The ROSY ESR dating program

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Abstract : *ROSY is a program that enables the calculation of average dose rates and age estimates in the ESR dating of tooth enamel, but has more general applicability to other situations involving layers of different media in planar geometry. The user has the freedom to change a wide range of parameters, including the composition of each of the media. The latest Version, 1.4, includes consideration of gradients in the alpha track dose as well as in the beta dose, and several options for the input or computation of gamma and cosmic ray doses. The theoretical assumptions and procedures used in the ROSY calculations are described. We discuss the various user-controllable features of the program and the input and output of data, and aspects that may need particular attention by users are highlighted. Possible improvements to the software in future Versions are discussed.*

1 Introduction

ROSY is a program that enables the calculation of dose rates and age estimates for a planar geometry involving up to three layers embedded in an infinite matrix. It is named after a hippopotamus which died at the Toronto Zoo and posthumously lost her teeth to the cause of ESR dating at McMaster University Geology Department. While the program employs terminology specific to the ESR dating of tooth enamel, it may be adapted readily to other situations in luminescence or ESR dating where the geometry is essentially planar for the purpose of beta dose calculations, such as mollusc shells and thin burned flints. The primary purpose of the present paper is to outline the various user-controllable features and the methodology employed in ROSY and to comment on aspects that may need to be considered by a user. This includes coverage of improvements made to the software since a brief summary of the program was previously presented (Brennan *et al.*, 1997). Not all the features discussed are implemented in versions of ROSY earlier than the current version, 1.4.

The most significant feature of ROSY is the use of "one-group" theory in the calculation of beta dose contributions, and this aspect has been discussed elsewhere. Brennan *et al.* (1997) describe the formalism and present comparisons of ROSY beta dose estimates with estimates from the DATA software based on the approach of Grün (1986), theoretical Monte Carlo results, and the experimental results of Aitken *et al.* (1985). These comparisons revealed significant differences, with ROSY and the Monte Carlo results in broad agreement but yielding lower doses than either DATA or Aitken *et al.* (1985). Yang *et al.* (1998) conducted careful experiments to measure beta attenuation in planar dose geometry, and these produced results in substantial agreement with one-group and Monte Carlo calculations. As a consequence, we believe that the ROSY software provides better estimates of the beta dose (and hence of the total dose) to a layer than previous software.

It is arguable that modern Monte Carlo-based data would be more accurate again, as has been suggested (Grün, 1998). The rationale for applying the one-group theory arose from its suitability in accounting for layered geometry, in particular the effect of back-scattering at boundaries. This simplified model leads to an exponential behavior for the dose attenuation resulting from external irradiation from each side. It should be emphasised that it is an experimentally established fact that the dose distribution for a given beta emitter is not exponential. As a consequence, no unique attenuation coefficient exists and any effective attenuation coefficient representing the actual distribution would vary with the range over which the distribution is being approximated. The concordance of results based on the use of one-group attenuation coefficients with Monte Carlo calculations and the results of Yang *et al.* (1998) is thus probably fortuitous. Work is currently in preparation incorporating into ROSY the use of Monte Carlo-based data in place of one-group theory for estimating beta doses (Marsh, 1999).

Version 1.4 of ROSY allows for alpha dose variation near the boundaries of the enamel layer, whereas previous versions simply used the "infinite matrix" dose rate for the enamel. Proper allowance for such alpha dose gradients is necessary in dating thin enamel or mollusc layers where stripping of boundary material is not appropriate.

2 Layered Geometries in ROSY

ROSY can calculate the dose for tooth enamel in a range of environments and solve for the age consistent with the observed equivalent dose, D_E, using different uranium uptake models for the enamel, cementum, and dentine tissues. In calculating the beta and alpha doses to the enamel "target" dose absorber, ROSY makes the assumption that all layers (enamel, sediment, cementum, and dentine) are homogeneous, planar, and parallel. The dose includes an internal component due to sources within the enamel and an external component due to sources in other layers. The most complex geometry that ROSY can work with consists of a layer of enamel sandwiched between cementum and dentine in surrounding sediments (Figure 1).

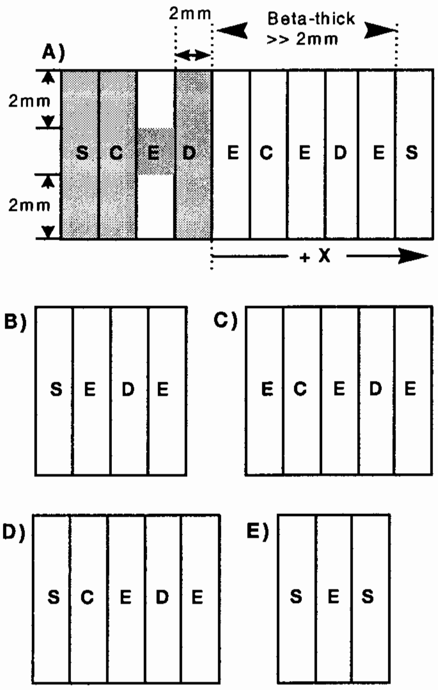


Figure 1. *Beta dose geometry of tooth enamel layers.*

A) Cross-sectional view of one possible sequence of layers in a bovid or cervid tooth showing cementum (C), enamel (E) and dentine (D) surrounded by sediment (S) on both sides. The enamel portion for dating (shaded in Figure 1A) should be adjacent to a dentine layer that is at least 2 mm thick, and C, E, D should all be located in planar layers that extend for 2mm beyond the enamel edges. This insures proper 2 π geometry for beta irradiation. In most cases, the internal layering labelled beta-thick (and the dentine adjacent to the enamel if present) will shield the dated enamel from beta irradiation by the sediment layer on the positive X side (diagram right). The ROSY calculation will include a beta contribution from sediment on this side if too small a value is entered for the thickness of the "dentine" layer.

Four cases of actual geometries which can be used in ROSY:

B) SED: Outer enamel layer that occurs between sediment and dentine.
C) CED: Inner enamel layer that occurs between cementum and dentine.
D) SCED: Outer enamel layer that lies between cementum and dentine.
E) SES: Enamel detached from tooth and surrounded completely by sediment.

The geometry of layers in mammal teeth depends on taxon. Figure 1 is a schematic diagram showing the arrangement of layers seen in a transect across a bovid or cervid tooth (horse teeth can have as many as 25 different layers across a single transect). Although the layers are idealised as true planar layers in Fig. 1, in real situations the outer enamel layers are generally more planar, albeit slightly curved, while the inner layers of enamel are more convoluted. Workers may choose to use the outer enamel layers or inner enamel layers, but some simple rules about geometry are important. As Figure 1A shows, the ideal enamel section for dating should come from a region where the layers are nearly planar (slightly curved layers are a good approximation to planar geometry). In addition, the layers adjacent to the enamel should extend some 2mm laterally beyond the dated portion, so that edge effects which disrupt planar irradiation geometry during burial can be avoided. The 2mm maximum range of most of the beta particles controls this dimension. In addition, when the inner tooth layers are beta-thick (that is, greater than the 2mm maximum range of natural beta particles), they shield the enamel from any beta dose being delivered by the sediment in the region $X>0$ in Figure 1A. ROSY software calculations always include a beta dose contribution from the sediment in the region $X>0$ (on the right of each diagram) unless the thickness of dentine entered into the program is at least 2000 micrometer (2mm). Sediment "layers" are always assumed to be infinitely thick for the purpose of beta dose calculations.

There are four general cases to which ROSY is applicable, which include most if not all configurations of dental layers found in nature. These are summarised in Figures 1B-E. In both the caption and the discussion which follows, the labels used list in left-to-right order the layers in each geometric configuration which contribute the bulk of the beta dose to the enamel.

SED (Figure 1B): Cementum thickness is zero, as no cementum is present on the external surface of the enamel.

CED (Figure 1C): Both C and D are beta-thick; this configuration could represent an inner enamel layer of a hypsodont tooth, where typically the enamel is bordered by cementum and dentine. If either C or D are not beta-thick (> 2 mm) then some beta dose from adjacent E must be included (see discussion below). Use of a layer thickness significantly larger than 2 mm for input into ROSY can result in minor variations (at the 1% level) in the beta doses calculated by ROSY, arising from numerical roundoff errors and approximations in the calculation algorithm when very thick layers are involved.

SCED (Figure 1D): A beta-thin C layer is external to E. This layer acts as a partial absorber of beta particles from S, and also generates a beta dose which is computed by ROSY from its U concentration and thickness.

SES (Figure 1E): A special case in which the enamel has been completely isolated from the other layers of the tooth. For age calculations one must assume this has been true for virtually all of the burial history. In this case, with the thicknesses of both the C and D layers being zero, the sediments provide the entire external beta dose.

Data input is more complex for cases where internal dentine layers (such as those in Figs. 1B, C, D) or an internal cementum layer (as in Fig. 1C) are not a full 2mm thick. In these cases, the actual sources of external beta dose to the dated enamel are in a set of multiple tissue layers such as cementum (or dentine) plus the next nearest neighbour enamel layer. Here the problem is that ROSY input needs to reflect the fact that the C+E or D+E layer of approximately 2mm thickness has a mixed composition.

The soundest approach is to use ROSY to model an interior sequence such as $E_1CE_2DE_3$ (with the E_2 layer being dated) by using the five layers in a ROSY SCEDS sequence and replacing the "sediment" parameters with parameters appropriate to the layers E_1 and E_3. This requires the assigned parameters of those two enamel layers to be identical, and a gamma dose rate now has to be entered separately into ROSY (as the sediment source concentrations are no longer available for use). If the combined thickness of E_1C or DE_3 is not beta-thick, then even this approach will be approximate.

A less satisfactory approach would be to input parameters for the C and D layers in ROSY which reflect averages for any composite C+E or D+E layers. However, if the C and/or D layers in the composite layers are U-rich, simple averaging of the bulk composition of the composite layer would not reflect the fact that the largest part of the beta dose received by the enamel emanates from the portion nearest the enamel. If a C or D layer is at least one mm thick, treating the composite layer as if it were fully C or D would be more accurate than using a simple average.

Alpha radiation doses from the external radiation sources (and also the gradient in the internal alpha dose near the edges of the enamel) can be removed by stripping a thin layer off each side of the enamel. Stripping of at least 40 micrometer from each side is recommended to accomplish this.

While the terminology used for the layers in ROSY is specific to the context of dating tooth enamel, the approach is valid for any geometrically similar problem involving adjacent planar homogeneous layers of different materials. ROSY can be used in such situations by simply assigning new meanings to the built-in titles "sediment", "cementum", "enamel", and "dentine", as in the discussion for internal layers above, and adjusting the compositions of media accordingly.

3. Data input

For the range of environments discussed above, ROSY calculates the dose to the stripped tooth enamel layer, and solves for the age consistent with the observed D_E using different uptake models. The compositions (including water content) of all media and the thicknesses of the enamel, cementum and dentine layers may be varied. Age estimates are calculated assuming early and linear U uptake (see, for instance, Grün *et al.*, 1987) in all tooth tissues, and also for a user-changeable combination in which either early or linear uptake may be chosen separately for each tooth tissue. The defaults for this combination are early uptake in enamel and linear uptake in dentine and cementum.

ROSY gives the user the options of reading input data from a file or using default data and it is then possible to make changes to these data. The first menu screen, a typical example of which is shown in Figure 2, displays and handles changes for various parameters (and their errors where appropriate). The parameters on this screen include those defining the geometry, water composition, and radioactive source concentrations for all media, other data relating to the dosimetry, and parameters specific to the enamel material used as a dosimeter.

Since the program is written in FORTRAN 77 for an MS-DOS screen, the screen interaction is not sophisticated, but an easy sequence of mainly letter-based keystrokes and returns invokes appropriate prompts, enabling straightforward alteration of any parameter or its error. The parameters are displayed in lines on the screen and parameters on each line may be altered on entering the alphabetic character at the left of that line. Prompts and messages appear at the bottom of the screen. The input screen is then updated to await requests for any further changes. It is intended that reading the prompts and messages will provide a self-explanatory route through the program, so that a detailed user instruction manual is not required. Explanatory comments relating to some of the parameters follow.

Concentrations of radioelements in sediment or tooth are given as ppm U, Th, and weight percent K, as fractions of the dry material. The density of the dental tissues and sediment can be user-defined. The default values of density for enamel, cementum and dentine are the average values found by Rink and Hunter (1998) for fossil teeth.

The assumptions and methodology used in alpha dose calculations are detailed in the section on dose calculations. The input value for alpha efficiency is taken to be the *k* value for the entire track length of an alpha particle at reference energy 5.3 MeV, which was the alpha energy used by de Canniere *et al.* (1986) in obtaining a *k* value of 0.15 for tooth enamel.

Four options are available for gamma and cosmic ray dose rates in ROSY Version 1.4:

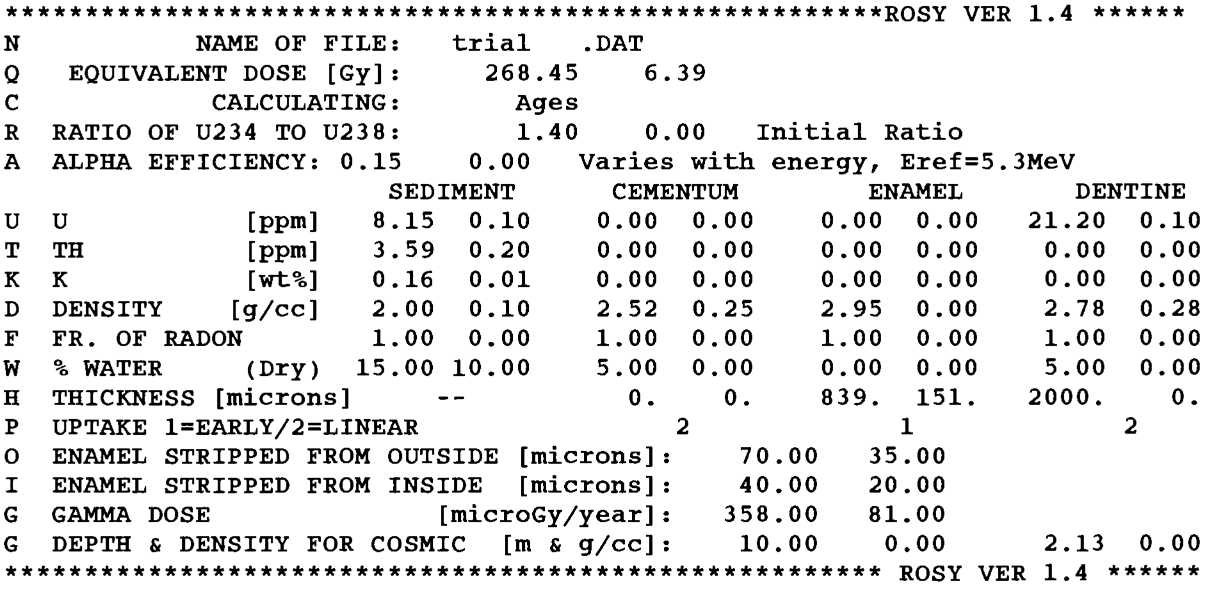
1) The combined total dose rate may be specified;
2) the gamma dose rate may be specified, with the cosmic dose rate being calculated by ROSY using input values for depth and density of overburden;
3) the cosmic dose rate may be specified, with the gamma dose rate being calculated by ROSY using the sediment U, Th and K concentrations for the latter; and
4) the user may request ROSY to calculate both the cosmic ray and gamma dose rates.

Figure 2 shows an example using the second of these options. Note that if the sediment concentration values used are atypical and reflect only the material within about 2mm of the tooth (for the purpose of accurate beta dose calculations), a value for gamma dose will need to be supplied. In other situations, allowance may need to be made for the presence of significant quantities of non-sedimentary material around the dated material. This can modify the sediment infinite-matrix gamma dose rate (see Rink *et al.*, 1996, for an example involving an elephant tooth encased in a mandible).

A second menu screen prompts in a similar fashion for changes to the 'dry' composition by weight of each medium, using a limited range of elements (H, C, N, O, Na, Mg, Al, Si, P, S, Cl, K, Ca, Fe, Zn). The starting compositions are those read in from the input file, or default compositions if no input file is used. On exit from this second menu screen, ROSY revises the composition of each medium including the water content specified on the first menu screen.

This water content may be specified as a percentage of the dry mass of the medium or of the mass of the wet medium.

Since these compositions are used exclusively for computing interaction cross-sections and/or ranges, there is freedom on the second menu screen to group elements with similar atomic masses in representing the composition. Consistent with this approach, note that the content of (natural) potassium entered in the first menu screen, used to calculate K-40 activity, and the potassium content entered for a medium in the second menu screen do not have to be identical.



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*******************************************************ROSY VER 1.4 ******
N           NAME OF FILE:   trial    .DAT
Q   EQUIVALENT DOSE [Gy]:     268.45    6.39
C            CALCULATING:       Ages
R  RATIO OF U234 TO U238:       1.40    0.00   Initial Ratio
A  ALPHA EFFICIENCY: 0.15    0.00   Varies with energy, Eref=5.3MeV
                        SEDIMENT      CEMENTUM        ENAMEL       DENTINE
U  U           [ppm]   8.15  0.10    0.00  0.00    0.00  0.00   21.20  0.10
T  TH          [ppm]   3.59  0.20    0.00  0.00    0.00  0.00    0.00  0.00
K  K           [wt%]   0.16  0.01    0.00  0.00    0.00  0.00    0.00  0.00
D  DENSITY    [g/cc]   2.00  0.10    2.52  0.25    2.95  0.00    2.78  0.28
F  FR. OF RADON        1.00  0.00    1.00  0.00    1.00  0.00    1.00  0.00
W  % WATER     (Dry)  15.00 10.00    5.00  0.00    0.00  0.00    5.00  0.00
H  THICKNESS [microns]      --          0.    0.     839.  151.   2000.     0.
P  UPTAKE 1=EARLY/2=LINEAR                2             1             2
O  ENAMEL STRIPPED FROM OUTSIDE [microns]:    70.00   35.00
I  ENAMEL STRIPPED FROM INSIDE  [microns]:    40.00   20.00
G  GAMMA DOSE              [microGy/year]:   358.00   81.00
G  DEPTH & DENSITY FOR COSMIC  [m & g/cc]:    10.00    0.00      2.13  0.00
******************************************************* ROSY VER 1.4 ******
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Please enter the letter corresponding to the parameter you want to change.
To change an error value, type E, press return and enter the letter corresponding to the error you want to change.
If you enter any other character, this data will be used for calculations.

Figure 2. A typical example of the first menu screen for data input to ROSY, Version 1.4. All relevant parameters apart from the media compositions are changed using this screen. The format of the line(s) labeled "G" varies with the option selected by the user.

4 Data output:

Once changes to compositions are complete, the user is given the option when calculating age estimates of including the error estimate. The computation time is then a little longer, but with a Pentium CPU the time penalty is negligible.

When ROSY is used to calculate ages (the usual mode), the results for each uptake model in the output file consist of the calculated dose (equal to the equivalent dose), the age estimate and its error estimate, a table showing a breakdown of average dose rates, the average (alpha plus beta) dose rate, and the average total dose rate. The table lists average annual dose rate components by type (alpha, beta, gamma, cosmic), and, where appropriate within each type, by source medium (enamel, cementum, dentine, sediment) and by radiation parent (U, Th, K, total). A briefer summary is written to the screen.

The user is allowed to calculate either the ages consistent with the equivalent dose for each uptake model ('Ages' option) or the dose rates for specified ages ('Dose rates' option). It would be usual to use the 'Ages' option, but the 'Dose rates' option can be useful to make comparisons (e.g., with other age algorithms) or to test variation of any component of the dose with time.

5 Dose calculations

Version 1.4 uses the data of Adamiec and Aitken (1998) on half-lives, energies, and branching ratios as the primary data for ROSY calculations. By comparison with the previously used data of Nambi and Aitken (1986), the most significant adjustments to infinite matrix dose rates, all downwards, occur for beta and gamma doses from the Th-232 series (-4.4% and –8.3%) and for beta doses from K-40 (-4.1%). In the specific context of dating tooth enamel, these are rarely major contributors to the total average dose rate, and the effect on an age estimate is not likely to exceed 2%.

Age estimates for each uptake model are obtained by finding the zero in the difference between the calculated total dose and the input equivalent dose as a function of time. For a given trial age and uptake model, ROSY first computes the total number of decay events per unit volume for each radioactive source in each medium. This computation allows for changes in U concentration associated with the style of uptake in D, C, and E (but not in S) and for the corresponding changes in activity as a result of approach of the U-series isotopes to secular radioactive equilibrium (as in Grün *et al.*, 1987). The decay event densities are then used to calculate the average total dose at the trial age to the enamel remaining after stripping. Using standard numerical techniques, the trial age is varied until the calculated dose matches the equivalent dose to within one part in a million.

At the completion of each age estimate, ROSY checks the implied initial ratio for the activities of U-234 and U-238 in the tooth tissues (a constant ratio of unity is assumed for the sediments). If this ratio is less than 0.6 or greater than 8.0, the initial ratio is set equal to 0.6 or 8.0 as appropriate, the age is calculated on that basis, and an error message is printed warning that the age estimate is invalid. For older samples, such unrealistic ratios can result when the user selects the option to specify the present activity ratio and this is then extrapolated back in time using the uptake model in question. Specification of the initial ratio or of a present ratio closer to unity may be required to yield a 'valid' age. If the present ratio used is based on sample data, the invalid age may reflect fluctuations in uranium mobility and uptake over the age of the sample which cannot be modelled accurately with ROSY.

Alpha dose

Version 1.4 of ROSY calculates the effective alpha dose on the assumption that the alpha-induced signal is proportional to the *track-dose*, that is, to the deposited *effective track length* per unit volume. The calculation uses an algorithm based on the approach of Aitken (1987) to model the gradient in track dose near a boundary of the enamel layer. This approach is accurate where the amount stripped off each side of the enamel is small or zero, and yields the expected infinite matrix dose when more than 40 micrometer is stripped off each side.

The effective track length is less than the actual track length because the final portion of an alpha track (AT_F) yields very little signal, despite the large amount of energy deposited on average in this ineffective portion of the track. In ROSY calculations, the effective track length of an individual alpha particle (in units of density times distance) is set equal to the actual track length minus a proxy value of AT_F (0.875 mg cm^{-2}), which is the experimental value of Lyons and Brennan (1989) for ESR in calcite. No direct measurement of AT_F for tooth enamel is available. As mentioned above, the input value to ROSY for alpha efficiency is the k value for the entire track length of a 5.3 MeV alpha particle. Alphas of this energy coincidentally have an effective track length which is almost exactly the average value for alphas from natural uranium. Because track dose is used in the calculation, the k value for an individual alpha depends on the alpha energy

TRIM data (Ziegler *et al.*, 1985) for the ranges of the natural and reference alpha energies in the elements are incorporated in ROSY, and the specified elemental compositions of the materials are used to estimate the ranges of these alphas for each material. For each alpha energy, the reciprocal of the range in each element is taken as a proxy for the average stopping power for that element, and the range in the material is obtained by computing the weighted sum of these proxies and then taking the reciprocal of that sum. This straightforward technique copes with arbitrary variations in the compositions of all materials, but it is approximate, being exact only if the variation of stopping power with energy is of the same form for all elements. However, comparison with TRIM results for a range of feasible compositions indicates that the ROSY range estimates are accurate to at worst 1%. The consequent error in the alpha dose to a layer would be dwarfed by other uncertainties, such as in the alpha effectiveness.

The alpha dose to the enamel remaining after any stripping is then calculated using the approach of Aitken (1987). However, as opposed to Aitken (1987), we use the effective track length in place of the track length itself. In effect, the track dose is the enamel infinite matrix dose rate, less any track dose deficit resulting from the escape of internal alpha particles, and plus any track dose deposited in the enamel from external sources. Grün (1987) applied Aitken's original formulation in a similar fashion to the external alpha irradiation of a calcite layer.

It is straightforward to show that equations such as (3), (4) and (6) of Aitken (1987) apply also where an inert layer is irradiated by alpha sources in an adjacent but different medium. The assumptions of these results are that the alpha-induced signal is proportional to the deposited effective track length, that all alpha tracks are straight, and that the ratio of the ranges of an alpha particle in the two adjacent media is a constant independent of the alpha energy. Departures from these assumptions in practice are not expected to result in large errors in the alpha dose estimate for the layer.

Beta dose

The mathematical basis for the application of one-group theory to beta dosimetry near planar interfaces is summarised in Prestwich *et al.* (1997), and briefer qualitative descriptions are to be found in Yang *et al.* (1998) and Brennan *et al.* (1997). The reader is referred to these papers for detail. In applying one-group theory, which was originally developed for modelling neutron transport, the complex interaction with media of betas from the spectrum of a beta emitter is modelled by considering a single group of electrons all with the mean energy. These interact via a combination of isotropic elastic scattering and complete absorption of part of each beam. The absorption cross section is taken to be the ratio of the stopping power to energy, evaluated at the average energy, and the scattering cross section is taken to be the Lewis transport cross section. Boundary conditions are imposed at interfaces to ensure continuity of electron flux in each direction. The theory shows reasonable agreement with experimental data on beta dose gradients in planar geometry (O'Brien *et al.*, 1964 and Yang *et al.*, 1997) and with theoretical results based on Monte Carlo simulations (Brennan *et al.*, 1997).

The work of Brennan *et al.* (1997) and Yang *et al.* (1998) shows that the approach based on one-group theory yields better estimates of average beta doses than other software used in ESR and TL dating for planar geometry. However, as mentioned in the introduction, the theory is based on *ad hoc* and entirely hypothetical assumptions and the results are necessarily approximate. For these reasons, use of Monte Carlo-based data would be preferable and the complex process of properly incorporating such data in a future version of ROSY is proceeding.

Gamma and cosmic ray doses

When calculating the gamma dose from the sediment source concentrations, ROSY estimates the infinite matrix gamma dose rate using the data of Adamiec and Aitken (1998). The estimate includes the factor given by Equation (4.7) of Aitken (1985), which allows for the enhanced mass absorption coefficient of the hydrogen-rich water. Situations where this infinite matrix estimate may not be appropriate have been mentioned in the previous section.

For cosmic dose rates, version 1.4 of ROSY uses equation (2) of Prescott and Hutton (1994) with the addition of a term that approximates the 'soft' component of the cosmic dose for very shallow burial depths. However, it should be noted that the formula used assumes level terrain at sea level and a latitude of 55°. Users may prefer to input their own cosmic ray dose rate estimate to ROSY. Graphs of parameters used in adjusting for latitude and altitude are displayed in Figure 2 of Prescott and Hutton (1994).

Error estimates

Errors in age estimates are calculated on the assumptions that the errors in individual parameters are independent of one another and that the input errors in parameters represent symmetric random errors and are estimates of standard deviation. Each input parameter is varied up and down by one standard deviation, the age estimate is recalculated and the variation is used to estimate the contribution of that parameter to the variance of the age. Where a parameter has an error that matches or exceeds the assigned value of the parameter (including the case of a parameter with an assigned value of zero, but with a non-zero error), a "one-sided" estimate of the error contribution is made.

6 Conclusion

The ROSY dating program provides a flexible tool for calculating ages and dose rates in situations involving planar geometry with up to three adjacent layers embedded in a sediment matrix. The user has considerable freedom to vary many parameters, including the compositions of all the media. In version 1.4, effects associated with dose gradients near boundaries for both alpha and beta radiation are modelled effectively, with these gradients extending to approximately 2mm for the beta dose and 40 micrometer for the alpha dose. ROSY provides more accurate estimates of dose rate, and thus in principle of age, than other software packages appropriate to planar geometry. The improvement mainly reflects the use of one-group theory in calculating beta doses.

As mentioned above, beta dose estimates can be made more accurate still with the proposed incorporation of data using dose-point-kernels based on Monte Carlo calculations. Another procedure being developed for ROSY will extend the range of uptake models to include coupled ESR and U-series data (Grün *et al.*, 1988). In principle, the sample age and uptake model parameters can be estimated simultaneously by fitting data on uranium series activity ratios as well as the equivalent dose (see for instance Schwarcz and Grün, 1993; Monigal *et al.*, 1997). This procedure can remove the restriction of age estimates to early and linear uptake (or combinations of early and linear uptake in different materials). We note that the ROSY calculations in this approach will provide a better beta dose estimate than was previously available. This ROSY approach is currently being applied to three sites in the Crimea, which form a significant set of U-series and ESR results where ^{14}C control is available (Rink *et al.*, 1998). Modification of ROSY to provide a more convenient user interface in a WINDOWS environment is also intended.

Prospective users of ROSY may obtain a copy of the latest version by contacting Lynn Falkiner at the McMaster University address of WJR and HPS, preferably by email to falkiner@mcmaster.ca.

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Comments
It is unfortunate that the authors still use Fortran 77, which was a great at its release in 1977, but has outlived its use-by date by a great number of years. Reasonable graphic interfaces can be created by any more recent Fortran editor. The main reason for not using ROSY is the clumsiness of data inputs compared to a program such as DATA. However, this should not serve as an excuse to promote a scientifically outdated program (i.e. DATA).