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Note verbale datée du 12 décembre 2002 adressée au Secrétaire général par la Mission permanente de l'Italie auprès de l'Organisation des Nations Unies (Vienne)

Additif

La Mission permanente de l'Italie auprès de l'Organisation des Nations Unies (Vienne), rappelant sa note verbale datée du 12 décembre 2002, a l'honneur de communiquer de nouveaux documents, à savoir les troisième, quatrième et cinquième bulletins sur les prévisions de rentrée dans l'atmosphère du satellite italien BeppoSAX (voir annexe).

La nouvelle date de rentrée devrait se situer intervenir entre le 25 avril et le 13 juin 2003. Cette prévision sera actualisée plus fréquemment à mesure que la date de rentrée approchera.

On trouvera des informations sur la rentrée de BeppoSAX sur le site Web: « www.asdc.asi.it/bepposax/reentry ».

Le Gouvernement italien a mis en place une structure de mission temporaire pour coordonner et gérer toute initiative et activité concernant le déclin d'orbite et la rentrée de BeppoSAX (n^{os} de téléphone: + (39) (06) 68202266 et + (39) (06) 682022314; fax: (39) (06) 68897689).

* Document réédité pour raisons techniques.

Annexe

Annex to the note verbale dated 12 December 2002 from the Permanent Mission of Italy to the United Nations (Vienna) addressed to the Secretary-General*

No. 3 **30 January 2003**

BEPPOSAX REENTRY PREDICTIONS

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SATELLITE ORBITAL STATUS

Currently, the BeppoSAX satellite completes a revolution around the earth every 92 minutes at an altitude in between 374 km (perigee) and 379 km (apogee). The orbit is inclined by 3.96 degrees with respect to the equator, which means the satellite may fly over any location included in the latitude band between 3.98 degrees North and South. However, the motion is significantly perturbed by the residual atmosphere present at that altitude. The main effect of the resulting drag force is a progressively increasing altitude loss, which will culminate in the satellite reentry on the earth.

Because the orbit is near circular, the average altitude loss per revolution (Δh_{rev}) may be approximated using the following equation:

$$\Delta h_{rev} = -\, 2\pi B \rho a^2,$$

where ρ is the average atmospheric density along the orbit, a is the semi-major axis (i.e. the average distance from the center of the earth) and B is the satellite ballistic parameter [Ref. 1]. B is a complex function of spacecraft mass, size, shape, attitude and surface properties; in addition, it depends on the local atmosphere density, temperature and composition.

BALLISTIC PARAMETER EVOLUTION

In order to predict the future behavior of the ballistic parameter, critical for reentry predictions, a detailed study of its past evolution was carried out [Ref. 2]. Monthly average values of B were estimated by fitting, in a least squares sense, the BeppoSAX semi-major axis decay observed during the last three years. All the relevant orbit perturbations were included and the Jacchia-Roberts 1971 model was adopted to describe the varying atmospheric density. The orbital data, as two-line elements based on US Space Surveillance Network measurements, were provided by the NASA/GSFC Orbital Information Group. Figure 1 shows the values of B obtained for the period following the satellite deactivation, on 30 April 2002.

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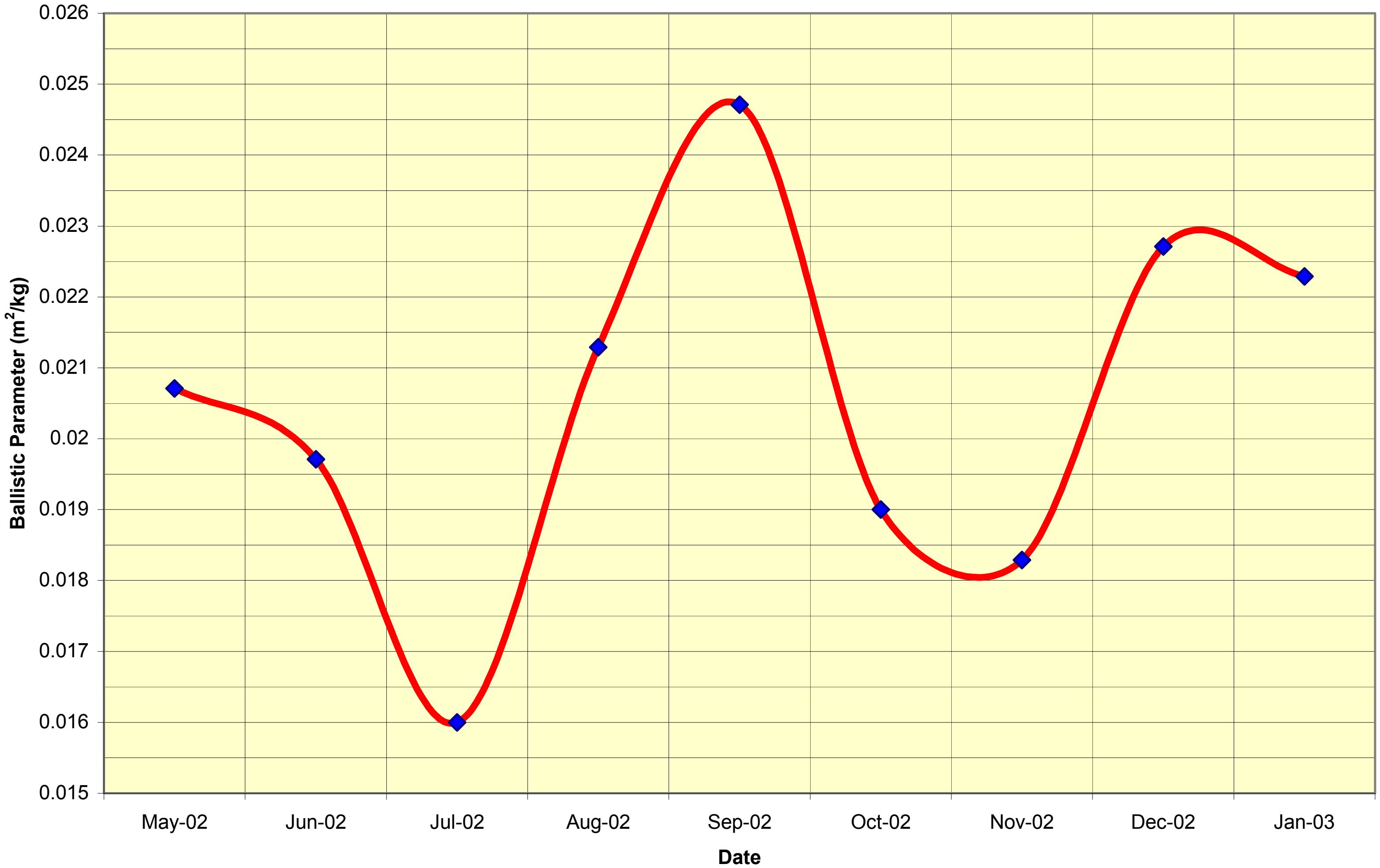

Fig. 1 – Ballistic parameter evolution (monthly averages) after the BeppoSAX deactivation (May 2002 – January 2003)

After the spacecraft switch off, and the consequent deactivation of the attitude control system, the average ballistic parameter obtained was (May 2002 – January 2003):

$$\langle B \rangle = 0.02051 \text{ m}^2/\text{kg} \pm 12\% \text{ (one standard deviation).}$$

As shown in Figure 1, during the last nine months the ballistic parameter oscillated around this average value, with no significant increasing or decreasing trend. Therefore, such a value was used for the nominal residual lifetime estimation.

BEPPOSAX REENTRY WINDOW

The expected residual lifetime of the satellite was computed by propagating its last available state vector (epoch: 30 January 2003, 02:24 UTC) with a numerical trajectory predictor including the geopotential harmonics up to the 16^{th} order and degree, the luni-solar attraction, the solar radiation pressure with eclipses and the aerodynamic drag. The air density was computed with the Jacchia-Roberts 1971 model.

Concerning the predicted solar flux at 10.7 cm (used by the atmospheric model as a proxy of the solar irradiance at extreme ultraviolet frequencies) and the geomagnetic planetary index A_p, the last 27-day forecast (corresponding to one solar rotation), issued by the NOAA Space Environment Center, was adopted. For the subsequent months, such solar flux predictions were reiterated, applying an average reduction of 4.8 standard units per month [Ref. 2], while a constant average value ($A_p = 12$) was used for the geomagnetic planetary index.

A reentry window with a confidence level of 90%, taking into account the observed variability of B and the intrinsic uncertainties of the solar activity predictions, was defined as follow. First of all, three-month running averages of B (after the satellite deactivation) and solar flux (after the last maximum) were computed to the present day. The three-month averaging period was chosen because comparable to the BeppoSAX residual lifetime. The statistical dispersions of such averages were therefore analyzed in order to find the ranges of variability assuring a confidence level of 90% (corresponding, in a normal distribution, to $\pm$ 1.645 standard deviations).

For B, a variability range of $\pm$ 8% was found, which implicitly includes also the inaccuracies of the atmospheric model. For the solar flux, the variability range with respect to the decreasing trend recorded during the last 14 months [Ref. 2] was $\pm$ 17 standard units, corresponding to an air density variation of $\pm$ 22% at the present satellite altitude and solar activity level. A reentry window with a confidence level of 90% could then be obtained by varying the nominal ballistic parameter by $\pm [(8\%)^2 + (22\%)^2]^{1/2} = \pm 23.4\%$.

Using for BeppoSAX the average ballistic parameter ⟨B⟩, the nominal reentry date of 10 May 2003 was obtained. Assuming a conservative attitude for the definition of the reentry window, a variation of ± 25% was adopted, as shown in Table 1.

Table 1
BeppoSAX Reentry Window

Reentry Window	Criteria	B (m^2/kg)	Reentry Date
Opening	⟨B⟩ + 25%	0.02563	19 April 2003
Nominal Reentry	⟨B⟩	0.02051	10 May 2003
Closure	**⟨B⟩ – 25%**	**0.01538**	21 June 2003

LATITUDE BELT POTENTIALLY AFFECTED BY THE SURVIVING DEBRIS IMPACT

A reentry destructive analysis carried out for ASI by HTG [Refs. 3 and 4] has shown that 42 fragments of BeppoSAX, with a total mass of about 656 kg, will reach the ground. The fragments will rain down vertically, with respect to the local horizon, with terminal velocities in between 60 and 465 km/h. The debris footprint on the earth surface, aligned with the sub-satellite track, will be approximately 330 km long. Following the HTG results, the cross-track dispersion might reach ± 0.375 degrees, corresponding to about ± 42 km.

The definition of the latitude belt potentially affected by the impact of the surviving fragments results from the following relationship:

$$L_{max} = I_{max} + \delta + \Lambda,$$

where L_{max} is the limiting latitude (North or South) of the above mentioned belt, I_{max} is the maximum satellite orbit inclination, δ is a corrective term, for the conversion from geocentric to geodetic coordinates, and Λ is the maximum cross-track dispersion of the fragments. Taking into account the higher orbital inclination foreseen during the reentry window, L_{max} = 4.356 degrees. Therefore, the BeppoSAX surviving fragments might reach any location in between 4.356 degrees North and South.

The countries or territories crossed by the above mentioned latitude belt are the following:

- **Africa:** Burundi, Cameroon, Central African Republic, Congo, Democratic Republic of Congo, Equatorial Guinea, Ethiopia, Gabon, Kenya, Rwanda, São Tomé and Príncipe, Seychelles, Somalia, Sudan, Tanzania, Uganda. Cap

Palmas, at the border between Liberia and Côte d'Ivoire, and the Niger river delta, in Nigeria, are also skimmed by the limiting northern latitude;

- **Asia:** Brunei, Indonesia, Malaysia, Maldives, Singapore;

- **Oceania:** Baker Island (USA), Federated States of Micronesia, Howland Island (USA), Jarvis Island (USA), Kiribati, Marshall Islands, Nauru, Palau, Papua New Guinea;

- **South America:** Brazil, Colombia, Ecuador, French Guiana, Guyana, Peru, Suriname, Venezuela.

This list of countries or territories updates those presented in Refs. 5 and 6.

By following the approach presented in Ref. 7 and considering, in the latitude belt between 4 degrees South and 4 degrees North, an average population density, in 2003, of 6.778 people per square kilometer [Ref. 8], the debris casualty area (30 m^2) obtained by the HTG study [Refs. 3 and 4] implies an a priori expected number of human casualties of about 2×10^{-4}. Table 2 summarizes the reentry probability as a function of latitude.

Table 2

BeppoSAX Reentry Probability as a Function of Latitude

Latitude Belt	Reentry Probability
0° – 1° N or S	**0.081**
1° – 2° N or S	**0.086**
2° – 3° N or S	**0.103**
3° – 4° N or S	**0.230**

NEXT UPDATE

The next reentry prediction will be issued on 13 February 2003.

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No. 4 13 February 2003

BEPPOSAX REENTRY PREDICTIONS

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SATELLITE ORBIT STATUS

Currently, the BeppoSAX satellite completes a revolution around the earth every 92 minutes at an altitude in between 365 km (perigee) and 370 km (apogee). The orbit is inclined by 3.96 degrees with respect to the equator, which means the satellite may fly over any location included in the latitude band between 3.98 degrees North and South. However, the motion is significantly perturbed by the residual atmosphere present at that altitude. The main effect of the resulting drag force is a progressively increasing altitude loss, which will culminate in the satellite reentry on the earth.

BALLISTIC PARAMETER ESTIMATION

The nominal ballistic parameter B_N, defined according to the relationship $B_N = C_D A/m$, where C_D, m and A are, respectively, the satellite drag coefficient, mass and average cross-sectional area, was estimated by fitting, in a least squares sense, the satellite semi-major axis decay observed during the last three months. All the relevant orbit perturbations were included and the Jacchia-Roberts 1971 model was adopted to describe the varying atmospheric density. The orbital data were provided by the NASA/GSFC Orbital Information Group and by Nicholas L. Johnson of NASA/JSC. The value obtained was $B_N = 0.02186$ m^2/kg.

BEPPOSAX REENTRY WINDOW

The expected residual lifetime of the satellite was computed by propagating its last available state vector (epoch: 12 February 2003, 10:10 UTC) with a numerical trajectory predictor including the geopotential harmonics up to the 16^{th} order and degree, the luni-solar attraction, the solar radiation pressure with eclipses and the aerodynamic drag. The air density was computed with the Jacchia-Roberts 1971 model.

BEPPOSAX REENTRY PREDICTIONS **13 February 2003 – No. 4**

Concerning the predicted solar flux at 10.7 cm (used by the atmospheric model as a proxy of the solar irradiance at extreme ultraviolet frequencies) and the geomagnetic planetary index A_p, the last 27-day forecast (corresponding to one solar rotation), issued by the NOAA Space Environment Center, was adopted. For the subsequent months, such solar flux predictions were reiterated, applying an average reduction of 4.8 standard units per month, while a constant average value ($A_p = 12$) was used for the geomagnetic planetary index.

Using for BeppoSAX the ballistic parameter estimated by fitting the orbital decay observed during the last three months, the nominal reentry date of 6 May 2003 was obtained. In order to take into account the intrinsic uncertainties of this kind of predictions, a reentry window with an assumed confidence level of approximately 90% was computed by varying the nominal ballistic parameter B_N of ± 25%, as shown in Table 1.

Table 1

BeppoSAX Reentry Window

Reentry Window	**Criteria**	**B (m^2/kg)**	Reentry Date
Opening	B_N + 25%	0.02732	19 April 2003
Nominal Reentry	B_N	0.02186	6 May 2003
Closure	**B_N – 25%**	**0.01639**	7 June 2003

At present, solar flux predictions are still the leading source of uncertainty. This situation will change only a few weeks before reentry, when the ballistic coefficient will play a comparable role. Geomagnetic storms might have a significant impact on the reentry date during the last ten days of satellite lifetime. If updated BeppoSAX state vectors will be available during the last 6 hours, the final uncertainty on the predicted reentry time might be reduced to ± 45 minutes, corresponding to one full orbital track.

NEXT UPDATE

The next reentry prediction will be issued on 27 February 2003.

BEPPOSAX REENTRY PREDICTIONS

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SATELLITE ORBIT STATUS

Currently, the BeppoSAX satellite completes a revolution around the earth every 91.8 minutes at an altitude in between 356 km (perigee) and 362 km (apogee). The orbit is inclined by 3.96 degrees with respect to the equator, which means the satellite may fly over any location included in the latitude band between 3.98 degrees North and South. However, the motion is significantly perturbed by the residual atmosphere present at that altitude. The main effect of the resulting drag force is a progressively increasing altitude loss, which will culminate in the satellite reentry on the earth.

BALLISTIC PARAMETER ESTIMATION

The nominal ballistic parameter B_N, defined according to the relationship $B_N = C_D A/m$, where C_D, m and A are, respectively, the satellite drag coefficient, mass and average cross-sectional area, was estimated by fitting, in a least squares sense, the satellite semi-major axis decay observed during the last three months. All the relevant orbit perturbations were included and the Jacchia-Roberts 1971 model was adopted to describe the varying atmospheric density. The orbital data were provided by the NASA/GSFC Orbital Information Group and by Nicholas L. Johnson of NASA/JSC. The value obtained was B_N = 0.02276 m^2/kg.

BEPPOSAX REENTRY WINDOW

The expected residual lifetime of the satellite was computed by propagating its last available state vector (epoch: 26 February 2003, 10:04 UTC) with a numerical trajectory predictor including the geopotential harmonics up to the 16^{th} order and degree, the luni-solar attraction, the solar radiation pressure with eclipses and the aerodynamic drag. The air density was computed with the Jacchia-Roberts 1971 model.

Concerning the predicted solar flux at 10.7 cm (used by the atmospheric model as a proxy of the solar irradiance at extreme ultraviolet frequencies) and the geomagnetic planetary index A_p, the last 27-day forecast (corresponding to one solar rotation), issued by the NOAA Space Environment Center, was adopted. For the subsequent months, such solar flux predictions were reiterated, applying an average reduction of about five standard units per month, while a constant average value ($A_p = 12$) was used for the geomagnetic planetary index.

Using for BeppoSAX the ballistic parameter estimated by fitting the orbital decay observed during the last three months, the nominal reentry date of 11 May 2003 was obtained. In order to take into account the intrinsic uncertainties of this kind of predictions, a reentry window with an assumed confidence level of approximately 90% was computed by varying the nominal ballistic parameter B_N of ± 25%, as shown in Table 1.

Table 1

BeppoSAX Reentry Window

Reentry Window	**Criteria**	**B (m^2/kg)**	Reentry Date
Opening	B_N + 25%	0.02845	25 April 2003
Nominal Reentry	B_N	0.02276	11 May 2003
Closure	**B_N – 25%**	**0.01707**	13 June 2003

At present, the solar flux predictions are still the leading source of uncertainty. This situation will change only a few weeks before reentry, when the ballistic coefficient will play a comparable role. Geomagnetic storms might have a significant impact on the reentry date during the last ten days of satellite lifetime.

NEXT UPDATE

The next reentry prediction will be issued on 17 March 2003.

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