EXPACS: Excel-based Program for calculating Atmospheric Cosmic-ray Spectrum User's Manual

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I. INTRODUCTION

EXPACS represents "EXcel-based Program for calculating Atmospheric Cosmic-ray Spectrum". It can instantaneously calculate terrestrial cosmic ray fluxes of neutrons, protons, ions with charge up to 28 (Ni), muons, electrons, positrons, and photons nearly anytime and anywhere in the Earth's atmosphere, using the PHITS-based Analytical Radiation Model in the Atmosphere: PARMA. Based on the calculated fluxes, EXPACS can also estimate the effective dose, ambient dose equivalent, and absorbed dose in air due to cosmic-ray exposure. After version 4.0, the angular differential fluxes of terrestrial cosmic rays can be also calculated.

The software is opened for public via its web site whose URL is given below. The detailed descriptions of the calculation procedure were presented in Ref. [1-4]. Hence, this manuscript focuses on giving instruction of how to use the software.

URL: http://phits.jaea.go.jp/expacs/

II. INPUT DATA

The following 7 information must be supplied in cells B7-17 of "Main" sheet.

B7: Input altitude from the sea level in (km) or (ft), or atmospheric depth in (g/cm^2). Note that the applicable atmospheric depth range of PARMA is 0.15 - 1095 g/cm^2, which roughly corresponds to -0.5 – 63 km in altitude. The calculated cosmic-ray fluxes at the outer ranges are not reliable, particularly for secondary particles. When altitude is specified in B7 cell, it is automatically converted to the atmospheric depth using US Standard Atmosphere 1976 [5], except when the latitude is specified in B8 cell where the atmospheric depth is determined considering the latitude dependence of the relation between altitude and atmospheric-depth obtained from the NRL-MSISE-00 [6] calculation.

B8,9: Input location or the vertical cut-off rigidity at the point of your interest. When the location is specified by latitude (-90°~90°, north+) and longitude (-180°~180°, east+), EXPACS automatically calculates the vertical cut-off rigidity at the position using its database built by MAGNETOCOSMICS [7].

The vertical cut-off rigidity means that charged particle with rigidity below this value cannot reach the top of atmosphere because of the earth's magnetic field. Note that the centennial geomagnetic changes are not considered in our calculation of vertical cut-off rigidity, so if you would like to know the cosmic-ray spectra long time ago, you should specify the vertical cut-off rigidity directly instead of inputting the latitude and longitude.

B10-12: Input W-index that expresses the solar activity, time (GMT) or count rate of the Oulu neutron monitor. When time is specified by year, month and day, EXPACS automatically calculates the W-index based on the count rates of several ground-level neutron monitors on the date (see Table 1). If the specified date is before year 1951, *i.e.* before ground-level neutron monitors in operation, EXPACS estimates the W-index based on the reconstructed cosmic-ray intensity by Usoskin et al [8]. EXPACS can calculate the W-index from year 1611, but cannot estimate during the Maunder Minimum (1647-1699) because of the lack of sunspot number data. If you want to calculate recent cosmic-ray fluxes when the W-index value has not been evaluated, you should download the daily count rate of your preferable neutron monitor count from NMDB [9], and input the value in the column B10. Note that W-index estimated by this method is different from the corresponding data estimated using various neutron monitors. You can also specify W-index directly by selecting "W-value" in C10. Typical W-index for the solar minimum and maximum periods are approximately 0 and 150.

B13,14: Select surrounding environment and input local effect parameter. This parameter influences only on the neutron spectra. For ground-level neutron spectra, input fraction of water in ground. For neutron spectra in aircraft, input mass of the aircraft. Note that both parameters are NOT pure physical quantities, and can be adjustable. See Ref. [4] in more detail.

B15: Select type of dose to be calculated. For converting calculated cosmic-ray fluxes to the corresponding dose, if you select "effective dose", EXPACS uses the fluence to the effective dose conversion coefficients for isotropic exposure given in ICRP Publication 116 [10] and 123 [11]. If you select "H*(10)", EXPACS uses the fluence to ambient dose equivalent conversion coefficients given in ICRP Publication 74 [12] for neutrons below 200 MeV, and calculated by PHITS for other particles. If you select "absorbed dose in air", EXPACS uses restricted collision stopping power below 10 keV in dry air for electron and positron to avoid the double counting of the contributions of higher-energy electrons, and unrestricted collision stopping power for other particles.

B16: Select the unit of output flux. The unit of (/cm^2/s/(MeV/n)) is equivalent to (/cm^2/s/MeV) except for nucleus fluxes; *i.e.* n=1 for other particles.

B17: Select the unit of output dose.

III. OUTPUT DATA

EXPACS provides the following information.

B30-39: The calculated dose rates due to cosmic-ray exposure. The dose type and unit are specified in B15 and B17 cells, respectively. B30 cell shows the total dose rates, while B31 to B39 cells shows the contributions from each particle type.

D35-AL174: Calculated cosmic-ray fluxes for the input condition.

IV. ANGULAR DIFFERENTIAL FLUX

After version 4.0, EXPACS can calculate the angular differential fluxes of terrestrial cosmic rays. For the calculation, the basic conditions such as location, time, and local geometry should be specified in "Main" sheet in the same manner as the omni-directional fluxes, while the zenith angle and particle type for outputting angular differential fluxes should be defined in "Angle" sheet. You can output the angular differential fluxes for 4 conditions at once.

In "Angle" sheet, you have to specify the condition name in line 4, to select the particle type in line 5, to specify the zenith angle in line 6, and to select whether the black hole mode is activated or not in line 7. In specifying the zenith angle, 0 degree, i.e. cos(θ)=1, indicates the vertical downward direction, while 90 degree, i.e. cos(θ)=0, indicates the horizontal direction. Note that the azimuthal angle dependence cannot be considered. The black hole mode should be selected when you would like to estimate the cosmic ray fluxes excluding the contribution from the Earth's albedo particles.

The calculated results are outputted in lines from 35 to 174. For each condition, left and right columns show the angular differential fluxes and relative angular distribution, respectively. The angular differential fluxes can be determined from the omni-directional fluxes shown in "Main" sheet multiplied with the relative angular distribution.

V. SHEET INFORMATION

EXPACS consists of a number of EXCEL sheets. Only "Main" and "Update Log" sheets are shown in the default setting, but you can see other sheets using “unhide” command. Followings are brief descriptions of each sheet.

- ✓ **Main**: The main sheet that is described in the previous sections. Figure 1 provides the graphical instruction for using this sheet.
- ✓ **Update Log**: Update-log sheet.
- ✓ **UpData**: Data sheet containing variables used in “Update Log” sheet.
- ✓ **Data**: Data sheet containing variables used in “Main” sheet
- ✓ **Data-angle**: Data sheet containing variables used in “Angle” sheet
- ✓ **AngCal**: Main calculation sheet for angular distribution for all particles
- ✓ **AngNeutron**: Sheet for calculating neutron angular distribution
- ✓ **AngProton**: Sheet for calculating proton angular distribution
- ✓ **AngHe**: Sheet for calculating He-ion angular distribution
- ✓ **AngMuon**: Sheet for calculating muon angular distribution
- ✓ **AngElePos**: Sheet for calculating electron and positron angular distribution
- ✓ **AngPhoton**: Sheet for calculating photon angular distribution
- ✓ **Neutron**: Sheet for calculating neutron flux
- ✓ **Primary**: Sheet for calculating primary cosmic-ray fluxes such as proton and nucleus
- ✓ **Secondary**: Sheet for calculating secondary cosmic-ray fluxes, including secondary protons and nucleus.
- ✓ **mu+**: Sheet for calculating positive muon flux
- ✓ **mu-**: Sheet for calculating negative muon flux
- ✓ **USAir**: Data sheet containing the relation between altitude and atmospheric depth calculated using US Standard Atmosphere1976
- ✓ **MSIS**: Data sheet containing the relation between altitude and atmospheric depth as a function of latitude calculated using NRL-MSISE-00
- ✓ **Rc**: Data sheet containing the vertical cut-off rigidity map calculated using MAGNETOCOSMICS
- ✓ **DailyW**: Data sheet containing daily W-index estimated from the count rates of neutron monitors
- ✓ **AnnualW**: Data sheet containing annual W-index calculated from the reconstructed cosmic-ray intensity by Usoskin et al [10]
- ✓ **DCC**: Data sheet containing the conversion coefficients for dose type selected in B15 cell of “Main” sheet
- ✓ **ED**: Data sheet containing the fluence to the effective dose conversion coefficients for isotropic exposure

- ✓ **H10**: Data sheet containing the fluence to the ambient dose equivalent ,H*(10), conversion coefficients
- ✓ **AirDose**: Data sheet containing the stopping power for calculating absorbed dose in air
- ✓ **dEdxTable**: Data sheet containing the stopping power calculated by PHITS
- ✓ **Ground**: Sheet containing the database used in the calculation of the ground effect on neutron fluxes
- ✓ **Aircraft**: Sheet containing the database used in the calculation of the aircraft effect on neutron fluxes

VI. SUMMARY

If you have any questions or requests for this program, please E-mail to nsed-expacs@jaea.go.jp

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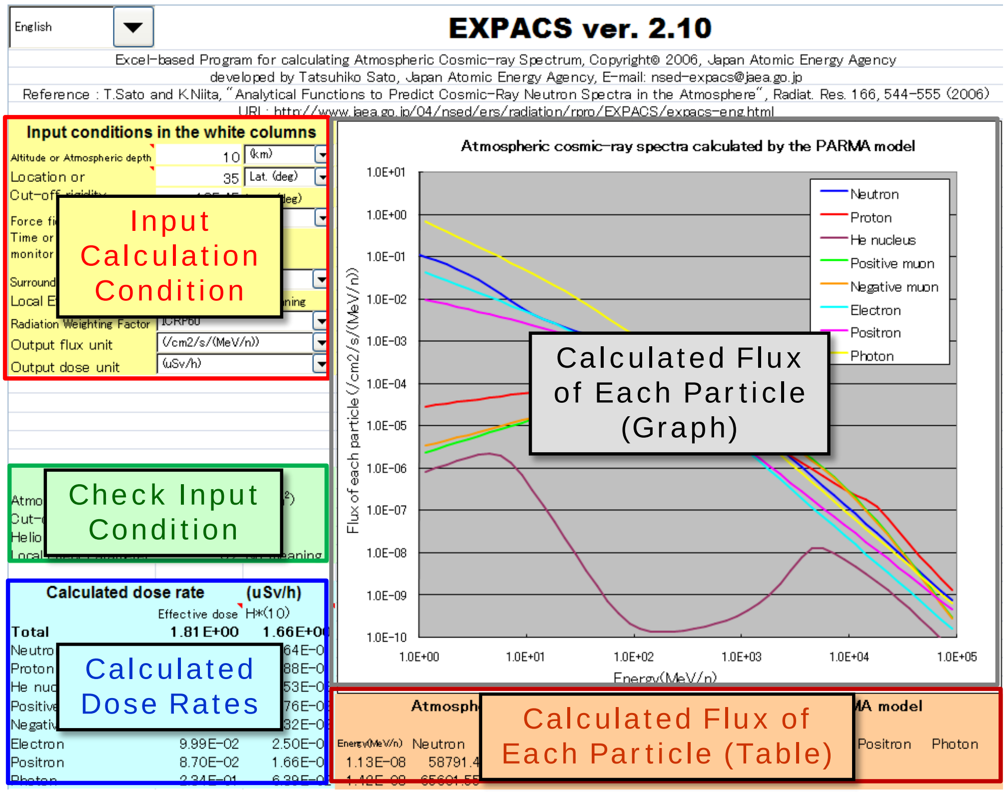

Figure 1. Graphical instruction for using EXPACS

Table 1. List of neutron monitors used for evaluating W-index

Station name	Shorten name	R_c (GV)	Altitude (m)	Operator
Athens	ATHN	8.53	260	National and Kapodistrian University of Athens
Apatity	APTY	0.65	30	Polar Geophysical Institute Russian Academy of Sciences
Fort Smith	FSMT	0.3	180	Bartol Research Institute, University of Delaware
Inuvik	INVK	0.3	21	Bartol Research Institute, University of Delaware
Jungfraujoch	JUNG	4.5	3570	Physikalisches Institut of the University of Bern
Kerguelen	KERG	1.14	33	French Polar Institute and Paris Observatory
McMurdo	MCMU	0.3	345	Bartol Research Institute, University of Delaware
Nain	NAIN	0.3	46	Bartol Research Institute, University of Delaware
Newark	NEWK	2.4	50	Bartol Research Institute, University of Delaware
Oulu	OULU	0.8	15	Sodankyla Geophysical Observatory of the University of Oulu
South Pole	SOPO	0.1	2820	Bartol Research Institute, University of Delaware
Terre Adelie	TERA	0	32	French Polar Institute and Paris Observatory
Thule	THUL	0.3	260	Bartol Research Institute, University of Delaware