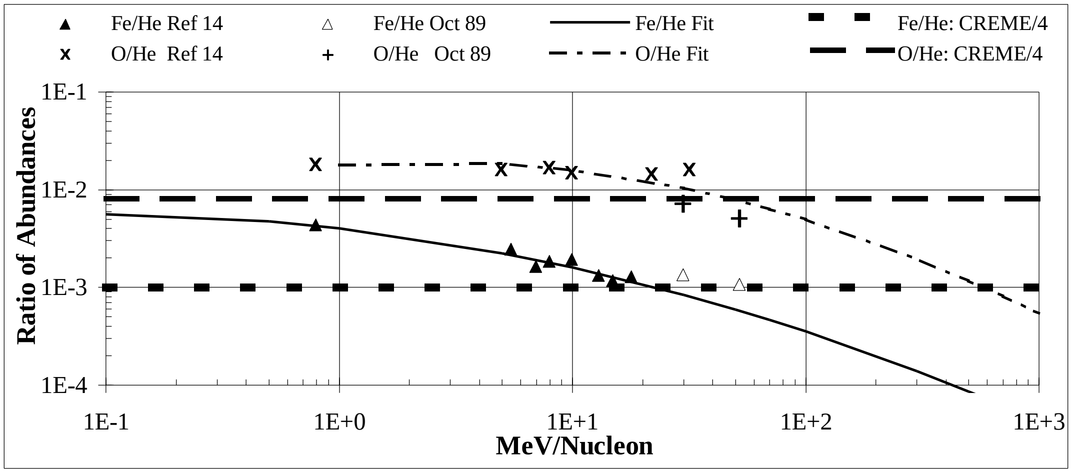

Figure 2 The Fe/He and O/He Ratios as a Function of Energy from 10 Flares [12] and October 19, 1989, Flare [14]

Therefore, the results of the study by Mazur [12] of the abundances of the ions He, O, and Fe during 10 large flares occurring from November 1977 to May 1981 were utilized in this work. These abundances were characterized as a function of the energy per nucleon of the ions. These abundances, as well as the abundance ratios for O and Fe relative to He, showed a distinct decrease as the energy per nucleon increased. This is seen in Figure 2 that also includes two curves that are quadratic fits of the abundance ratios as a function of energy per nucleon. Along with the Mazur data [12], Figure 2 also contains two higher energy data points measured on the Galileo spacecraft during the October 1989 solar flare [13, 14]. Using the data in Figure 2 as a guide, the model kept the CREME approach of using a constant abundance ratio over energy, but used values that are one quarter of the CREME abundances for ions with Z>2. As seen in Figure 2, using a quarter of the CREME abundance ratios gives results that are much more representative of the high energy measured data. To some extent the factor of one quarter is arbitrary. The value had to be less than one to account for the decrease in abundances as the energy per nucleon increases but it could easily have been 0.3 or 0.2. The adequacy of the factor of 0.25 can better be judged in the section Applications of the Model.

E. Reduced Charge State of the Heavy Ions

The solar flare heavy ions are in a partial ionization state characterized by the charge state *q* that is obtained by fitting the available data on the charge state of solar flare ions as a function of the atomic number, *Z*, of the ion. These data are mainly for low energy ions, approximately 1 MeV per nucleon, and are based on charge state measurements for flares in 1977–78 [16] and 1978–79 [15]. The resulting reduced charge state that is used in the MACREE code is obtained by a fit to these data resulting in

$$q = 0.98 + 1.45\ln(Z) + 0.78(\ln(Z))^2 \qquad (7)$$

and this is plotted in Figure 3 along with the measured charge states.

Garrard and Stone [16] obtained similar results although, they characterize their data as *q/M* (where *M* is the atomic weight of the ion) rather than *q/Z* as used in our model. For ions ranging from C to Fe, the *q/Z* reduction decreases from 0.95 to 0.54 and *q/M* decreases from 0.47 to 0.25. Additionally, Garrard and Stone [13] showed that for the October 24–28 portion of the October 1989 flare the *q/M* ratio of the ions, in the energy range 9.5–15 MeV per nucleon, ranged from 0.27 to 0.48. Since this range of *q/M* is essentially identical to that observed with the low energy ions shown in Figure 3, this verifies that the reduced charge state of solar flare ions given by Eq. 7 also applies at higher energies.

IV. APPLICATIONS OF THE SOLAR FLARE MODEL

A. Comparisons with Measured Flare Heavy Ions

To assess how conservative this model is, based on the constant heavy ion to alpha particle abundance ratios, we

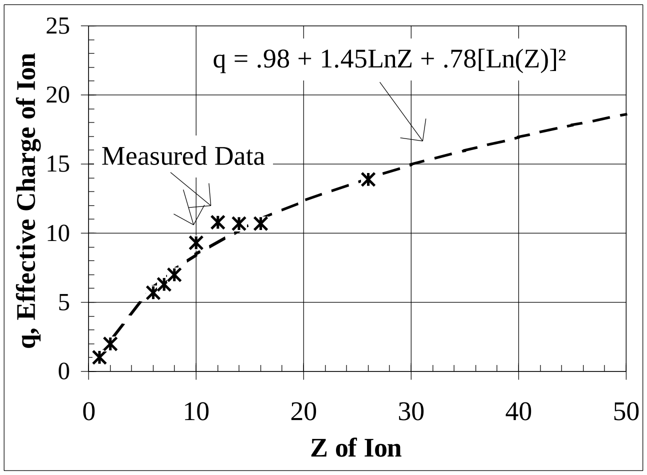

Figure 3 Effective Charge of Solar Flare Heavy Ions

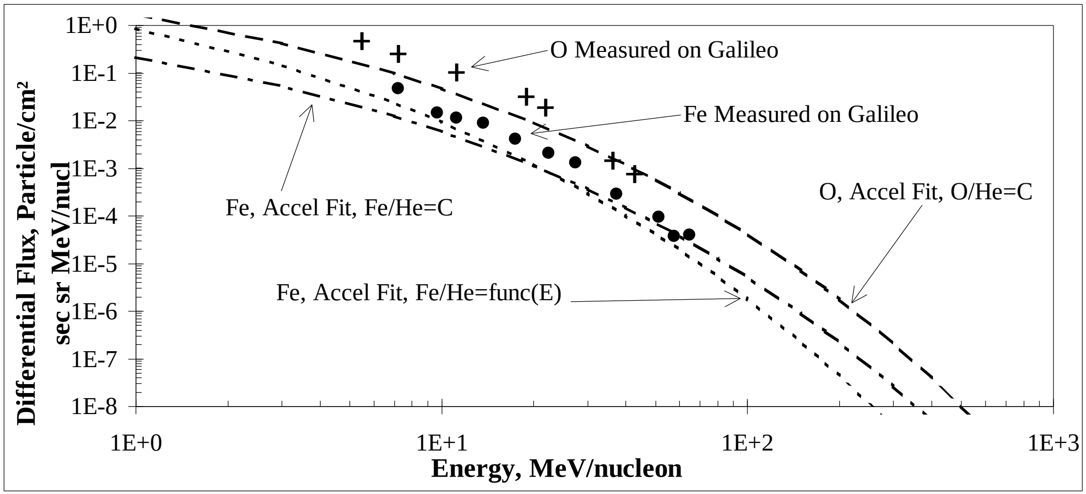

Figure 4 Comparison of Heavy Ions Measured on Galileo (October 89) Flare with Acceleration Model

have used the Fe ion fluxes measured on Galileo [14] as a base case. Galileo was launched on October 18, 1989, but the Heavy Ion Counter (HIC) was not turned on until October 21 and received reliable data beginning on October 22, three days into the flare. The heavy ion fluences obtained from Galileo [14] are therefore for the days October 22–27 1989. In Figure 4 the measured Galileo differential fluences for O and Fe are plotted along with those calculated using the solar flare model, i.e., using the alpha particle differential flux multiplied by the ratios of ion abundances (0.25 of the CREME abundances). For purposes of the Figure 4 comparison the alpha particle flux used was that for October 22–27, 1989. The actual model in MACREE, however, uses the alpha fluence for the entire October 1989 event.

From Figure 4 we see that using the constant abundance ratio over all energies (“FeHe=C” and “OHe=C” curves) gives a differential flux that is in relatively good agreement with the measured data. Figure 4 also shows the calculated results from two versions of the model, one in which the reduction factor applied to the abundances was a constant 0.25 and one in which the reduction factor was the quadratic fit of Fe to He ratio shown in Figure 2. The functional form of the reduction factor was obtained by fitting the Galileo data shown in Figure 4 to a quadratic in energy per nucleon. Thus the curve labeled “func E” in Figure 4 is based on a functional fit to the starting Fe data that is reapplied to the alpha flux multiplied by the CREME abundances to obtain the heavy ion fluxes. This version of the model gives somewhat better agreement but is overly dependent on the Galileo data and therefore was rejected in favor of the simpler constant factor of 0.25.

The key to the model is the assumed proportionality between the alpha and heavy ion fluences for the same value of energy per nucleon. To more broadly evaluate the adequacy of this assumption, we used the high energy heavy ion fluences measured by the University of Chicago Energetic Cosmic Ray and Solar Particle Experiment (ECRSPE) on IMP–8 for large flares between 1974 and 1984 compiled by Chenette [17]. Fluences are given for ions with Z≥6 and Range>100 mils Al (for C this is ~45 MeV per nucleon and for Fe it is ~90 MeV per nucleon). Alpha fluences at lower energies were compiled in [11] for flares between 1972 and 1986 based on measurements by the NASA–GSFC instruments on IMP–7 and –8. The acceleration fit was applied to the alpha fluence for 10 of these flares, all having fluences at the maximum four energies (energy per nucleon of 1, 4, 10, and 30 MeV per nucleon) to obtain alpha fluences for energy per nucleon > 50 and 100 MeV per nucleon. The ratios of the alpha fluence to the ECRSPE fluence Z>6 were obtained and are plotted in Figure 5 for both sets of alpha energies as a function of the flare integrated heavy ion (Z>6) fluence. The ratios are relatively constant for 9 of the 10 flares (the November 22, 1977, flare is the exception) and the alpha J(>100 MeV per nucleon) fluence shows a more uniform response than J(>50 MeV per nucleon) fluence.

B. Calculation of Solar Flare Heavy Ion Spectra

The ultimate use of the solar flare model and MACREE is to produce LET spectra of the heavy ions accompanying a worst case solar flare. This was done for the International Space Station Alpha (ISSA) program for a 500 km low earth

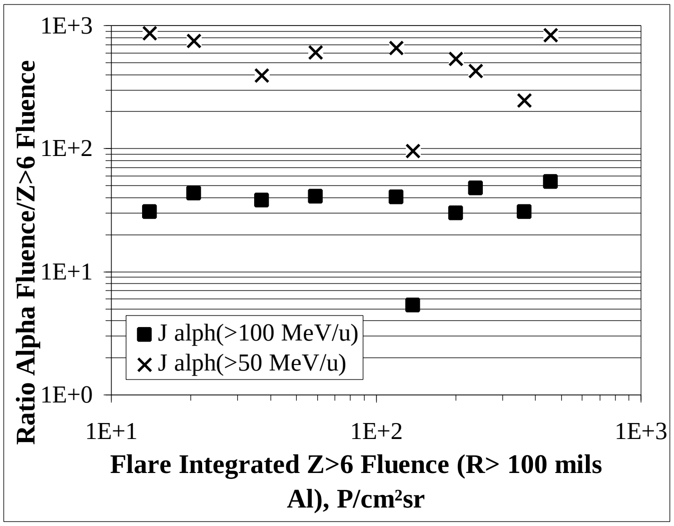

Figure 5 Correlation Between Heavy Ion (Z>6) and Alpha Particle Flare Fluences for 10 Flares

Table 3 Comparison of Measured Ultra–heavy GCR Abundances with Those in CREME

Type of Abundance	CREME Mean Values for Solar Flare	CREME Mean Values for GCR (Relative to Fe)	Measured GCR Ratios Relative to Fe, Based on HEAO and Ariel Measurements [21, 22]
Z=26 (Fe)	4.1E-5	1	1
20<Z<29	4.44E-5	1.55	
29<Z<41	7.47E-8	1.26E-3	
31<Z<41	1.27E-8	3.1E-4	2.39E-4
Z>31	1.48E-8	3.77E-4	3.11E-4
Ratio: (29<Z<41)/(20<Z<29)	1.68E-3	8.1E-4	1.306E-3* (Range of 9E-4 to 2.7E-3 for 19 lunar samples and 4 meteorites)
Ratio: (Z>31)/Fe	3.6E-4	3.77E-4	3.1E-4
Ratio: (31<Z<41)/(Z>31)	0.86	0.82	0.77

*Based on Apollo lunar samples

orbit at 51.6° inclination. These ISSA LET spectra for the worst case solar flare have been tabulated and plotted in two Space Station documents [18, 19]. These LET spectra can be used to calculated heavy ion induced single event upset and latchup rates using the standard [20] or ISSA prescribed [18, 19] rate calculation models.

V. EVALUATION OF ULTRA–HEAVY SOLAR FLARE IONS

Concerning the ultra–heavy ions, those heavier than the Fe group, i.e., with Z>30, CREME does have abundances for these ions in both the solar flare and GCR environments. Although these environments have different origins, the solar flare ions originating from the sun, while the GCR particles are from outside the solar system, on a practical level, for purposes of defining radiation environments, they appear to be fairly similar. This can be seen in Table 3 in which we have tabulated the two sets of ultra–heavy ion mean abundances from CREME (solar flares and GCR), along with GCR abundances that have been measured. In one case the measured data are abundances relative to iron measured on the HEAO and Ariel satellites using particle telescopes [21, 22]. In the second case the data is older, being based on analyses of particle tracks in lunar rocks, surface dust, and core layers brought back on Apollo missions [23]. In all cases of this GCR data, when it is expressed on a relative basis, i.e., compared to the abundance of Fe, or of a portion of the ultra–heavy Z ions, there is considerable measured data and there is good agreement between it and the CREME mean abundances (columns 2–4).

Unfortunately for the ultra–heavy ions accompanying a solar flare there are not comparable satellite measurements. There are, however, two very limited sets of measurements that, on a preliminary basis, appear to indicate that the CREME mean abundances significantly underpredict the ultra–heavy portion of solar flare ions. During the April 17–19, 1972 weak solar flare, Apollo 16 was on its lunar mission. Tracks made by the solar flare heavy ions in lexan and SiO_2 glass samples from the lunar module were subsequently analyzed [24]. From these tracks five groups of heavy ions could be distinguished: He, O, Fe, Z>32, and Z>44. For the He, O, and Fe ions, energy dependent fluences for the entire flare were determined; for the ultra–heavy ions, the fluence at only one energy (051 MeV per nucleon) could be obtained. In Table 4 are listed the measured abundances at ~1 MeV per nucleon normalized relative to He, for the April 1972 flare and the mean abundances found in CREME. It is apparent that the measured abundances for O and Fe agree fairly well with those in CREME, but for the ultra–heavy ions the measured abundances are higher by about two orders of magnitude relative to the mean values in CREME.

There is a second set of measurements of ultra–heavy ions during solar flares, also from the Apollo era, and these are based on tracks in olivine crystals within lunar fines that are

Table 4 Comparison of Measured Ultra–heavy Solar Flare Abundances with Those in CREME

Ion	CREME Mean Solar Flare Abundance Ratio (He=1)	E=0.5 MeV/nucleon		E=1 MeV/nucleon	
		April 1972 Solar Flare Fluences p•n/cm^2•sr•MeV	Ratio (Relative to He)	April 1972 Solar Flare Fluences p•n/cm^2•sr•MeV	Ratio (Relative to He)
He	1.0	2E7	1.0	1E7	1.0
O	3.2E-2	1E6	5E-2	3.7E5	3.7E-2
Fe	4.1E-3	1.5E5	7.5E-3	2.8E4	2.8E-3
Z>32	9.75E-7	3E3	1.5E-4	N/A*	N/A*
Z>44	1.72E-7	N/A*	N/A*	9.8E1	9.8E-6
Ratio: Z>32/Fe	2.38E-4		2E-2		N/A*
Ratio Z>44/Fe	4.2E-5		N/A*		3.5E-3
Ratio: (29<Z<41)/ (20<Z<29)		Olivine Crystals in Lunar Fines (E<20 MeV per nucleon)			
	1.7E-3	1.3E-2			

*Based on the single set of track data, the Z>32 value corresponds to 0.5 MeV per nucleon and the Z>44 value to 1 MeV per nucleon.

attributable to ions with E>20 MeV per nucleon [25]. In this case the data indicates that the ratio of the ultra–heavy ions to the Fe group (29<Z<41)/(20<Z<29) is 1.3×E-2 [23, 25]. When the data from the April 1972 solar flare in Table 4 is used to construct a roughly comparable ratio, Z>32/Fe, the ratio is ~200, in fair agreement with the value of 1.3E2. However, it is about one order of magnitude larger than the comparable ratio using the mean CREME solar flare abundances. This observed ratio for solar flares is also larger by about an order of magnitude than that derivable from the photosphere abundances, i.e., using solar abundance data. One explanation for this is that there is a charge dependent acceleration process operating at the sun [23].

It should be noted that it appears that the track analyses that these solar flare ultra–heavy abundance ratios are based on may have been performed assuming that the ions are fully stripped, which is true for the GCR but not for solar flares, as shown in Figure 3. It is unclear how much of an effect the charge of the ions has on the conclusions of the track analyses. There is clearly a scarcity of observed data on ultra–heavy solar flares ions, and the limited data that does exist is based on track analysis which may be somewhat uncertain. That data does indicate that, when compared to the abundances in CREME, while the measured values agree for Fe, the mean ultra–heavy ion abundances for solar flares appear to be 1 to 2 orders of magnitude too small. For some situations, e.g., thinly shielded spacecraft, this may be potentially significant, warranting further investigation along a variety of directions: re–evaluation of the track analyses, evaluation of the precise impact on solar flare LET spectra, and new schemes to obtain additional measurements of solar flare ultra–heavy ions. Data from the Cosmic Ray Isotope Spectrometer (CRIS), capable of measuring ions with Z>30 that will be on the Advanced Composition Explorer (ACE) satellite (scheduled launch in 1997) should provide more definitive evidence of the abundances of the ultra–heavy ions.

VI. OVERALL DESCRIPTION OF MACREE

To implement this flare model for evaluating flare–induced SEE effects for Space Station, CREME [1] was extended and became the MACREE code. After looking at the CREME documentation and coding, we decided that a complete rewrite would be the most efficient way to incorporate all the desired changes. Since most of our other tools are Microsoft Windows based programs we decided to implement MACREE under Windows. To simplify the development of the initial version, we generated it as a C++ program under QuickWin. Our intention is to port MACREE to full Windows capability in the next version.

In the cases where the CREME and MACREE capabilities are the same, the two programs give results that agree to within a few percent. The differences in the results are caused by differences in implementation and are not significant. This is illustrated in Figure 6 which shows the GCR heavy ion integral flux at solar minimum for a device in geosynchronous orbit and shielded by 100 mils of aluminum. As the figure shows, the results of the two calculations are the same. Also shown in Figure 6 is the heavy ion integral flux for the CREME Weather Index 11 case (worst case flare and mean element composition) compared to the MACREE model of the October 1989 flare. Again, these two fluxes are for a device in geosynchronous orbit and behind 100 mils of aluminum. As can be seen from the figure, the two flare models have similar integral fluxes at low LET, but the MACREE model for the flare yields a flux that is approximately an order of magnitude lower than that from the CREME model at high LET values. The flare model comparison shows that the CREME worst case flare model is too conservative, as discussed in Section IIIB above.

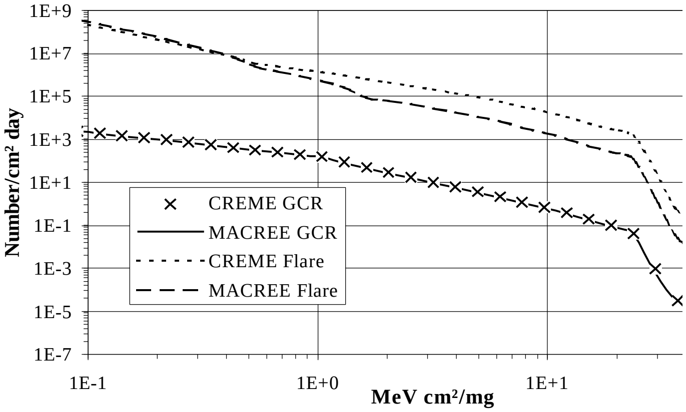

Figure 6 Comparison of CREEM and MACREE Integral Heavy Ion Flux for Two Cases. Geosynchronous Orbit and 100 mil Aluminum Shielding in all cases.

One of the drawbacks of CREME is its inability to track data flow. It is not possible, from a CREME final result, to determine the conditions leading to that result. MACREE implements data tracking through modifications of the input and output capabilities. Input comments are permitted in many portions of the program to facilitate data and process tracking. A batch file capability, with full input logging, has been implemented. Output enhancement includes internal time and date stamping of output files and echoing of input values, conditions, and comments. Some portions of the program use previously generated files as inputs. The output from these portions includes the comments, conditions, etc., copied from the previously generated files. This feature ensures complete data tracking, and the results in the final output can be traced back to all the inputs that were used in generating this result.

In generating the first version of MACREE, we unified five of the CREME modules (*STASS*, *GEOMAG*, *SPEC*, *LET*, and *UPSET*) into one program. While combining these CREME modules into one program, they where subdivided by functionality. The fluxes generated by the CREME weather indices were separated into individual routines, each of which calculates the contribution from one source (e.g., GCR background, anomalous component, or flare). The original "Weather Indices" can still be generated by choosing the appropriate combination of flux sources. However, combinations of sources which were not included in the original "Weather Indices" can also be calculated. The new worst case flare model described above was added. The result of these changes is a program that is both unified at the top or user level, and modular at the programmer's level. This increases the ease of use for the user and the ease of modification for the programmer. In addition, some of the algorithms of the calculation were modified or replaced. This was done either to increase the accuracy of the calculation, or, most often, to decrease the time required for the calculation. An "off by one" error (i.e., the values calculated were incorrectly stored in the array so that the functional value for the i*th* element was in the (i+1*)th* position) in CREME's calculation of the geomagnetic transfer function was corrected. The calculation of the effect of the earth's shadow on the geomagnetic transfer function was extended to elliptical orbits. Planned additions for future versions include additional ways to calculate SEE rates and functional fitting of experimental data.

Copies of MACREE, as executable QuickWin programs, are available without charge from the principal author. Source code will not, in general be distributed. However, source code for particular routines, such as the October 1989 flare model, will be distributed on a limited basis.

VII. CONCLUSIONS

A new heavy ion solar flare model has been described and implemented by way of a new analysis tool for SEE rate calculations called MACREE. It is being used to support Space Station SEE evaluations, and has been used to define the worst case flare environment for ISSA in terms of the heavy ion LET spectra. Since the highly energetic ions are of main concern for these evaluations, the new solar flare model uses 25% of the CREME abundances for ions with Z>2 in order to obtain good agreement with measured solar flare fluxes at high values of energy per nucleon. The model uses: a) October 19, 1989, as the worst case solar flare b) fits to measured proton and alpha differential fluxes for this flare, and c) the alpha particles fluxes multiplied by the abundances (0.25 of the CREME values) for ions with Z>2. Results of the MACREE calculations compare favorably with heavy ion solar flare measurements on Galileo and IMP8 (ECRSPE). The abundances of ultra–heavy ions (Z>30) used in CREME were compared with the few available measurements. For the GCR, the CREME ultra–heavy abundances appear to be in good agreement. However for the solar flare, based on two sets of track analysis data, the CREME ultra–heavy abundances may be too low by 1–2 orders of magnitude, and this warrants further investigation. MACREE was written in C++ to enable it to run efficiently on the PC. A number of programming improvements were made to the original CREME version to enhance its utility, e.g., eliminating the weather index system to allow the user to select the combination of sources that are most appropriate, and future modifications are also planned.

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