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Paper No. 4020 *e*-Ship++: A cloud-based radiological transport assistant

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Abstract

e-Ship++ (electronic Shipment) is a cloud-based application for calculating radiological characteristics of packages for the shipment of radioactive material in accordance with ADR/IATA/IAEA transport regulations. It has been developed in collaboration between CERN and Nucleonica. In contrast to traditional offline software packages, there is no software to install. *e*-Ship++ requires only an internet connection and browser and is accessible through the Nucleonica science platform (www.nucleonica.com) from any computer worldwide. The product is aimed at governmental institutions, research organizations, universities, and private companies involved in the transport of radioactive materials.

In this paper a detailed description of the various features of *e*-Ship++ are given. Users can create, edit, import, store / archive their packages in *e*-Ship++. In addition, a number of sample packages are provided for training and demonstration purposes. For each package, a radioactive material transport report is generated giving the source characterization and type of package required.

A key feature is the possibility to follow the decay a package mixture. The activity reported at a particular date can be updated to any future date and the decayed mixture can be saved as a new package.

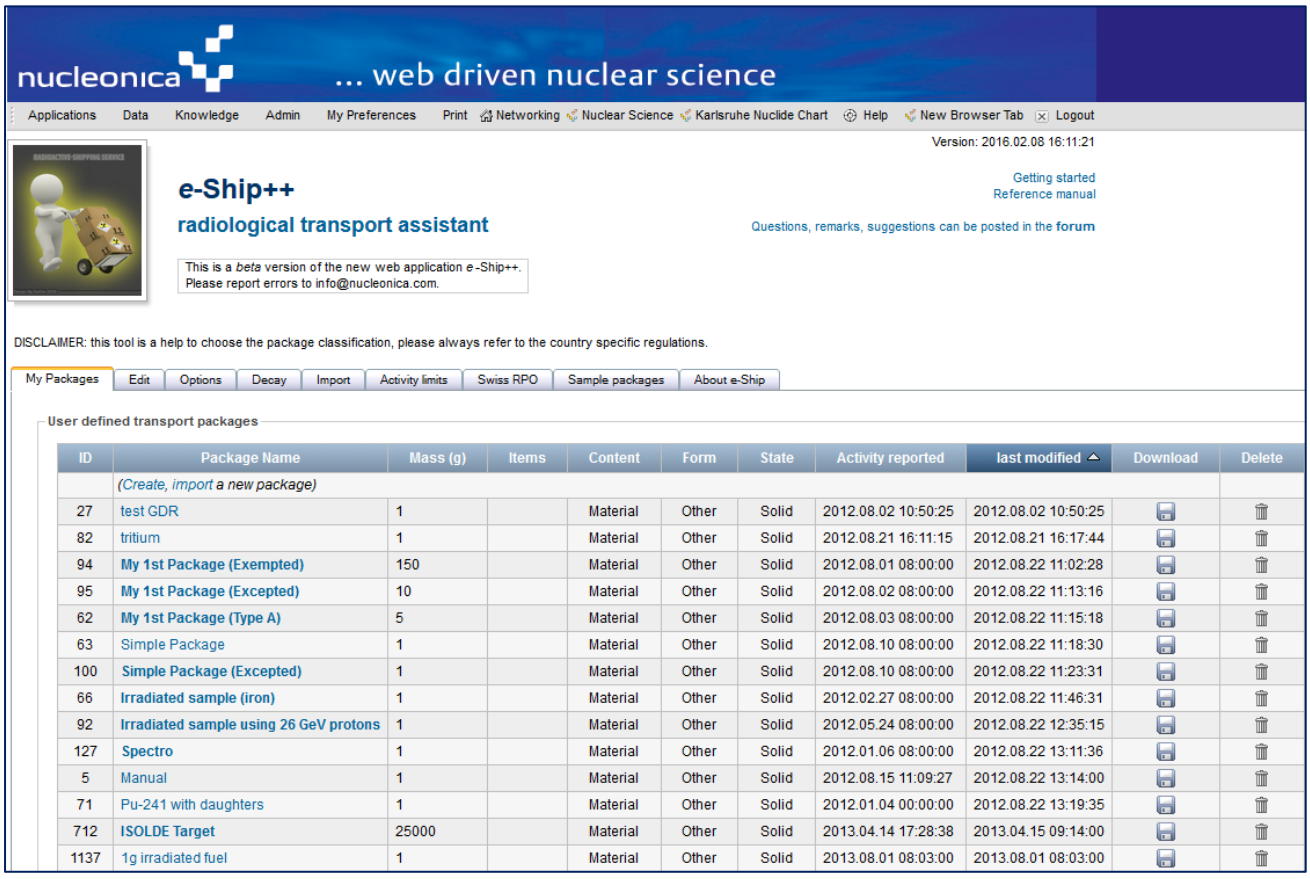
Introduction

Each year about 10 million packages of radioactive materials are transported worldwide by land, sea and air. Radionuclides are used for a variety of purposes e.g. in nuclear medicine, nuclear industry, materials testing, oil exploration etc. For these purposes radioactive materials must be packaged and transported to the location of interest. Before these materials can be shipped, care must be taken that the shipping regulations have been strictly followed. The purpose of these regulations, of course, is to ensure safety by containing the radioactivity to make sure that there is no negative effect on the environment, to control the radiation emitted from the package, make sure that nuclear fission criticality conditions cannot be met, and to dissipate any heat generated within the package.

For package classification purposes in accordance with the transport regulations, however, the application of the IAEA Transport Code is complex, can be confusing and open to interpretation, and it is relatively easy to introduce errors. To address these problems, the software tool *e*-Ship was

developed at CERN to assist in the classification of packages for the large number of radioactive sources transported annually. To make this software tool more user-friendly, versatile, resilient and widely available, a collaboration agreement was made between CERN and Nucleonica GmbH in 2012 to transform the *e*-Ship software into a modern cloud-based application within the Nucleonica nuclear science platform (www.nucleonica.com). In addition to the transport regulations, *e*-Ship++ provides information on radiation protection which allows the user to estimate the radiological impact of the shipment in the event of a release of radioactivity into the environment. For this purpose, data such as the ICRP 72 inhalation dose, ingestion dose, external radiation dose etc. are provided. Additionally, quantities such as the Swiss radiation protection authorization limits and exemption limits are also included.

In this paper a detailed description of the *e*-Ship++ cloud based software application is given. The main user interface for the *e*-Ship++ application is shown in fig. 1 below. The main features of the application are contained in the grid tabs i.e. My Packages, Edit, Options, Import, Activity limits, Sample packages.



ID	Package Name	Mass (g)	Items	Content	Form	State	Activity reported	last modified	Download	Delete
	(Create, import a new package)									
27	test GDR	1		Material	Other	Solid	2012.08.02 10:50:25	2012.08.02 10:50:25		
82	tritium	1		Material	Other	Solid	2012.08.21 16:11:15	2012.08.21 16:17:44		
94	**My 1st Package (Exempted)**	150		Material	Other	Solid	2012.08.01 08:00:00	2012.08.22 11:02:28		
95	**My 1st Package (Excepted)**	10		Material	Other	Solid	2012.08.02 08:00:00	2012.08.22 11:13:16		
62	**My 1st Package (Type A)**	5		Material	Other	Solid	2012.08.03 08:00:00	2012.08.22 11:15:18		
63	Simple Package	1		Material	Other	Solid	2012.08.10 08:00:00	2012.08.22 11:18:30		
100	**Simple Package (Excepted)**	1		Material	Other	Solid	2012.08.10 08:00:00	2012.08.22 11:23:31		
66	**Irradiated sample (iron)**	1		Material	Other	Solid	2012.02.27 08:00:00	2012.08.22 11:46:31		
92	**Irradiated sample using 26 GeV protons**	1		Material	Other	Solid	2012.05.24 08:00:00	2012.08.22 12:35:15		
127	**Spectro**	1		Material	Other	Solid	2012.01.06 08:00:00	2012.08.22 13:11:36		
5	Manual	1		Material	Other	Solid	2012.08.15 11:09:27	2012.08.22 13:14:00		
71	Pu-241 with daughters	1		Material	Other	Solid	2012.01.04 00:00:00	2012.08.22 13:19:35		
712	**ISOLDE Target**	25000		Material	Other	Solid	2013.04.14 17:28:38	2013.04.15 09:14:00		
1137	1g irradiated fuel	1		Material	Other	Solid	2013.08.01 08:03:00	2013.08.01 08:03:00		

Figure 1: My Packages tab showing list of packages and their characteristics

e-Ship++ Technical Documentation

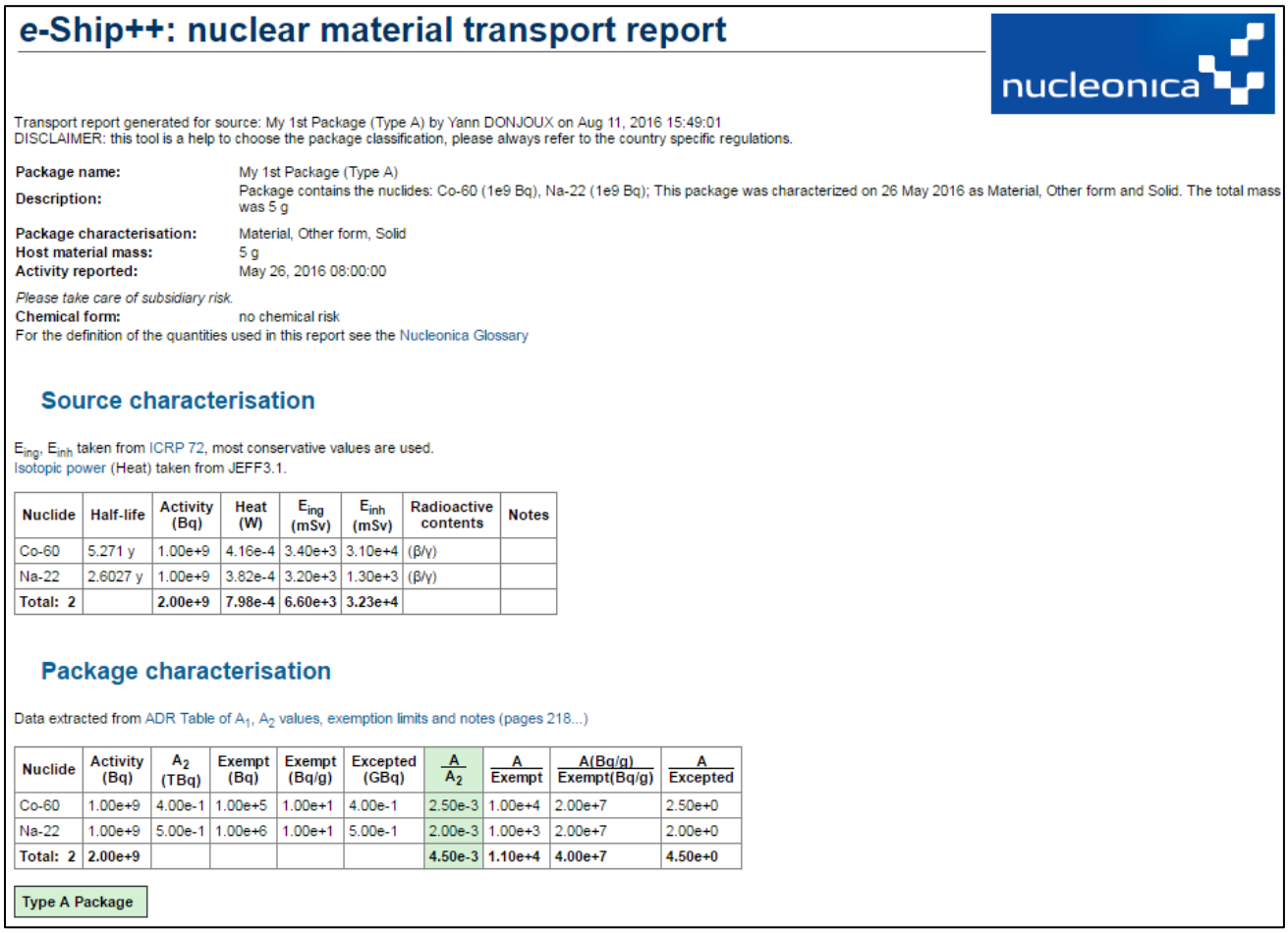
The full technical documentation for *e*-Ship++ is available online in Nucleonica's Wiki help page [1]. It can be accessed by clicking on the Help button in the taskbar in fig. 1. The page contents listing the table of contents is shown in fig. 2.

Figure 2: Technical documentation for *e*-Ship++ is available online via Nucleonica's Wiki help page.

A detailed manual can also be found on CERN EDMS server [2].

Nuclear Material Transport Report

The goal of the software is to provide a summary view for package characterisation, called transport report which can be downloaded in pdf format. See fig. 3:



e-Ship++: nuclear material transport report

nucleonica

Transport report generated for source: My 1st Package (Type A) by Yann DONJOUX on Aug 11, 2016 15:49:01
DISCLAIMER: this tool is a help to choose the package classification, please always refer to the country specific regulations.

Package name: My 1st Package (Type A)
Description: Package contains the nuclides: Co-60 (1e9 Bq), Na-22 (1e9 Bq); This package was characterized on 26 May 2016 as Material, Other form and Solid. The total mass was 5 g

Package characterisation: Material, Other form, Solid
Host material mass: 5 g
Activity reported: May 26, 2016 08:00:00

Please take care of subsidiary risk.
Chemical form: no chemical risk
For the definition of the quantities used in this report see the Nucleonica Glossary

Source characterisation

E_{ing}, E_{inh} taken from ICRP 72, most conservative values are used.
Isotopic power (Heat) taken from JEFF3.1.

Nuclide	Half-life	Activity (Bq)	Heat (W)	E_{ing} (mSv)	E_{inh} (mSv)	Radioactive contents	Notes
Co-60	5.271 y	1.00e+9	4.16e-4	3.40e+3	3.10e+4	(β/γ)	
Na-22	2.6027 y	1.00e+9	3.82e-4	3.20e+3	1.30e+3	(β/γ)	
Total: 2		**2.00e+9**	**7.98e-4**	**6.60e+3**	**3.23e+4**		

Package characterisation

Data extracted from ADR Table of A_1, A_2 values, exemption limits and notes (pages 218...)

Nuclide	Activity (Bq)	A_2 (TBq)	Exempt (Bq)	Exempt (Bq/g)	Excepted (GBq)	$\frac{A}{A_2}$	$\frac{A}{Exempt}$	$\frac{A(Bq/g)}{Exempt(Bq/g)}$	$\frac{A}{Excepted}$
Co-60	1.00e+9	4.00e-1	1.00e+5	1.00e+1	4.00e-1	2.50e-3	1.00e+4	2.00e+7	2.50e+0
Na-22	1.00e+9	5.00e-1	1.00e+6	1.00e+1	5.00e-1	2.00e-3	1.00e+3	2.00e+7	2.00e+0
Total: 2	**2.00e+9**					**4.50e-3**	**1.10e+4**	**4.00e+7**	**4.50e+0**

Type A Package

Figure 3: Radioactive Material Transport Report

This transport report provides at a glance all useful information for shipment, together will all isotopes inserted in the package :

- Classification according to IAEA regulations and associated calculations;
- But also radiation protection data like Heat, E_{ing}, E_{inh} according to ICRP 72

Once a mixture has been defined, e-Ship++ allows you to enter full details for the package (name, chemical risk if any, description, …) as described on fig. 4. Also shown is the Activity reported together with a date picker. This allows the user to specify the date and time at which the activity was reported (e.g. from gamma spectrometry measurements). To the right the package characteristics are shown e.g. Content (Material, Instruments/Articles), Form (Special or Other) and State of the material (Solid, Liquid, Gas) together with the Host material mass.

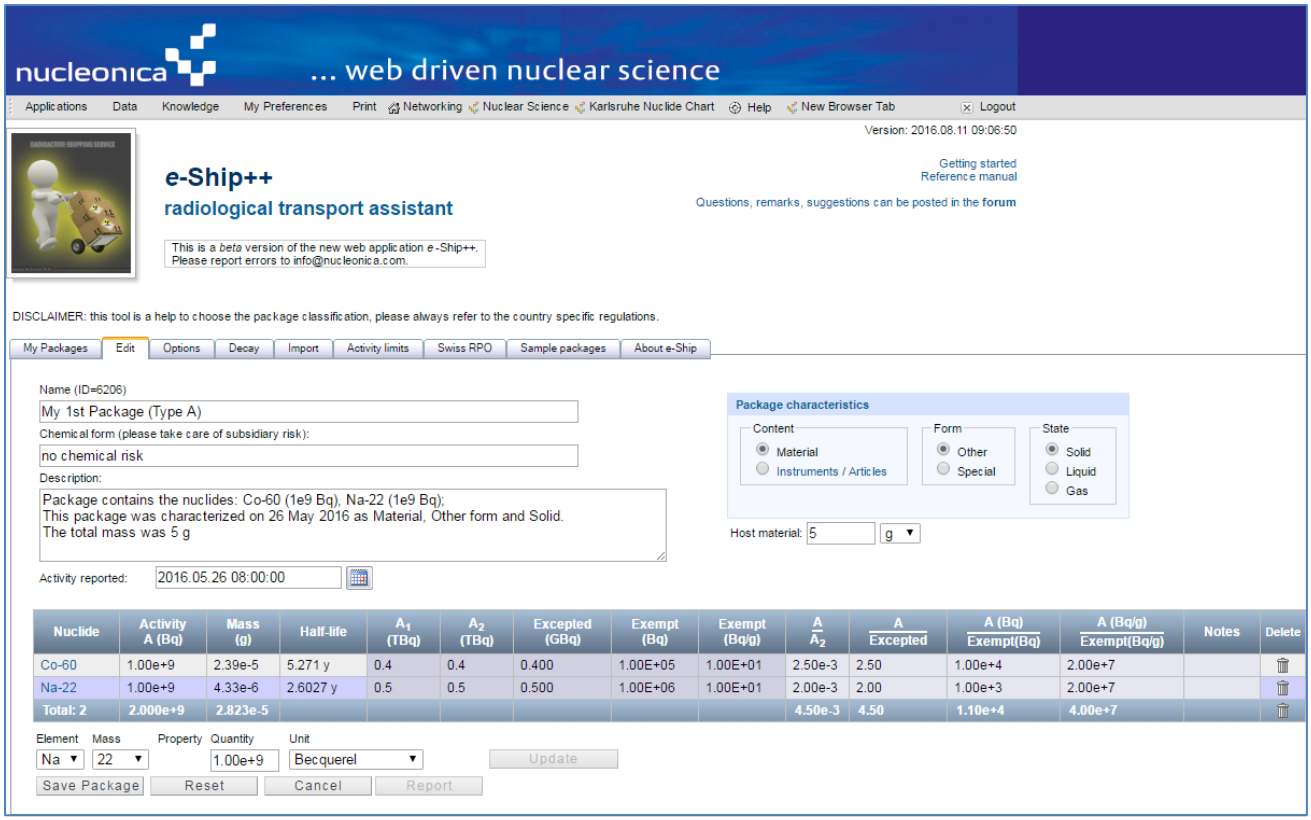


Figure 4: Edit tab showing how to create a package

The full list of quantities shown in the grid is given in more detail in the User Manual [2]. Quantities can be added or removed from the grid using the check buttons in the Options. In particular, The **Swiss Radiation Protection Ordinance** (RPO) [3] values are included in the Options to be used to estimate the radiological impact of the shipment in the event of a release of radioactivity into the environment. These are not necessary for radioactive material transportation but are nevertheless useful general quantities for radiation protection. **ICRP** data can be relevant to the individual nuclides such as:

- E_{ing}(mSv): the committed effective dose equivalent for ingestion. This depends both on the nuclide activity and the dose coefficient through the relation: $E_{ing}(Sv) = e_{ing}(Sv/Bq) \cdot A(Bq)$
- E_{inh}(mSv): the committed effective dose equivalent for inhalation. This depends both on the nuclide activity and the dose coefficient through the relation: $E_{inh}(Sv) = e_{inh}(Sv/Bq) \cdot A(Bq)$

It is also possible to calculate the gamma dose rate for the radioactive contents of the package and to show this in the grid in fig. 3 (for example to calculate the dose rate at 10 cm from the unshielded source or at the surface of the possibly shielded package). The underlying algorithm is the one from Nucleonica's Dosimetry & Shielding++ application. This allows the calculation of the gamma dose rates from point sources of single nuclides and nuclide mixtures. All known gamma lines and emission

probabilities for the nuclide(s) are accounted for in the calculation as is the build-up factor. The gamma dose rate is calculated at any distance from the source for a given shielding material and thickness and these can be specified as shown in fig. 5. The threshold energy can also be set. Dose contributions for daughters can also be included. For more information, the reader should refer to Nucleonica's Dosimetry & Shielding wiki [4].

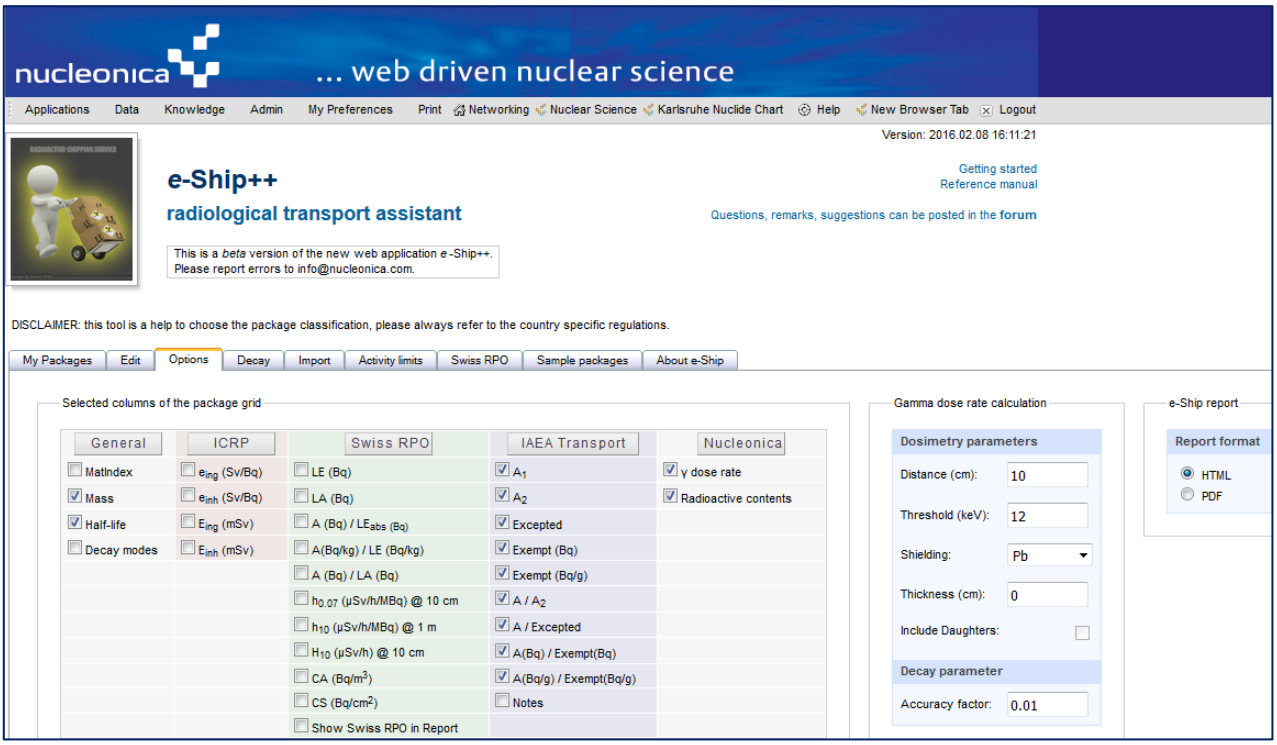


Figure 5: Options tab for displaying quantities in the Edit grid

When a nuclide is selected using the drop-down menus and updated in the grid, the Activity limits (given in the Activity limits tab) are taken form the ADR and inserted into the grid (e.g. Co-60 in fig. 6). One key feature of e-Ship++ is that the drop-down menu contains not only artificial radionuclides but some natural radioelements. This is the case for rhenium, rubidium, thorium and uranium as shown in fig. 6. For uranium, the user can select depleted, natural, or enriched (<20%) uranium.

In some cases the values given in the grid do not refer to the given nuclide itself but include also contributions of daughter nuclides with half-lives less than 10 days: these nuclides are marked with note (a). In some other cases the whole decay tree in equilibrium with the nuclide is taken into account: such nuclides are marked with the note (b) (e.g. Cs-137 in fig. 6).

For some nuclides, information on their physiological properties are given e.g. slow, medium, or fast lung absorption. The chemical form is specified in the Notes column. Isomers are usually identified through the isomer state m, n etc. or also using the half-life as criterion e.g. e.g. short- or long-lived Np-236 as shown in fig. 6.

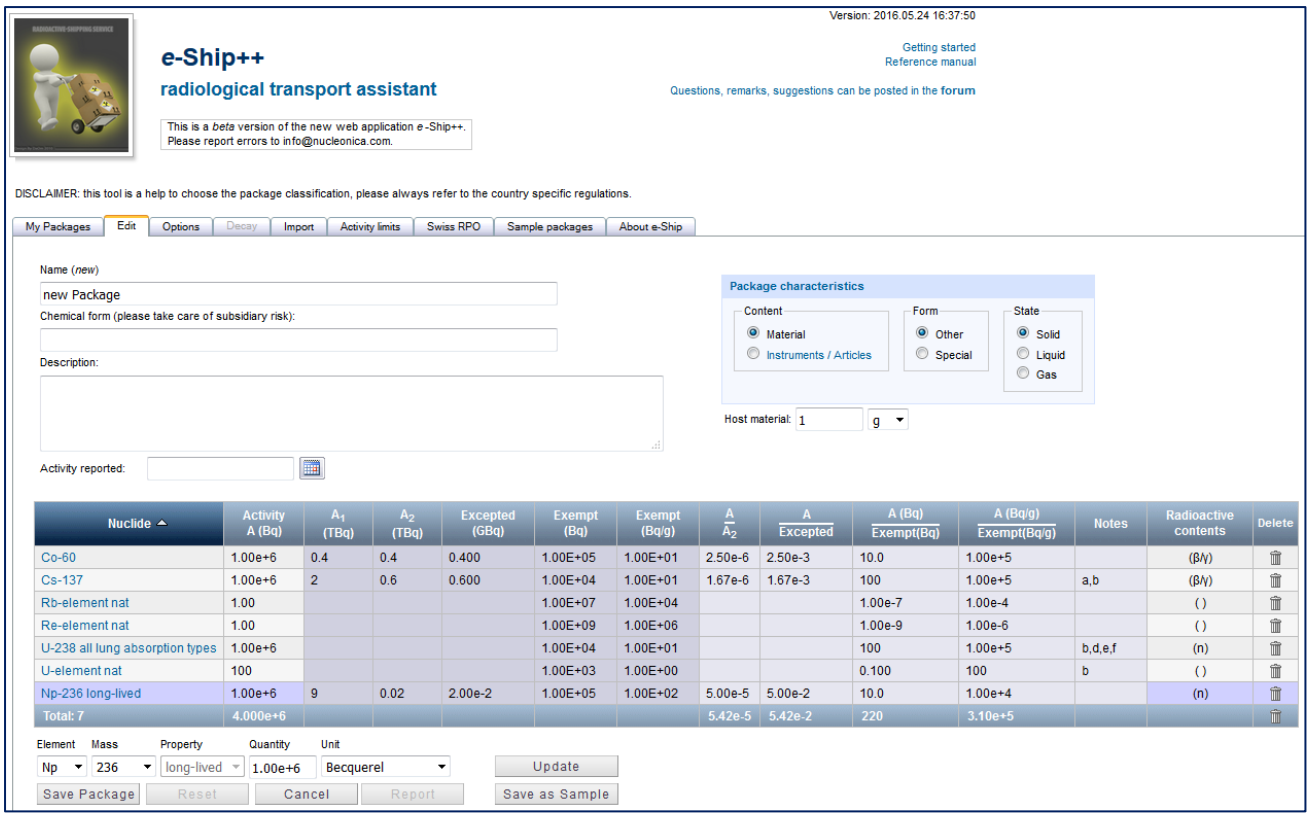


Figure 6: Edit tab mask for the creation of a new package

Classification of a mixture

If A_i is the activity of the nuclide *i* of a mixture, the total activity A_{total} of the mixture is given by:

$$A_{total} = \sum_i A_i$$

The derived quantities X_m of a mixture corresponding to the quantities A_1, A_2, exempt material or exempt consignment is defined by:

$$X_m = \frac{1}{\sum_i \frac{f(i)}{X(i)}}$$

where X(i) are the appropriate limits of A_1, A_2, exempt material, exempt consignment for each nuclide, f(i) being the activity ratio or activity concentration A_i/A_{total} of the nuclide.

The activity ratio of a mixture against the quantity limit X_m is given by the ratio of the two above quantities:

$$\frac{A_{total}}{X_m} = A_{total} \sum_i \frac{f(i)}{X(i)} = \sum_i \frac{A_{total} f(i)}{X(i)}$$

Replacing f(i) by its value:

$$\frac{A_{total}}{X_m} = \sum_i \frac{A_{total} \frac{A_i}{A_{total}}}{X(i)}$$

And simplifying by A_{total} (assumed different from 0) we get:

$$\frac{A_{total}}{X_m} = \sum_i \frac{A_i}{X(i)}$$

The formula is also verified in case $A_{total}=0$ which was discarded to allow simplification. These partial ratios are displayed in the corresponding columns of the edit-grid in *e*-Ship++ for each nuclide and summed together to obtain the ratios in the total row of the grid. These ratios computed for the mixture will finally determine the type of package to be used for the transport.

Radionuclide Values for Unknown Radionuclides

The procedure for determining the radionuclide values (i.e. A_1, A_2, Activity and Activity concentration limits) for unknown radionuclides is as follows:

1. In the Edit mask, add the nuclide of interest. If it is a "known nuclide" then the emitter type - α, β/γ, n - will be shown in brackets e.g. (α), (β/γ), (n) in the Report.
2. If it is an "Unknown nuclide", (i.e. not in the ADR/IATA list of known nuclides), the emitter type is shown without brackets e.g. α, β/γ, n. How the emitter type is determined is explained below.
3. Apply the rules given in the table in fig. 7 for beta/gamma, alpha, or neutron emitting nuclides to obtain the radionuclide values. The results are given in the columns A_1, A_2, Activity and Activity concentration limits in the Edit mask.

Radioactive content	A_1	A_2	Activity concentration limit for exempt material	Activity limit for an exempt *consignment*
	(TBq)	(TBq)	(Bq/g)	(Bq)
Only beta or gamma emitting nuclides are known to be present	0.1	0.02	1×10^{1}	1×10^{4}
Alpha emitting nuclides, but no neutron emitters are known to be present	0.2	9×10^{-5}	1×10^{-1}	1×10^{3}
Neutron emitting nuclides are known to be present or no relevant data are available	0.001	9×10^{-5}	1×10^{-1}	1×10^{3}

Figure 7: Radionuclide Values for Unknown Radionuclides [5]

Determination of the emission type of a nuclide

This is automatically computed by e-Ship++ upon selection of the nuclides through the following procedure and thank to the huge Nucleonica database:

1. Check if the nuclide or one of its daughter nuclide emits neutrons; if yes the nuclide is a neutron emitter, regardless of the quantity of emitted neutrons. (This information can be found in the Karlsruhe Nuclide Chart or in the Nuclide Explorer++ application in Nucleonica).
2. Otherwise get the nuclides of the decay chains until a nuclide with a half-life longer than 10 days or longer-lived than the parent is reached [6]. Such nuclides and their progenies will not be considered to determine the emission type of the parent. The remaining nuclides are considered in equilibrium with the parent. If the sum of the branching ratio products along the decay chains for alpha emission of these nuclides is greater than 0.1% the parent nuclide is considered as an alpha emitter [7].
3. Otherwise the nuclide is considered as a beta/gamma emitter.

Example:

- Dy-152 is a weak alpha emitter with an alpha branching ratio of 0.1% for alpha emission.
  Fig. 8 shows the decay chain of Dy-152. The daughter Tb-152 has a half-life longer that the parent and is thus not considered as belonging to the parent according to [6]. The second daughter Sm-148 has a half-life longer that the parent and should also not be considered as belonging to the parent for the same reason.

Nuclide	MatIndex	Activity A (Bq)	Mass (g)	Half-life
Dy-152	661520	7.22e+8	2.25e-9	2.38 h
Tb-152	651520	3.70e+7	8.49e-10	17.5 h
Gd-152	641520	1.62e-11	2.01e-11	1.1E14 y
Sm-148	621480	0	0	8.0E15 y
Nd-144	601440	0	0	2.3E15 y
Ce-140	581400	0	0	stable
He-4	20040	0	2.29e-14	stable
Total: 7		7.59e+8	3.12e-9	

Figure 8: Decay products of Dy-152.

In conclusion, Dy-152 can be considered as a separate nuclide. Dy-152 should not be considered as an alpha emitter for transport purposes but as a beta/gamma emitter with an A_2 of 20 GBq (rather than the 90 MBq for an alpha emitter). The branching ratio for alpha emission of 0.1 % is just at the limit of being considered as an alpha emitter.

Decay

e-Ship++ offers the possibility to follow the decay of the content of a transport package taking into account the special rules and conventions of the IAEA fig. 9. This feature allows the package composition to be monitored from the measurement date to the effective transport date as well as its evolution during the transport. The special rules from IAEA concern nuclides marked with the notes (a) and (b) in the IAEA activity limits table (the activity limits table is given in the tab Activity limits) where:

(a): A_1 and/or A_2 values include contribution from daughter nuclides with half-lives less than 10 days.

(b): Parent nuclides and their progeny included in secular equilibrium.

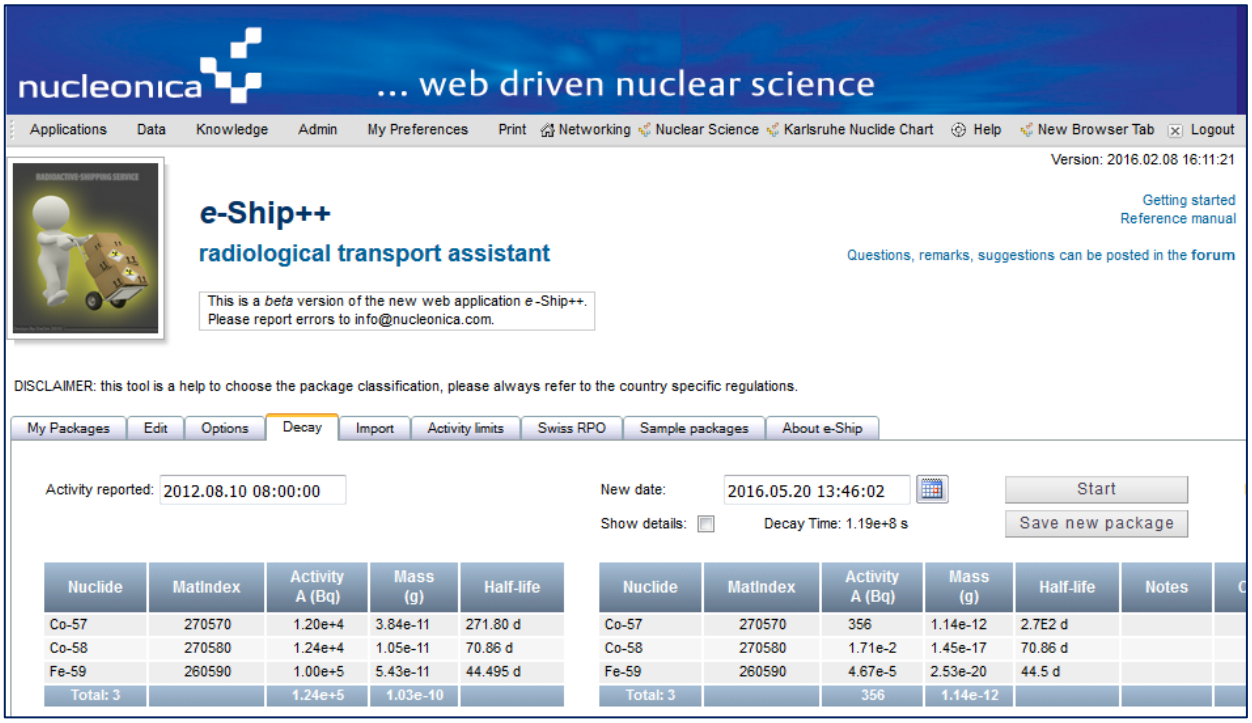


Figure 9: Decay tab for performing decay calculations [1]

Import/Upload

Users can upload their own nuclide datasets: some rules have to be observed for the data format in these files. At present the input format is kept as simple as possible. The following delimiters are allowed: Comma “,” Semicolon “;” Colon “:” Pipe “|” Octothorpe “#” TAB.

The files can be created for example in a spreadsheet, but must be saved as csv files. In the example shown in fig. 10, the nuclide name together with the nuclide activity is shown with a comma “,” as delimiter. Currently only the activity can be accepted as input.

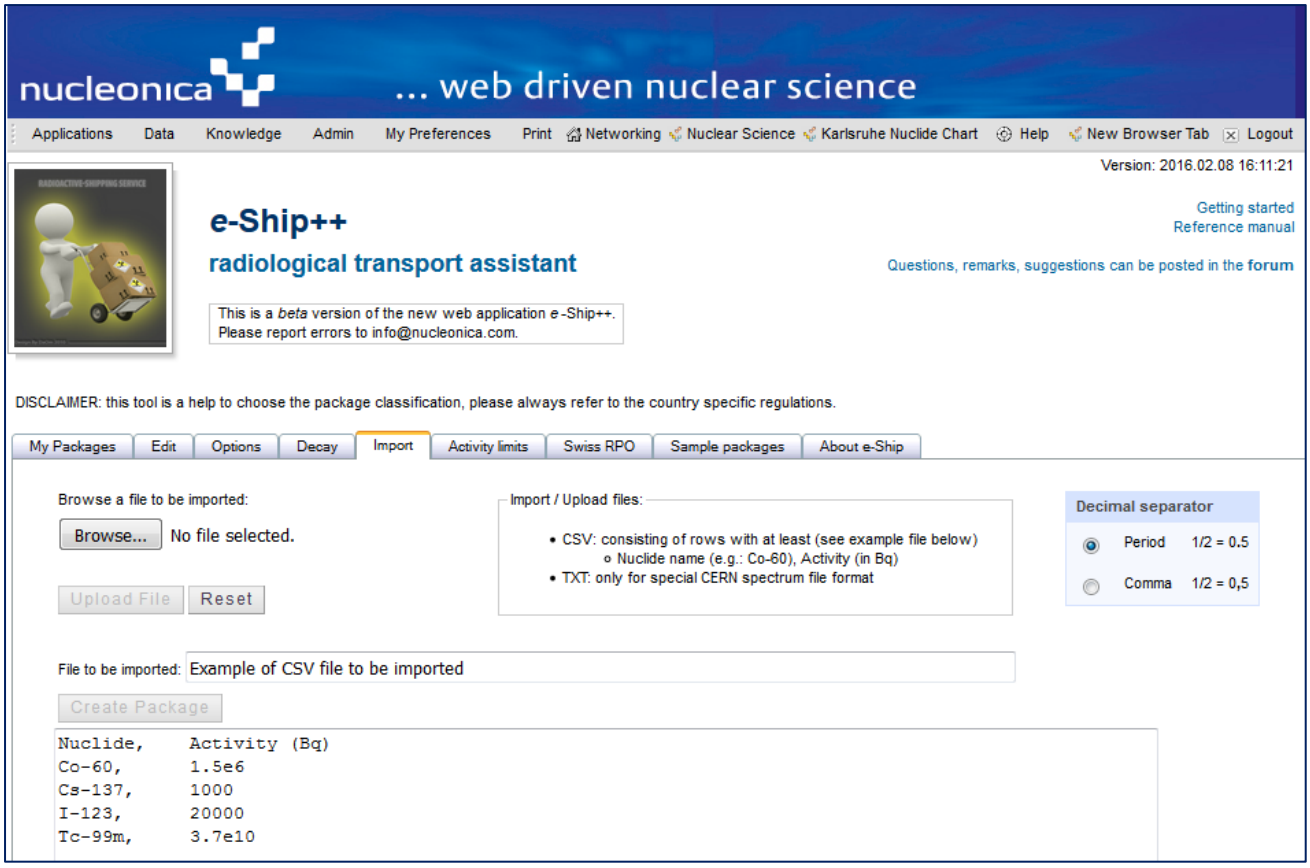


Figure 10: Import tab for uploading external data

Conclusions

The main features of the *e*-Ship++ radiological transport assistant have been described in detail. The cloud-based software application allows real-time collaboration and worldwide accessibility with an intuitive, user-friendly interface for classifying the transport of radioactive materials in accordance with ADR/IATA/IAEA transport regulations. A key feature is the possibility to follow decay of the package mixture from the activity reported date to any future date. A number of sample packages are provided for training and demonstration purposes. The product is aimed at governmental institutions, research organizations, universities, and private companies involved in the transport of radioactive materials.

In a future update of e-Ship++, the package classification (currently restricted to Exempted, Excepted, or Type A) will be extended to include industrial packages. Industrial packages are used to transport LSA (Low Specific Activity) and SCO (Surface Contaminated Object) material. In addition, a number of features will be introduced:

- Doses rates limits: The user can enter measured dose rates (at contact, 1m, etc.) and compare these with the dose rate limits to assess the package classification.
- Contamination limits: The user can enter measured dose rates (alpha and beta) and compare these with the contamination limits to assess the package classification.

- Marking, labeling, and placarding for all packages
- UN classification
- Isotopes, activities and transport index inserted automatically in the package label
- (I-WHITE, II-YELLOW, III-YELLOW) [1]
- Exclusive use
- Multiplication factors for tanks, containers and unpackaged LSA-I and SCO–I

An example of these improved features is shown in fig. 11.

References

[1] The *e*-Ship++ wiki page

http://www.nucleonica.com/wiki/index.php?title=Help%3AE-Ship%2B%2B#Options

[2] e-SHIP++ Documentation

https://edms.cern.ch/file/1712935/LAST_RELEASED/eShip_Documentation_docx_cpdf.pdf

[3] Swiss RPO (Radiation Protection Ordinance)

https://www.admin.ch/opc/en/classified-compilation/19940157/index.html

[4] Nucleonica's Dosimetry & Shielding++ wiki page:

http://www.nucleonica.com/wiki/index.php?title=Help%3ADosimetry_%26_Shielding%2B%2B#The_Dosimetry_.26_Shielding_Module

[5] Regulations for the Safe Transport of Radioactive Material 2012 Edition, IAEA, SSR-6,

http://www-pub.iaea.org/MTCD/publications/PDF/Pub1570_web.pdf

[6] ADR 2015: Volume I: Agreement and Protocol of Signature; Annex A: Parts 1 and 2, Part 3 (Chapters 3.1 and 3.2, Dangerous Goods List and Alphabetical Index)

http://www.unece.org/fileadmin/DAM/trans/danger/publi/adr/adr2015/ADR2015e_WEB.pdf

[7] Advisory Material for the IAEA Regulations for the Safe Transport of Radioactive Material, No. TS-G-1.1 (Rev. 1), page 273, IAEA. http://www-pub.iaea.org/mtcd/publications/pdf/pub1325_web.pdf

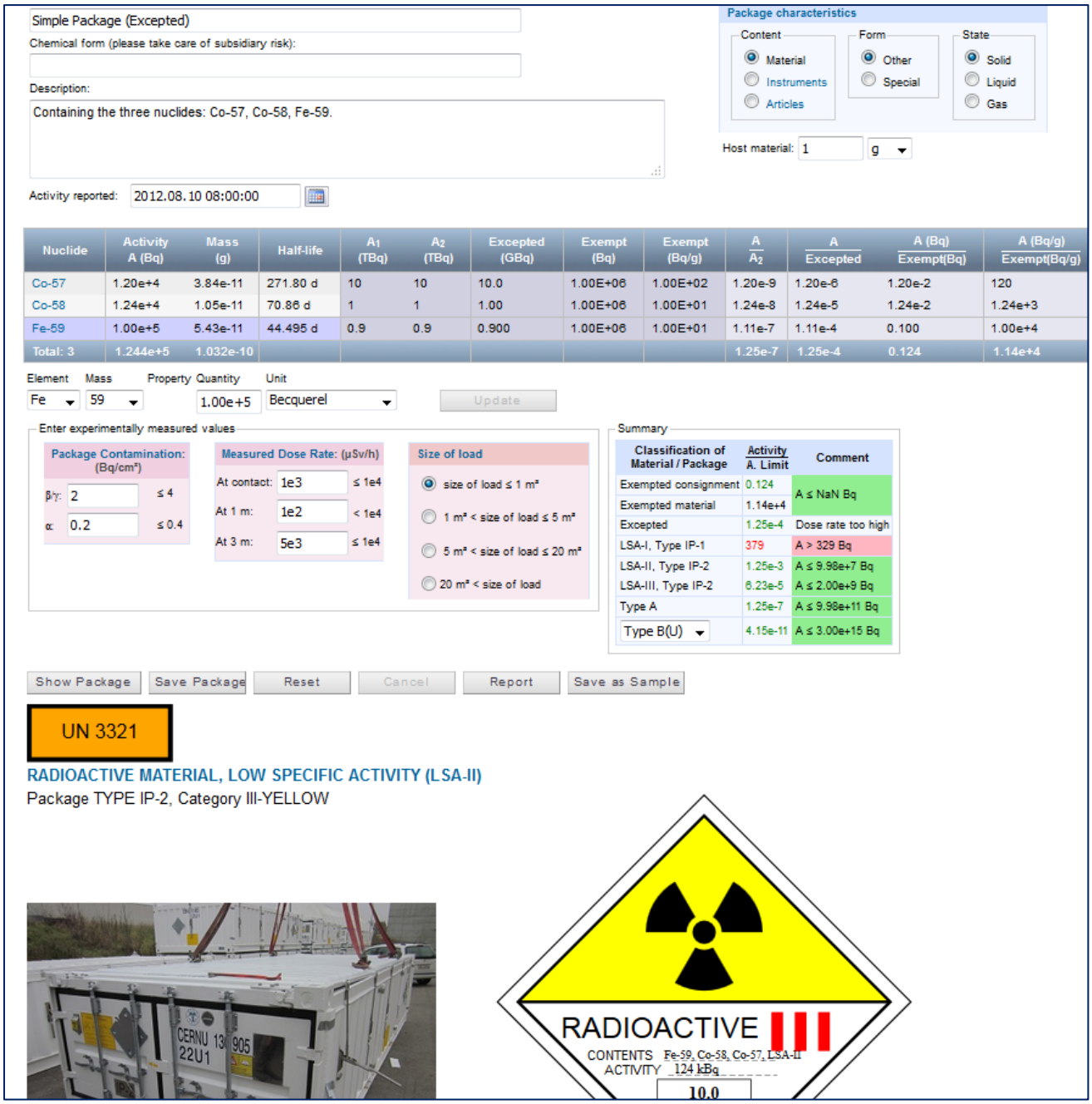


Figure 11 *e*-Ship++ with improved features (dose rate limits, contamination limits, marking and labelling, UN classification, etc.)