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ELSE NUCLEAR

# BONNER SPHERE SPECTROMETER

# USER MANUAL



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# Section 1
# General information

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## 1.1 Purpose

This User Manual explains in detail how to operate with the ELSE NUCLEAR Bonner Sphere Spectrometer.

## 1.2 Document Organization

The User Manual includes the following sections:

**Section 1: General Information**

Provides legal details and information about security and manual organization.

**Section 2: Product Description**

Provides the description of the product and of the available architectures.

**Section 3: "Single counter" configuration**

Provides complete installation/operating instructions related to the "Single counter" configuration of the BSS system.

**Section 4: "Datalogger" configuration**

Provides complete installation/operating instructions related to the "Datalogger" configuration of the BSS system.

**Section 5: RUFUS unfolding software**

Provides complete instruction related to RUFUS unfolding software.

**Section 6: Maintenance**

Describes maintenance procedures and instruction about how to manage breakdown or malfunction.

**Section 7: Technical Data**

Technical features and specifications.

## 1.3 Notations

A «Note» is represented as follows:



**NOTE: Important information.**

The following picture indicates that attention should be paid:



**ATTENTION: Important information concerning a safe and appropriate use of the product.**

A reference within the document is marked as follows: Section X.

## 1.4 Copyright

The rights of the Bonner Sphere Spectrometer User Manual wholly belong to ELSE NUCLEAR. ELSE NUCLEAR forbids its publication and allows its private use only for operation and maintenance of the Bonner Sphere Spectrometer.

The document can be disclosed and/or delivered to third parties only upon a written authorization by ELSE NUCLEAR. Procedure descriptions and functioning schemes shall not be made available to third parties. The document can be copied only for internal use.

Information can be modified by ELSE NUCLEAR without notice. In this case, ELSE NUCLEAR shall not be responsible for notice failure.



**All the information and data contained in this manual are STRICTLY CONFIDENTIAL. It is absolutely forbidden to reproduce or share this manual or part of it without the company's authorization.**

## 1.5 Warranty

ELSE NUCLEAR guarantees that the new product is without manufacturing defects and can be repaired under warranty for a period of twelve months after its acceptance date (unless otherwise specified by the Sales department in commercial documents).

Warranty applies only in the case of a correct use of the instrument.

## 1.6 Security, Reliability and Performance

ELSE NUCLEAR shall not be responsible for any repercussion on security, reliability and performance of the Bonner Sphere Spectrometer that is referrable to:

- Maintenance, transport, installation, use or repair operations carried out by the customer's personnel without following either the instructions written in this manual or the instructions given by the ELSE NUCLEAR's personnel
- Instrument alteration without ELSE NUCLEAR's authorization
- Use by non-qualified or untrained personnel
- Non-authorized removal of security equipment

## 1.7 Decline of Responsibility

ELSE NUCLEAR declines any responsibility for any damage to the personnel or the equipment that is referable to an inappropriate use of the Bonner Sphere Spectrometer.

## 1.8 Guidelines for Security

This instrument has been designed and manufactured to guarantee the highest level of security during ordinary operations. It should always be used in compliance with the following precautions and guidelines (as well as any other instruction illustrated in this manual) concerning security:

- The Bonner Sphere Spectrometer can be disassembled or repaired only by ELSE NUCLEAR's authorized personnel, or by other assistance staff upon written notice by ELSE NUCLEAR
- The Bonner Sphere Spectrometer cannot be altered in any part without ELSE NUCLEAR's authorization
- Before allowing anyone to use the Bonner Sphere Spectrometer, it is necessary to check whether the person has read and understood this User Manual. It would be appropriate to compile a list of authorized users
- Non-authorized personnel should be prevented from having access to the Bonner Sphere Spectrometer

If the instrument is not working properly or is not responding to controls as expected, even though all instructions have been carefully followed, it

is necessary to contact immediately the ELSE NUCLEAR Service Department to report the breakdown.

## 1.9 Owner's Liability

The instrument's owner shall make sure that anyone who uses the Bonner Sphere Spectrometer has read and fully understood this User Manual and any other relevant information concerning the Bonner Sphere Spectrometer and its class of instruments in general. ELSE NUCLEAR does not guarantee that the mere reading of this User Manual enables to operate with the Bonner Sphere Spectrometer.

# Section 2
# Product Description

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## 2.1 General description

The Bonner sphere spectrometer consists in an array of thermal neutron detectors (He-3 proportional counters), each housed in a spherical high-density polyethylene (HDPE) moderator of different diameters.



**Upon request, the moderators can be designed to host a different type of thermal neutron detector.**

Through the comparison between the counts detected by each sphere, it is possible to determine the incident neutron energies. These data must be processed by an unfolding code to calculate the neutron spectrum. ELSE NUCLEAR can provide an unfolding software (RUFUS), please find a complete description at Section 5 RUFUS unfolding software.

An accessory set is available upon request to extend the energy range up to 10 GeV.

The proportional counter is connected to a compact electronic module, housed in 2.5 cm diameter aluminum cylinder with a length of 7.6 cm, having the following main characteristics:

- Precision wide band charge sensitive pre-amplifier followed by an amplifier
- Twelve-turn trim pot to finely tune the amplifier sensitivity to the desired level to obtain a good high voltage plateau
- Discriminator circuit that produces, when a charged event is detected, a TTL pulse (width adjustable from 40 to 500 ns)
- Threshold control trim pot allowing to control the discriminator level
- Analog monitoring test point allowing direct monitoring of amplified charged events using an oscilloscope
- High performance high voltage generator, adjustable over a range of 0-2200 V
- Test point to measure and adjust the high voltage setting

A user-friendly dedicated acquisition software is installed on the PC; it allows to start and stop the measurements, to modify the parameters and to visualize the saved data.

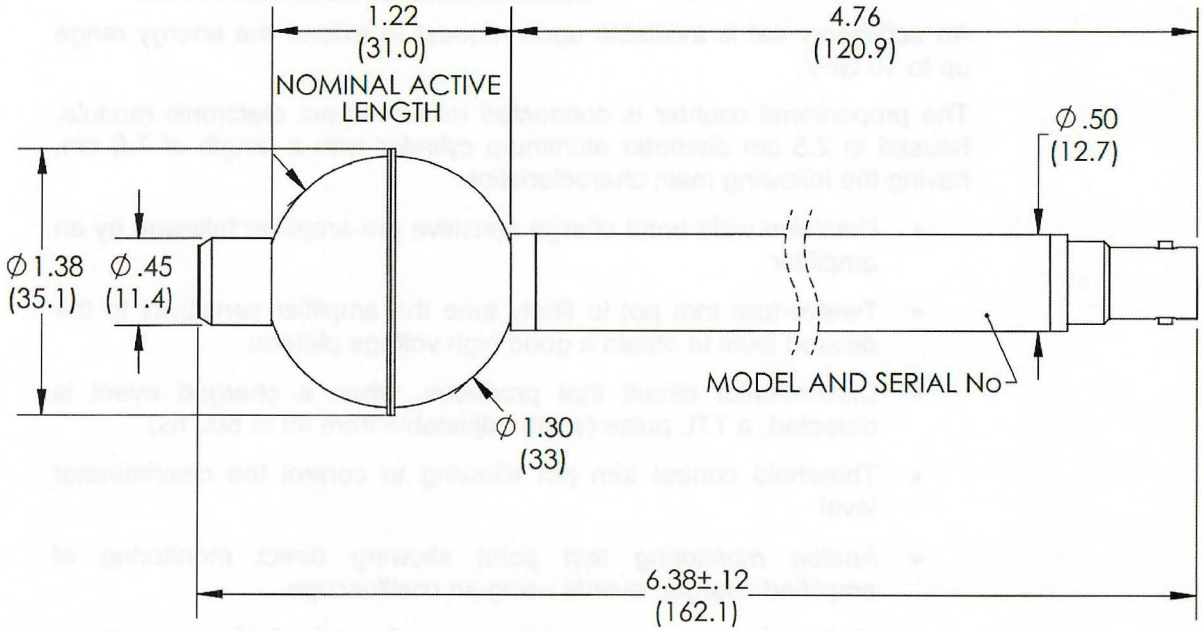
Each BSS system is supplied with custom-made aluminium supports for the moderator spheres, designed and manufactured in such a way that the centre of the detectors active volume is at the same height.

**Please note that some pictures/images provided in this Manual might slightly differ from the actual device, due to upgrades and/or updates both in the hardware and in the software that may occur during time. However, the functions and instrument description are both to be considered as valid.**

### 2.1.1 He-3 neutron proportional counter

Please find below an image of the ELSE NUCLEAR He-3 filled thermal neutron detector.

Dimensions are in inches and (millimetres).




### 2.1.2 PDT electronic module

Please refer to the producer documentation (always included in ELSE NUCLEAR BSS supplies) for specific instructions about the use and setting of the PDT electronic module.

## 2.2 Available architectures of BSS system

The ELSE NUCLEAR Bonner Sphere Spectrometer (also referred to as "BSS") is available in two different architectures, or configurations.

Please refer to "Single counter" configuration block diagram and "Datalogger" configuration block diagram for the detailed block diagrams of each configuration.

Please refer to Section 3 "Single counter" configuration and Section 4 "Datalogger" configuration for in-depth instruction about how to operate with BSS in each configuration.

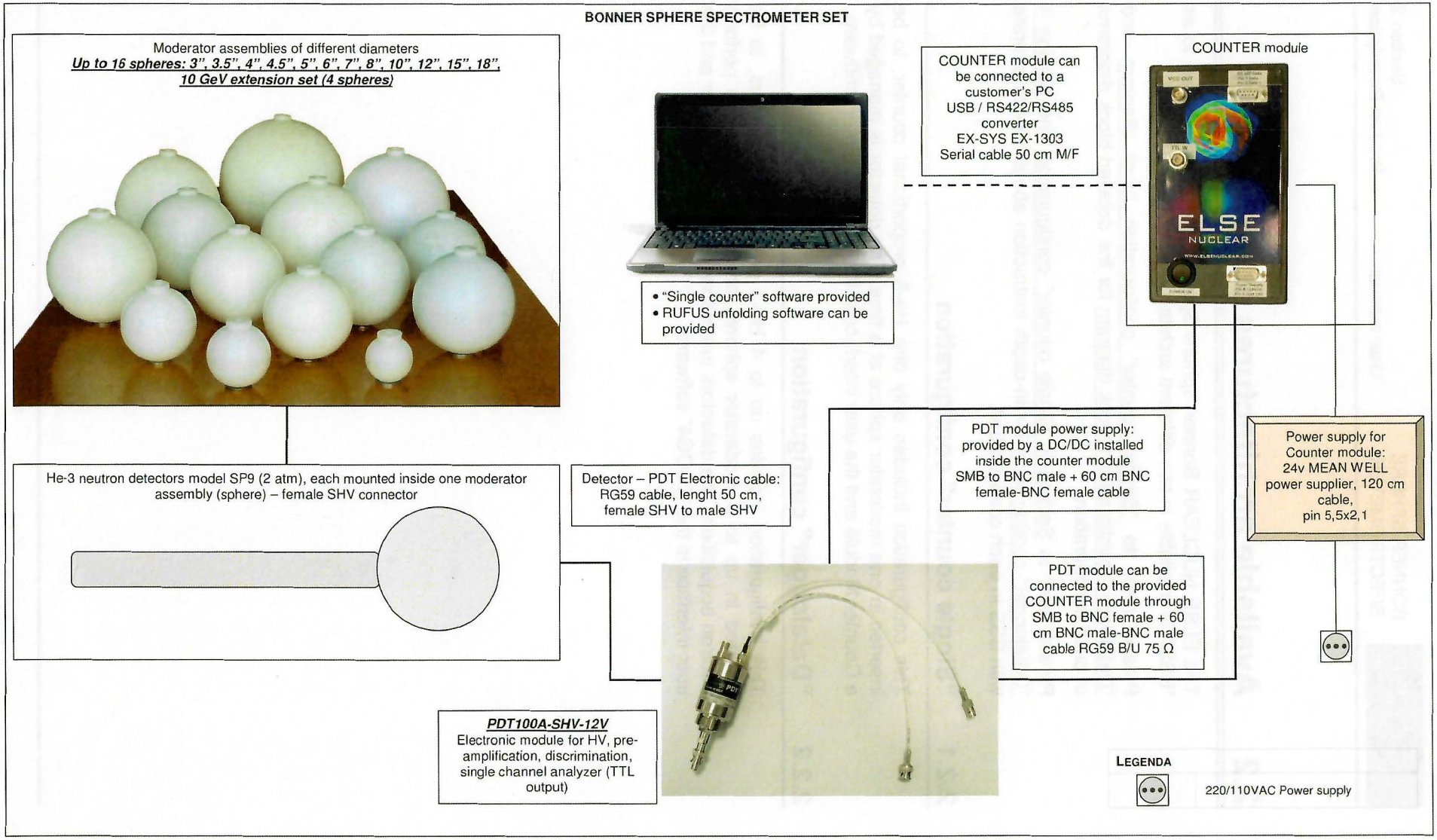
### 2.2.1 "Single counter" configuration

This configuration includes only one He-3 proportional counter, to be inserted in one moderator sphere at a time. The detector is managed by a Counter Module and the user interface is the "Single counter" software.

### 2.2.2 "Datalogger" configuration

This configuration includes up to 4 He-3 proportional counters, to be inserted in up to 4 moderator spheres at the same time to perform neutron acquisition. The detectors are managed by a Datalogger and the user interface is the "DLOG4" software.

## 2.2.3 "Single counter" configuration block diagram



## 2.2.4 "Datalogger" configuration block diagram

Moderator assemblies of different diameters
***Up to 16 spheres: 3", 3.5", 4", 4.5", 5", 6", 7", 8", 10", 12", 15", 18".***
***10 GeV extension set (4 spheres)***





- "DLOG4" software provided
- RUFUS unfolding software can be provided

DATALOGGER can be connected to a customer's PC through Ethernet connection

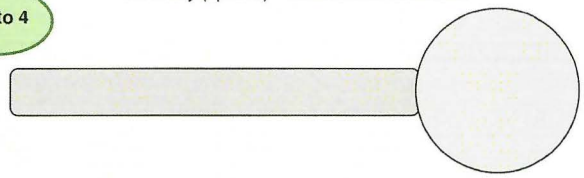
- Default ETH cable: 2 m
- Additional 20 m ETH cable

DATALOGGER



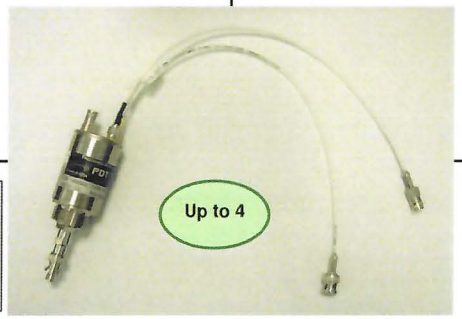
He-3 neutron detectors model SP9 (2 atm), each mounted inside one moderator assembly (sphere) – female SHV connector

Up to 4



Detector – PDT Electronic cable: RG59 cable, lenght 50 cm, female SHV to male SHV

PDT module power supply: provided by external power supply
SMB to BNC male + 60 cm BNC female-BNC female cable




PDT module can be connected to the provided DATALOGGER through SMB to BNC female + 60 cm BNC male-BNC male cable RG59 B/U 75 Ω

***PDT100A-SHV-12V***
Electronic module for HV, pre-amplification, discrimination, single channel analyzer (TTL output)

**LEGEND**

220/110VAC Power supply

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# Section 3
# "Single counter" configuration

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## 3.1 System description

With the "Single counter" version of the BSS, only one sphere data is acquired per time. Nevertheless, the proportional counter can be mounted inside a different moderator.

The device electronics is based on a ADLINK NuDAM 6080 counter module, configured to accept TTL level pulses. The minimum time resolution is 1 s. The COUNTER module is connected to the PC by means of a RS485 serial port. See also "Single counter" configuration block diagram.

The Single Counter acquisition software is designed to acquire and store pulse counts from the supplied COUNTER device.




*Figure 1: connected components of the single counter version*

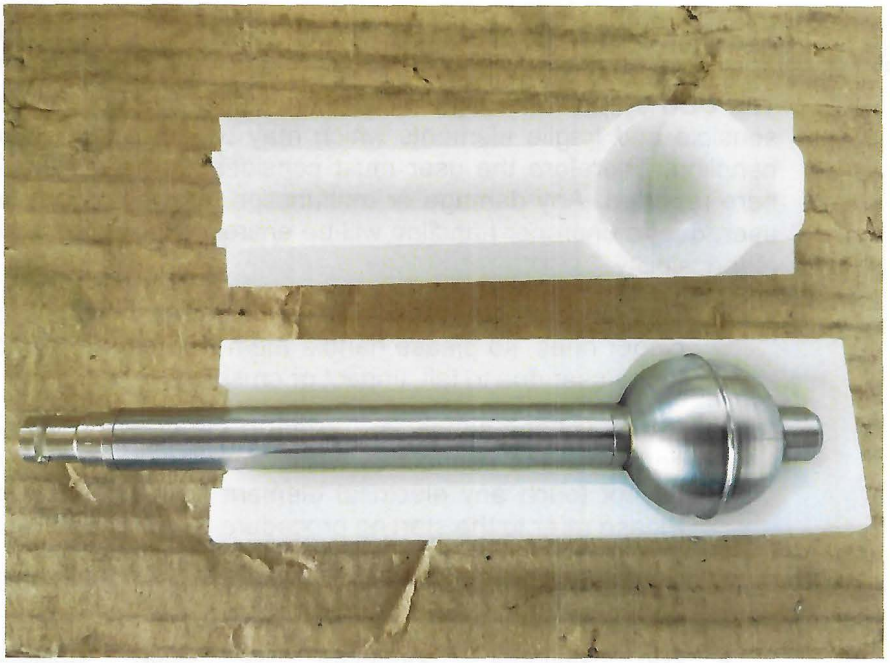


*Figure 2: proportional counter inside the moderator insert*

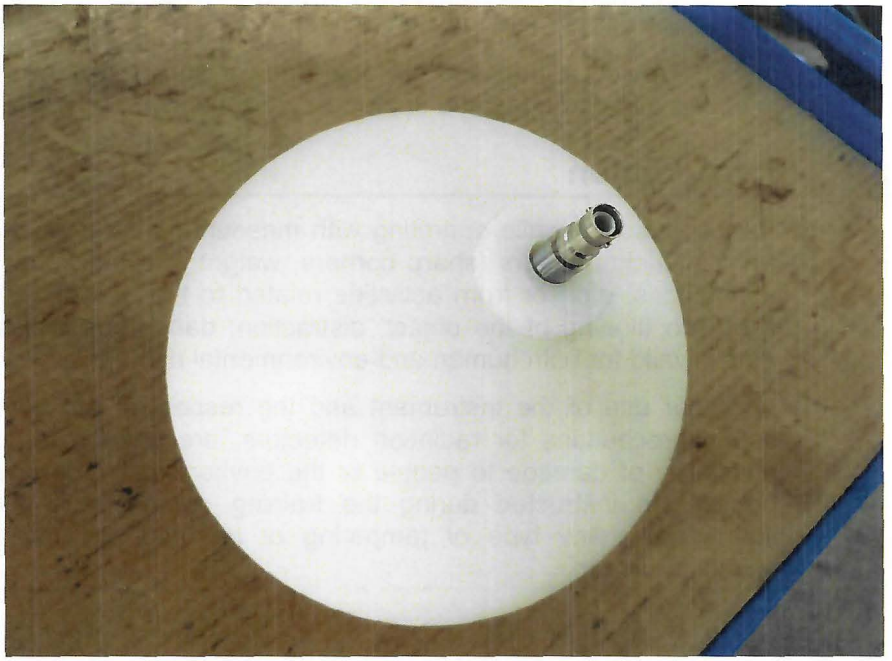


*Figure 3: proportional counter inserted inside a moderator sphere*

## 3.2 Handling, storage and transportation

The BSS system is a high-level technological instrument, composed of sensible and fragile elements which may be damaged by an unproper handling. Therefore the user must consider and follow the instructions here reported. Any damage or malfunction, as well as any harm to the user, due to unproper handling will be entirely considered under the user responsibility.

- The moderator assemblies can be rather heavy, especially the bigger ones, so please handle them with care to avoid any harm to the user due to fall, impact or crushing.
- A high-voltage supply is applied to the detector, so do not open and touch the connectors while the instrument is on. In general, do not touch any electrical element while the instrument is on. Please refer to the starting procedure for further details.
- Do not step on the cables, and place them in such a way that any harmful interaction is excluded.
- The detector connector is quite delicate; when plugging/unplugging the connector, do not damage the pins pulling or pushing them with too much strength. In general, do not try to force the connectors to plug: if they do not fit it means they are mis-allineated with the plug.
- Provide a safe and protected power supply to the instrument to avoid damages and unproper functionality.

### 3.2.1 Introduction

Handling issues while operating with measuring instruments may derive from intrinsic dangers (sharp corners, weight, moving parts, dangerous substances, etc.) or from activities related to the use of the instrument itself (positioning of the object, distraction, dangerous emissions, etc.). This is valid for both human and environmental damages.

A proper use of the instrument and the respect of the common basic safety precautions for radiation detectors, are enough to exclude any possibility of damage to people or the environment. The operator must behave as instructed during the training course while handling the instruments. Any type of tampering or unauthorized maintenance is strictly forbidden.

## 3.2.2 Specific danger analysis

**Handling**

The moderator assemblies can be rather heavy, especially the bigger ones, thus proper and related safety measures have to be applied to prevent any harm to people or objects due to accidental dropping. The danger's nature in this case would be purely mechanical.

While handling the detector, the operator must follow the instructions given during the training course; in general, normal caution measures must be applied. It is also important to avoid any type of shock or hit to the detectors.

**Electric shocks**

The BSS contains a number of electronic boards and wirings. A proper use of the instrument is recommended, which means neither tampering nor performing unauthorized maintenance activities. In particular, if maintenance is needed, or if the unit's electronics or cables are damaged and exposed, the operator must not touch anything while the detectors are connected to the power, and he/she must immediately turn off the power supply (and wait about 10 minutes for a complete capacitance discharge) before carrying out any activity.

**Working conditions**

The BSS must neither be immersed in water or any other liquid, nor used in wet environments or where water can be dropped or condensed on them.

Operation in environments characterized by extreme temperatures, outside of the operating range of the detector (0°C – 50°C), must be strictly avoided.

## 3.2.3 Storage and transportation specifications

No specific dangers are introduced by storage and transportation activities.

However, storage and transportation of the BSS can be performed only if all the precautions listed above have been read and have been respected. Moreover, all the system components must be protected during transport and storage against possible harms such as weather elements, mechanical shocks, strain and rubbing which can damage surfaces. Precautions to avoid unnecessary shocks and stresses, together with monitoring during transport are strongly suggested.

If supplied, use the flight/storage case.

## 3.3 Components connection

Please follow the procedure below to connect the provided components.

1. The COUNTER module has 4 connectors available (TTL IN, VCC OUT, RS 485 data, Power Supply) and a POWER ON switch

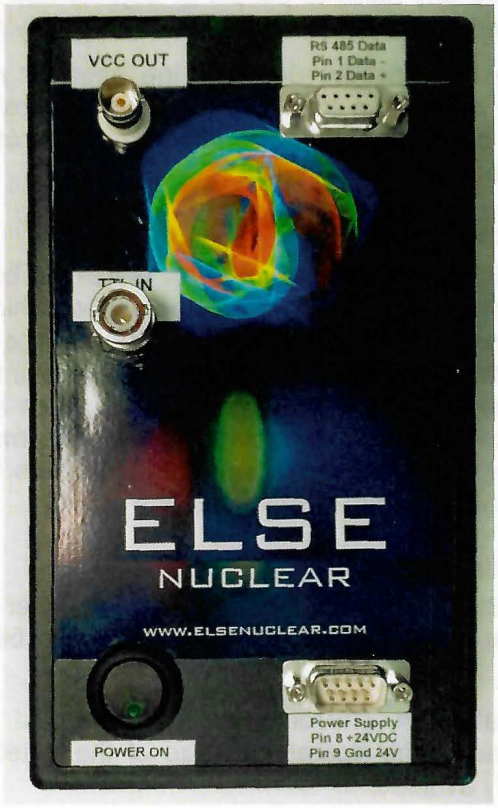



*Figure 4: counter module*

2. PDT module has 2 cables (TTL OUT and VCC IN) and 1 detector connector

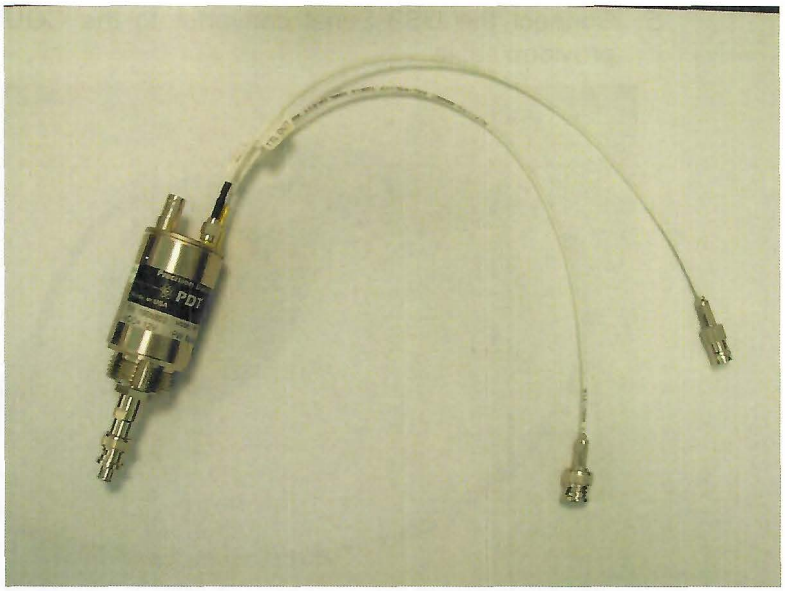



*Figure 5: PDT module*

3. Connect the PDT module to the COUNTER (TTL and VCC cables)
4. Connect the detector to the PDT module using the provided SHV-SHV cable

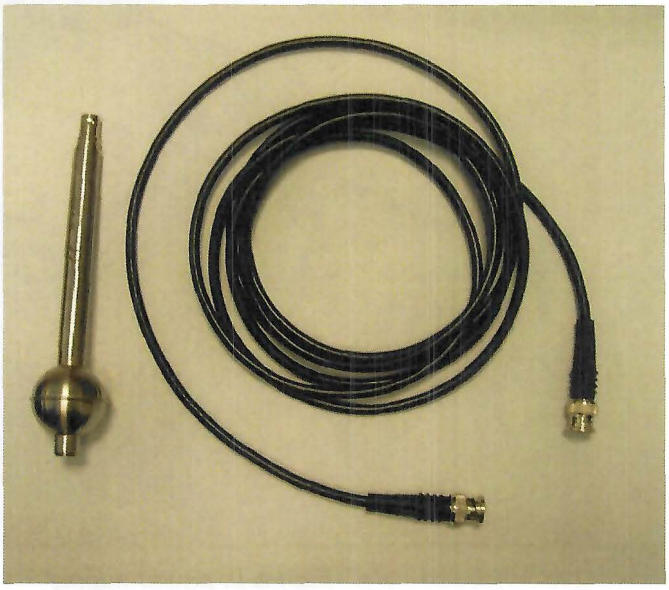


*Figure 6: proportional counter and cable*

5. Connect the USB-Serial converter to the COUNTER using the provided cable

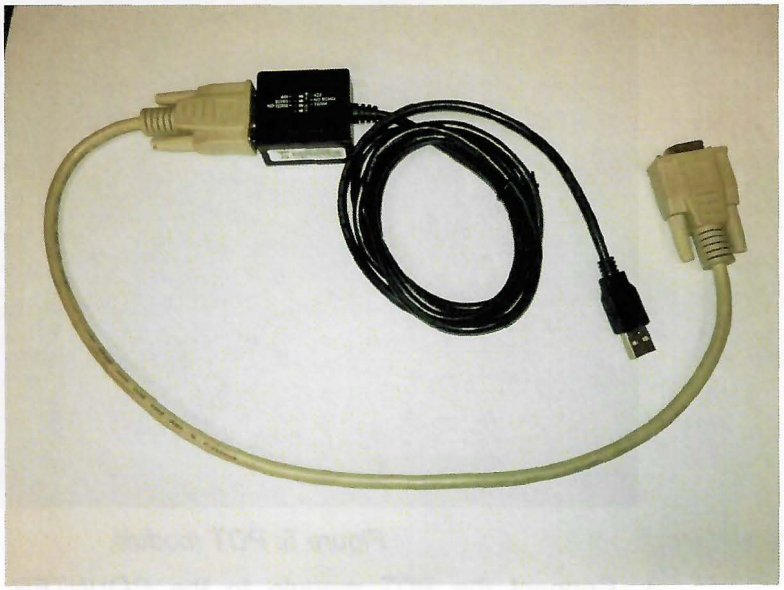


*Figure 7: USB-Serial converter and cable*

6. Connect the power supply

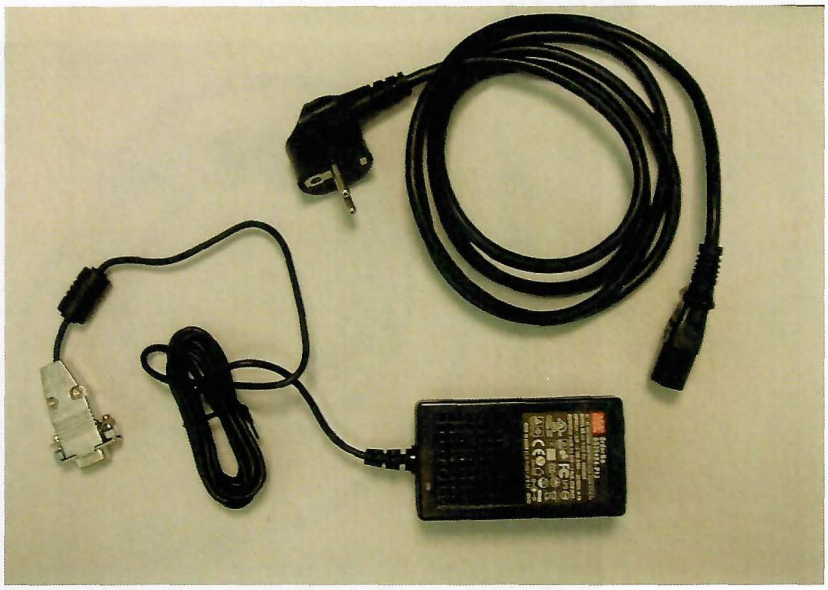


*Figure 8: power supply*

7. COUNTER is ready to be switched on

## 3.4 Device installation

As a preliminary operation, the user should install the EX-SYS EX-1303 USB-serial adapter's drivers in his PC. Drivers can be found on the provided media. After installation, plug the adapter to a free USB socket. Windows should recognize the adapter and load the proper drivers; a COM port number will be assigned to the serial port. If possible, configure the serial port as COM5 (check and change the setting by means of Windows' Device Manager, in the device Advanced Properties).

During connection, please take care not to move the micro-switches on the adapter box (correct settings are 485, NO ECHO, TERM).

You may want to install the NuDAM Administration Utility, to be found on the provided media. This program can connect to the NuDAM 6080 counter module of the device for configuration or diagnostic purposes. To verify the module status, one must select the correct serial port in the Network, ComPort... dialog, then Search the module. The NuDAM module is already properly configured for TTL signal and frequency measurement. Please don't change the configuration, otherwise the counter application will not work.

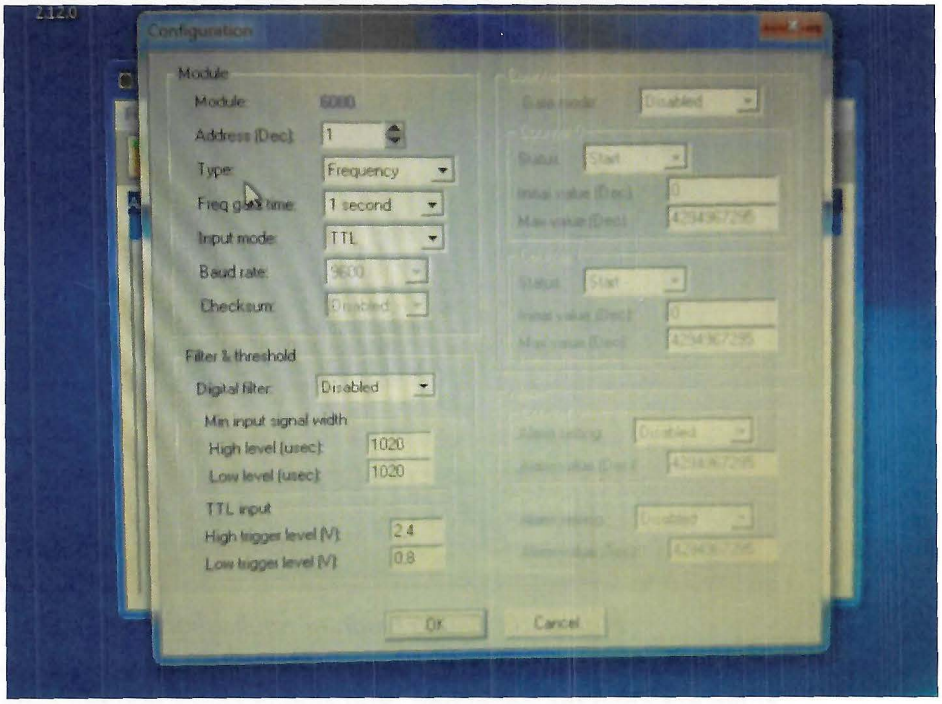



*Figure 9: NUDAM configuration panel*

Install the Single Counter application from the provided media running setup.exe and following the instructions on the screen.

If the installed serial port is not configured as COM5, open the text file "C:\Single Counter\Config\Single Counter.ini" and change the SerialPort setting to the actual port number; as an example, the line:

SerialPort=7

sets the serial port to COM7.

## 3.5 Single Counter software

Now run the Single Counter application. The following window will appear:

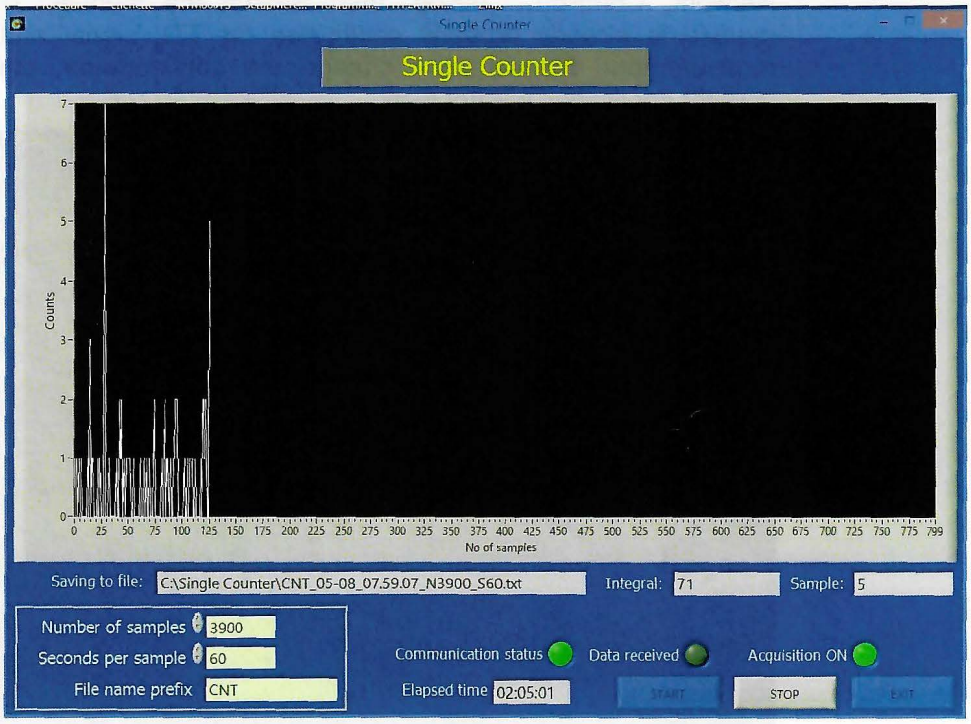



*Figure 10: Single Counter application main panel*

If the LED **Communication status** is red instead of green, the program could not open the serial port. You should check that the setting in the ini file is correct (see above) and no other program is currently using the port (for example, the NuDAM Utility program).

The user can select three acquisition parameters (on the left):

- **Number of samples**: the number of data to be collected and saved to a file
- **Seconds per sample**: the integration time for each sample, in seconds
- **File name prefix**: this string will be used as a prefix for the name of the saved file

To perform an acquisition, press **START**. The LED **Acquisition ON** will turn on. Whenever a new sample is completed, the LED **Data received** will flash and the indicators graph, **Integral** and **Sample** will be updated. **Sample** displays the counts in the last acquired sample, **Integral** the sum of all counts.

The graph indicator will show a maximum of 800 samples at once, after that the data series will be shifted to the left to allow each new sample in.

The user can **STOP** the measurement at any time before the full number of samples has been acquired.

If an acquisition error occurs, the LED **Communication status** will turn red and the acquisition aborted. The generated file will not contain the integral value.

## 3.6 Data storage

The sample series will be written to a text file located into the folder "C:\Single Counter". The file name will be automatically chosen by the program based on the prefix, the start time and the other settings. For example, with the default settings the file name could be as follows:

CNT_01-09_15.03.43_N3600_S1.txt

Where CNT is the prefix, the start date is September 1st at 15.03.43, the number of samples is 3600 (N3600) and the sample duration is 1 second (S1).

When acquisition is done, the integral will be written at the end of the file.

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# Section 4
# "Datalogger" configuration

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## 4.1 System description

With the "Datalogger" version of the BSS, up to four sphere data can be acquired at the same time.

The DATALOGGER module is connected to the PC by means of a ETH connection. See also "Datalogger" configuration block diagram.



**Please refer to the Datalogger manual for a complete description of the device and a detailed explanation of the DLOG4 software interface (document code MAN_DATALOGGER_EN).**

## 4.2 Handling, storage and transportation

Please refer to Handling, storage and transportation for the precaution recommendations, as they are equally applicable to both the available configurations.

## 4.3 Components connection

Please refer to Components connection as the procedure is quite the same.



**Please note that the connection sequence is the same, with the only exception of the connection of the PDT modules to the Datalogger. Refer to "Datalogger" configuration block diagram for further details.**

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# Section 5
# RUFUS unfolding software

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# 5.1 Introduction

RUFUS is a user friendly unfolding software designed to operate with the ELSE NUCLEAR Bonner Sphere Spectrometer.

# 5.2 RUFUS software



**The RUFUS software user guide here presented is directly transposed from the on-line help guide that is provided with the application. Therefore, the reader of this manual will find the links to each section of the on-line interactive help guide. Each section is also here transposed in the following paragraphs.**

Welcome in RUFUS User guide.

Start Here to learn how to use RUFUS.

The following table lists the input files RUFUS needs to work and a brief description. Each file format is thoroughly explained in its documentation page

## 5.2.1 List of Input files

| Input file | Description |
|---|---|
| Counts File | contains the experimental counts and uncertainties |
| Guess File | contains the guess spectrum for the experimental counts |
| Response Function File | contains the sensitivity Response Function of the experimental setup |

Here there are some RUFUS features. The user can learn more about a feature by clicking on its name. It's warmly suggested to read what inputs RUFUS needs to work before.

- Rebinning
- Automatic exclusion of Bonner Spheres
- Live Spectrum plot
- Interactive uncertainties editing (**affects user's file!**)

- Zoom/pan/export plot
- Automatic unfolding abort on increasing Chi2rid
- Export simulated counts and spectra
- Live residues evaluation and plot
- Live Predicted Counts

### 5.2.2 Counts file

This page contains information about the counts file format.

**A counts file must contain 3 columns, separated by spaces.**

**The first two row are never read**, so that the user can write there anything he wants.

Then:

- First column contains the bonner spheres. They must be a subset of the bonner spheres in the Response Function file. Learn more
- Second column contains the bonner sphere counts
- Third column contains uncertainty (percentage) of the bonner sphere

This is an example of counts file.

```
#  This lines are never read
#  so I can write anything i want
BARE 0.000557 0.2
Sp2,5 0.050863 0.2
Sp3 0.171140 0.2
Sp3,5 0.377581 0.2
Sp4 0.656777 0.2
Sp4,5 0.970294 0.2
Sp5 1.312581 0.2
Sp6 1.873737 0.2
Sp7 2.272960 0.2
Sp8 2.387667 0.2
Sp9,5 2.315790 0.2
Sp10 2.228580 0.2
Sp12 1.702386 0.2
Sp15 0.975742 0.2
Sp18 0.554416 0.2
~
~
~
~
```

*Figure 11: example of counts file*

### 5.2.3 Guess file

This page contains information about the guess file format.

**A guess file must contain 3 columns, separated by spaces.**

**The first two row are never read,** so that the user can write there anything he wants.

Then:

- First column contains the energy ;
- Second column contains the group fluency

**Important**: the energy $E_i$ in the i-th row, first column, is the lower bound of the i-th energy bin. The i-th group fluency is the integral of the fluency in the energy interval $[E_i, E_{i+1}]$.

Please refer to the IAEA document TRS 403 for more information.

This is an example of guess file.

```
# this line is a comment_
# this line is a comment
0.001 0
0.00215 0
0.00464 0
0.01 0
0.0215 0
0.0464 0
0.1 0
0.215 0
0.464 0
1.00E+00 0
2.15 0
4.64 0
1.00E+01 0
21.5 0
46.4 0
1.00E+02 0
2.15E+02 0
4.64E+02 0
1.00E+03 0
2.15E+03 0
4.64E+03 0
1.00E+04 0
1.25E+04 0
1.58E+04 0
1.99E+04 0
2.51E+04 0
```

*Figure 12: example of guess file*

### 5.2.4 Response Function file

This page contains information about the Response Function file format.

A Response Function file must contain the Response Function matrix, which is expressed in energies x sensitivities.

So:

- **Within each row, two entries are separated by a space;**
- **Each row is separated by a newline.**

Then:

- **The first two row are never read**, so that the user can write there anything he want;
- The third row contains the bonner spheres, separated by a space. Counts file must contain a subset of this set of spheres. Learn more;
- From the fourth row, the first value is the energy, and then a row of the Response Function matrix;

To sum up, let $K_{ij}$ be the Response Function matrix and say K is a MxN matrix.

Then from the third row included, the Response Function file has this structure:

| VOID | Bonner sphere #1 | Bonner sphere #2 | ... | ... | ... | Bonner sphere #N |
|---|---|---|---|---|---|---|
| Energy bin #1 | $K_{11}$ | $K_{12}$ | ... | ... | ... | $K_{1N}$ |
| Energy bin #2 | $K_{21}$ | $K_{22}$ | ... | ... | ... | $K_{2N}$ |
| ... | ... | ... | ... | ... | ... | ... |
| ... | ... | ... | ... | ... | ... | ... |
| ... | ... | ... | ... | ... | ... | ... |
| Energy bin #M | $K_{M1}$ | $K_{M2}$ | ... | ... | ... | $K_{MN}$ |

Please refer to the IAEA document TRS 403 for more information.

This is an example of Response Function file.

```
# this is a comment. Never read by RUFUS
# this is a comment. Never read by RUFUS
ENERGIES BARE Sp2,5 Sp3 Sp3,5 Sp4 Sp4,5 Sp5 Sp6 Sp7 Sp8 Sp9,5 Sp10 Sp12 Sp15 Sp18
1.00E+02 6.02E-02 1.47E+00 2.14E+00 2.53E+00 2.63E+00 2.51E+00 2.29E+00 1.69E+00 1.14E+00 7.23E-01 3.64E-01 2.89E-01 1.01E-01 2.21E-02 3.78E-03
2.15E+02 4.05E-02 1.30E+00 1.98E+00 2.41E+00 2.58E+00 2.52E+00 2.32E+00 1.74E+00 1.20E+00 7.85E-01 3.90E-01 3.08E-01 1.17E-01 2.39E-02 3.54E-03
4.64E+02 2.79E-02 1.14E+00 1.83E+00 2.30E+00 2.51E+00 2.52E+00 2.34E+00 1.80E+00 1.25E+00 8.28E-01 4.13E-01 3.26E-01 1.20E-01 2.40E-02 3.66E-03
1.00E+03 1.91E-02 1.01E+00 1.67E+00 2.18E+00 2.43E+00 2.47E+00 2.36E+00 1.87E+00 1.31E+00 8.73E-01 4.36E-01 3.46E-01 1.28E-01 2.27E-02 4.27E-03
2.15E+03 1.27E-02 8.83E-01 1.53E+00 2.04E+00 2.35E+00 2.44E+00 2.36E+00 1.90E+00 1.37E+00 9.13E-01 4.68E-01 3.70E-01 1.34E-01 2.46E-02 4.84E-03
4.64E+03 9.01E-03 7.64E-01 1.39E+00 1.92E+00 2.26E+00 2.39E+00 2.33E+00 1.92E+00 1.42E+00 9.47E-01 5.00E-01 3.83E-01 1.43E-01 2.65E-02 5.42E-03
1.00E+04 6.86E-03 6.98E-01 1.31E+00 1.84E+00 2.21E+00 2.36E+00 2.33E+00 1.96E+00 1.46E+00 9.90E-01 5.23E-01 4.06E-01 1.46E-01 2.94E-02 6.01E-03
1.25E+04 6.24E-03 6.69E-01 1.27E+00 1.81E+00 2.18E+00 2.35E+00 2.33E+00 1.98E+00 1.48E+00 1.01E+00 5.34E-01 4.22E-01 1.54E-01 3.12E-02 6.35E-03
1.58E+04 5.62E-03 6.39E-01 1.23E+00 1.78E+00 2.15E+00 2.34E+00 2.33E+00 2.00E+00 1.50E+00 1.04E+00 5.45E-01 4.38E-01 1.62E-01 3.30E-02 6.69E-03
1.99E+04 4.99E-03 6.09E-01 1.20E+00 1.74E+00 2.13E+00 2.33E+00 2.34E+00 2.02E+00 1.53E+00 1.06E+00 5.56E-01 4.53E-01 1.66E-01 3.48E-02 7.03E-03
2.51E+04 4.37E-03 5.81E-01 1.16E+00 1.71E+00 2.10E+00 2.32E+00 2.34E+00 2.05E+00 1.55E+00 1.08E+00 5.70E-01 4.69E-01 1.65E-01 3.63E-02 7.31E-03
3.16E+04 3.83E-03 5.54E-01 1.13E+00 1.67E+00 2.08E+00 2.31E+00 2.35E+00 2.08E+00 1.58E+00 1.12E+00 5.91E-01 4.83E-01 1.67E-01 3.72E-02 7.49E-03
3.98E+04 3.36E-03 5.26E-01 1.09E+00 1.64E+00 2.06E+00 2.31E+00 2.37E+00 2.12E+00 1.62E+00 1.16E+00 6.15E-01 4.97E-01 1.73E-01 3.78E-02 7.62E-03
5.01E+04 2.90E-03 4.99E-01 1.05E+00 1.61E+00 2.04E+00 2.30E+00 2.38E+00 2.16E+00 1.67E+00 1.21E+00 6.37E-01 5.10E-01 1.87E-01 3.84E-02 7.76E-03
6.30E+04 2.43E-03 4.71E-01 1.02E+00 1.57E+00 2.02E+00 2.29E+00 2.39E+00 2.20E+00 1.73E+00 1.25E+00 6.64E-01 5.29E-01 2.06E-01 4.01E-02 7.97E-03
7.94E+04 1.97E-03 4.41E-01 9.77E-01 1.53E+00 1.99E+00 2.28E+00 2.41E+00 2.25E+00 1.80E+00 1.32E+00 7.03E-01 5.61E-01 2.26E-01 4.48E-02 8.39E-03
1.00E+05 1.64E-03 4.09E-01 9.33E-01 1.49E+00 1.95E+00 2.27E+00 2.43E+00 2.31E+00 1.87E+00 1.38E+00 7.52E-01 6.09E-01 2.40E-01 5.09E-02 9.16E-03
1.25E+05 1.47E-03 3.77E-01 8.87E-01 1.44E+00 1.92E+00 2.26E+00 2.44E+00 2.37E+00 1.95E+00 1.46E+00 8.14E-01 6.70E-01 2.54E-01 5.71E-02 1.03E-02
1.58E+05 1.31E-03 3.45E-01 8.35E-01 1.38E+00 1.88E+00 2.24E+00 2.46E+00 2.43E+00 2.05E+00 1.56E+00 8.93E-01 7.43E-01 2.84E-01 6.37E-02 1.20E-02
1.99E+05 1.15E-03 3.13E-01 7.78E-01 1.32E+00 1.83E+00 2.22E+00 2.47E+00 2.50E+00 2.15E+00 1.68E+00 9.84E-01 8.24E-01 3.25E-01 7.14E-02 1.42E-02
2.51E+05 9.96E-04 2.81E-01 7.19E-01 1.25E+00 1.77E+00 2.19E+00 2.47E+00 2.57E+00 2.27E+00 1.80E+00 1.08E+00 9.19E-01 3.79E-01 8.52E-02 1.83E-02
3.16E+05 8.95E-04 2.49E-01 6.57E-01 1.17E+00 1.70E+00 2.13E+00 2.44E+00 2.62E+00 2.41E+00 1.95E+00 1.21E+00 1.03E+00 4.50E-01 1.06E-01 2.47E-02
3.98E+05 8.61E-04 2.17E-01 5.94E-01 1.09E+00 1.61E+00 2.07E+00 2.40E+00 2.66E+00 2.52E+00 2.08E+00 1.35E+00 1.14E+00 5.37E-01 1.32E-01 3.10E-02
5.01E+05 8.28E-04 1.87E-01 5.27E-01 9.97E-01 1.51E+00 1.97E+00 2.33E+00 2.68E+00 2.59E+00 2.22E+00 1.52E+00 1.29E+00 6.52E-01 1.73E-01 4.07E-02
6.30E+05 7.94E-04 1.59E-01 4.61E-01 8.96E-01 1.38E+00 1.86E+00 2.23E+00 2.67E+00 2.65E+00 2.35E+00 1.69E+00 1.46E+00 7.77E-01 2.28E-01 5.80E-02
7.94E+05 7.60E-04 1.34E-01 3.96E-01 7.96E-01 1.26E+00 1.73E+00 2.10E+00 2.61E+00 2.70E+00 2.47E+00 1.88E+00 1.66E+00 9.34E-01 3.12E-01 8.93E-02
1.00E+06 7.22E-04 1.11E-01 3.39E-01 6.97E-01 1.13E+00 1.59E+00 1.98E+00 2.53E+00 2.71E+00 2.57E+00 2.06E+00 1.85E+00 1.12E+00 4.31E-01 1.39E-01
1.25E+06 6.79E-04 9.38E-02 2.90E-01 6.02E-01 1.00E+00 1.42E+00 1.82E+00 2.42E+00 2.67E+00 2.65E+00 2.22E+00 2.02E+00 1.32E+00 5.70E-01 2.08E-01
1.58E+06 6.37E-04 7.58E-02 2.42E-01 5.13E-01 8.67E-01 1.25E+00 1.63E+00 2.25E+00 2.58E+00 2.64E+00 2.35E+00 2.19E+00 1.51E+00 7.23E-01 3.07E-01
1.99E+06 5.94E-04 5.80E-02 1.94E-01 4.24E-01 7.33E-01 1.08E+00 1.45E+00 2.06E+00 2.44E+00 2.54E+00 2.41E+00 2.30E+00 1.68E+00 8.93E-01 4.30E-01
2.51E+06 5.51E-04 4.42E-02 1.54E-01 3.47E-01 6.13E-01 9.20E-01 1.26E+00 1.82E+00 2.25E+00 2.38E+00 2.36E+00 2.29E+00 1.77E+00 1.03E+00 5.79E-01
3.16E+06 4.94E-04 3.52E-02 1.24E-01 2.85E-01 5.10E-01 7.60E-01 1.07E+00 1.57E+00 2.02E+00 2.16E+00 2.22E+00 2.18E+00 1.77E+00 1.11E+00 7.51E-01
3.98E+06 4.19E-04 2.63E-02 9.54E-02 2.24E-01 4.08E-01 6.27E-01 8.88E-01 1.36E+00 1.78E+00 2.01E+00 2.13E+00 2.10E+00 1.88E+00 1.31E+00 9.22E-01
5.01E+06 3.44E-04 1.95E-02 7.21E-02 1.77E-01 3.30E-01 5.14E-01 7.36E-01 1.16E+00 1.55E+00 1.87E+00 2.03E+00 2.03E+00 1.98E+00 1.55E+00 1.10E+00
6.30E+06 2.70E-04 1.52E-02 5.66E-02 1.49E-01 2.80E-01 4.09E-01 6.29E-01 9.63E-01 1.31E+00 1.62E+00 1.80E+00 1.82E+00 1.89E+00 1.59E+00 1.22E+00
7.94E+06 1.97E-04 1.10E-02 4.15E-02 1.21E-01 2.30E-01 3.03E-01 5.22E-01 7.98E-01 1.07E+00 1.31E+00 1.56E+00 1.60E+00 1.68E+00 1.52E+00 1.25E+00
1.00E+07 1.39E-04 7.43E-03 2.81E-02 7.95E-02 1.55E-01 2.25E-01 3.61E-01 5.95E-01 8.07E-01 1.02E+00 1.24E+00 1.31E+00 1.43E+00 1.40E+00 1.22E+00
1.58E+07 1.00E-04 4.65E-03 1.77E-02 4.26E-02 8.39E-02 1.40E-01 2.04E-01 3.53E-01 5.25E-01 6.80E-01 8.69E-01 9.15E-01 1.05E+00 1.09E+00 1.08E+00
2.51E+07 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00
3.98E+07 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00
6.30E+07 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00
1.00E+08 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00
1.58E+08 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00
2.51E+08 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00
3.98E+08 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00
```

*Figure 13: example of Response Function file*

As it can be seen from the file prototype, file columns ar not guaranteed to be correctly stacked. This doesn't matter, because RUFUS automatically put two entry separated by a space in two different column. For example, Sp15 will be put correctly as the first entry of the penultimate column.

### 5.2.5 Rebinning

This page contains information about the rebining feature.

In case the guess file has a binning different from the default one used for the response matrix, the guess spectrum is linearly piecewise interpolated and re-binned to the default energy binning.

### 5.2.6 Autoexclusion of Bonner Spheres

This page contains information about the automatic exclusion of a Bonner Sphere.

Suppose there is a broken Bonner Sphere in the experimental setup. Then the count file will not contain the corresponding count entry. This mistmatches the dimension of the counts vector and the Response Function matrix. Then the Response Function matrix needs to be modified in order to exclude the row corrersponing to the sensitivity profile of that broken sphere.

This is precisely the scenario this feature attemps to solve. RUFUS uses this feature to automatically import only the matrix rows for which a entry is present in the counts file.

This requires that **Bonner spheres name listed in the counts file must be a subset of those listed in Response Function files.**

The user can check himself that the Counts file and the Response Function file reported below share all and only the same Bonner Spheres name.

```
# this is a comment. Never read by RUFUS
# this is a comment. Never read by RUFUS
ENERGIES BARE Sp2,5 Sp3 Sp3,5 Sp4 Sp4,5 Sp5 Sp6 Sp7 Sp8 Sp9,5 Sp10 Sp12 Sp15 Sp18
1.00E+02 [illegible]+00 7.23E-01 3.64E-01 2.89E-01 1.01E-01 2.21E-02 3.78E-03
2.15E+02 4.05E-02 1.30E+00 1.98E+00 2.41E+00 2.58E+00 2.52E+00 2.32E+00 1.74E+00 1.20E+00 7.85E-01 3.90E-01 3.08E-01 1.17E-01 2.39E-02 3.54E-03
4.64E+02 2.79E-02 1.14E+00 1.83E+00 2.30E+00 2.51E+00 2.52E+00 2.34E+00 1.80E+00 1.25E+00 8.28E-01 4.13E-01 3.26E-01 1.20E-01 2.40E-02 3.66E-03
1.00E+03 1.91E-02 1.01E+00 1.67E+00 2.18E+00 2.43E+00 2.47E+00 2.36E+00 1.87E+00 1.31E+00 8.73E-01 4.36E-01 3.46E-01 1.28E-01 2.27E-02 4.27E-03
2.15E+03 1.27E-02 8.83E-01 1.53E+00 2.04E+00 2.35E+00 2.44E+00 2.36E+00 1.90E+00 1.37E+00 9.13E-01 4.68E-01 3.70E-01 1.34E-01 2.46E-02 4.84E-03
4.64E+03 9.01E-03 7.64E-01 1.39E+00 1.92E+00 2.26E+00 2.39E+00 2.33E+00 1.92E+00 1.42E+00 9.47E-01 5.00E-01 3.83E-01 1.43E-01 2.65E-02 5.42E-03
1.00E+04 6.86E-03 6.98E-01 1.31E+00 1.84E+00 2.21E+00 2.36E+00 2.33E+00 1.96E+00 1.46E+00 9.90E-01 5.23E-01 4.06E-01 1.46E-01 2.94E-02 6.01E-03
1.25E+04 6.24E-03 6.69E-01 1.27E+00 1.81E+00 2.18E+00 2.35E+00 2.33E+00 1.98E+00 1.48E+00 1.01E+00 5.34E-01 4.22E-01 1.54E-01 3.12E-02 6.35E-03
1.58E+04 5.62E-03 6.39E-01 1.23E+00 1.78E+00 2.15E+00 2.34E+00 2.33E+00 2.00E+00 1.50E+00 1.04E+00 5.45E-01 4.38E-01 1.62E-01 3.30E-02 6.69E-03
1.99E+04 4.99E-03 6.09E-01 1.20E+00 1.74E+00 2.13E+00 2.33E+00 2.34E+00 2.02E+00 1.53E+00 1.06E+00 5.56E-01 4.53E-01 1.66E-01 3.48E-02 7.03E-03
2.51E+04 4.37E-03 5.81E-01 1.16E+00 1.71E+00 2.10E+00 2.32E+00 2.34E+00 2.05E+00 1.55E+00 1.08E+00 5.70E-01 4.69E-01 1.65E-01 3.63E-02 7.31E-03
3.16E+04 3.83E-03 5.54E-01 1.13E+00 1.67E+00 2.08E+00 2.31E+00 2.35E+00 2.08E+00 1.58E+00 1.12E+00 5.91E-01 4.83E-01 1.67E-01 3.72E-02 7.49E-03
3.98E+04 3.36E-03 5.26E-01 1.09E+00 1.64E+00 2.06E+00 2.31E+00 2.37E+00 2.12E+00 1.62E+00 1.16E+00 6.15E-01 4.97E-01 1.73E-01 3.78E-02 7.62E-03
5.01E+04 2.90E-03 4.99E-01 1.05E+00 1.61E+00 2.04E+00 2.30E+00 2.38E+00 2.16E+00 1.67E+00 1.21E+00 6.37E-01 5.10E-01 1.87E-01 3.84E-02 7.76E-03
6.30E+04 2.43E-03 4.71E-01 1.02E+00 1.57E+00 2.02E+00 2.29E+00 2.39E+00 2.20E+00 1.73E+00 1.25E+00 6.64E-01 5.29E-01 2.06E-01 4.01E-02 7.97E-03
7.94E+04 1.97E-03 4.41E-01 9.77E-01 1.53E+00 1.99E+00 2.28E+00 2.41E+00 2.25E+00 1.80E+00 1.32E+00 7.03E-01 5.61E-01 2.26E-01 4.48E-02 8.39E-03
1.00E+05 1.64E-03 4.09E-01 9.33E-01 1.49E+00 1.95E+00 2.27E+00 2.43E+00 2.31E+00 1.87E+00 1.38E+00 7.52E-01 6.09E-01 2.40E-01 5.09E-02 9.16E-03
1.25E+05 1.47E-03 3.77E-01 8.87E-01 1.44E+00 1.92E+00 2.26E+00 2.44E+00 2.37E+00 1.95E+00 1.46E+00 8.14E-01 6.70E-01 2.54E-01 5.71E-02 1.03E-02
1.58E+05 1.31E-03 3.45E-01 8.35E-01 1.38E+00 1.88E+00 2.24E+00 2.46E+00 2.43E+00 2.05E+00 1.56E+00 8.93E-01 7.43E-01 2.84E-01 6.37E-02 1.20E-02
1.99E+05 1.15E-03 3.13E-01 7.78E-01 1.32E+00 1.83E+00 2.22E+00 2.47E+00 2.50E+00 2.15E+00 1.68E+00 9.84E-01 8.24E-01 3.25E-01 7.14E-02 1.42E-02
2.51E+05 9.96E-04 2.81E-01 7.19E-01 1.25E+00 1.77E+00 2.19E+00 2.47E+00 2.57E+00 2.27E+00 1.80E+00 1.08E+00 9.19E-01 3.79E-01 8.52E-02 1.83E-02
3.16E+05 8.95E-04 2.49E-01 6.57E-01 1.17E+00 1.70E+00 2.13E+00 2.44E+00 2.62E+00 2.41E+00 1.95E+00 1.21E+00 1.03E+00 4.50E-01 1.06E-01 2.47E-02
3.98E+05 8.61E-04 2.17E-01 5.94E-01 1.09E+00 1.61E+00 2.07E+00 2.40E+00 2.66E+00 2.52E+00 2.08E+00 1.35E+00 1.14E+00 5.37E-01 1.32E-01 3.10E-02
5.01E+05 8.28E-04 1.87E-01 5.27E-01 9.97E-01 1.51E+00 1.97E+00 2.33E+00 2.68E+00 2.59E+00 2.22E+00 1.52E+00 1.29E+00 6.52E-01 1.73E-01 4.07E-02
6.30E+05 7.94E-04 1.59E-01 4.61E-01 8.96E-01 1.38E+00 1.86E+00 2.23E+00 2.67E+00 2.65E+00 2.35E+00 1.69E+00 1.46E+00 7.77E-01 2.28E-01 5.80E-02
7.94E+05 7.60E-04 1.34E-01 3.96E-01 7.96E-01 1.26E+00 1.73E+00 2.10E+00 2.61E+00 2.70E+00 2.47E+00 1.88E+00 1.66E+00 9.34E-01 3.12E-01 8.93E-02
1.00E+06 7.22E-04 1.11E-01 3.39E-01 6.97E-01 1.13E+00 1.59E+00 1.98E+00 2.53E+00 2.71E+00 2.57E+00 2.06E+00 1.85E+00 1.12E+00 4.31E-01 1.39E-01
1.25E+06 6.79E-04 9.38E-02 2.90E-01 6.02E-01 1.00E+00 1.42E+00 1.82E+00 2.42E+00 2.67E+00 2.65E+00 2.22E+00 2.02E+00 1.32E+00 5.70E-01 2.08E-01
1.58E+06 6.37E-04 7.58E-02 2.42E-01 5.13E-01 8.67E-01 1.25E+00 1.63E+00 2.25E+00 2.58E+00 2.64E+00 2.35E+00 2.19E+00 1.51E+00 7.23E-01 3.07E-01
1.99E+06 5.94E-04 5.80E-02 1.94E-01 4.24E-01 7.33E-01 1.08E+00 1.45E+00 2.06E+00 2.44E+00 2.54E+00 2.41E+00 2.30E+00 1.68E+00 8.93E-01 4.30E-01
2.51E+06 5.51E-04 4.42E-02 1.54E-01 3.47E-01 6.13E-01 9.20E-01 1.26E+00 1.82E+00 2.25E+00 2.38E+00 2.36E+00 2.29E+00 1.77E+00 1.03E+00 5.79E-01
3.16E+06 4.94E-04 3.52E-02 1.24E-01 2.85E-01 5.10E-01 7.60E-01 1.07E+00 1.57E+00 2.02E+00 2.16E+00 2.22E+00 2.18E+00 1.77E+00 1.11E+00 7.51E-01
3.98E+06 4.19E-04 2.63E-02 9.54E-02 2.24E-01 4.08E-01 6.27E-01 8.88E-01 1.36E+00 1.78E+00 2.01E+00 2.13E+00 2.10E+00 1.88E+00 1.31E+00 9.22E-01
5.01E+06 3.44E-04 1.95E-02 7.21E-02 1.77E-01 3.30E-01 5.14E-01 7.36E-01 1.16E+00 1.55E+00 1.87E+00 2.03E+00 2.03E+00 1.98E+00 1.55E+00 1.10E+00
6.30E+06 2.70E-04 1.52E-02 5.66E-02 1.49E-01 2.80E-01 4.09E-01 6.29E-01 9.63E-01 1.31E+00 1.62E+00 1.80E+00 1.82E+00 1.89E+00 1.59E+00 1.22E+00
7.94E+06 1.97E-04 1.10E-02 4.15E-02 1.21E-01 2.30E-01 3.03E-01 5.22E-01 7.98E-01 1.07E+00 1.31E+00 1.56E+00 1.60E+00 1.68E+00 1.52E+00 1.25E+00
1.00E+07 1.39E-04 7.43E-03 2.81E-02 7.95E-02 1.55E-01 2.25E-01 3.61E-01 5.95E-01 8.07E-01 1.02E+00 1.24E+00 1.31E+00 1.43E+00 1.40E+00 1.22E+00
1.58E+07 1.00E-04 4.65E-03 1.77E-02 4.26E-02 8.39E-02 1.40E-01 2.04E-01 3.53E-01 5.25E-01 6.80E-01 8.69E-01 9.15E-01 1.05E+00 1.09E+00 1.08E+00
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1.58E+08 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00
2.51E+08 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00
3.98E+08 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00
```

*Figure 14: example of Response Function file*

```
#  This lines are never read
#  so I can write anything i want
BARE 0.000557 0.2
Sp2,5  0.050863 0.2
Sp3 0.171140 0.2
Sp3,5  0.377581 0.2
Sp4 0.656777 0.2
Sp4,5  0.970294 0.2
Sp5 1.312581 0.2
Sp6 1.873737 0.2
Sp7 2.272960 0.2
Sp8 2.387667 0.2
Sp9,5  2.315790 0.2
Sp10 2.228580 0.2
Sp12 1.702386 0.2
Sp15 0.975742 0.2
Sp18 0.554416 0.2
~
~
~
~
```

*Figure 15: example of counts file*

### 5.2.7 Live Spectrum plot

This page contains information about the Live Spectrum Plot feature.

This feature is automatically enabled once the unfolding starts. Evey 10 steps of the unfolding the unfolded spectrum is drawn on the plot. Thus, its immediately clear if the unfolding is performing well or if it's going to stop due to a reduced chi squared increase.

This is an example of a live plot (animation available only in the on-line guide).

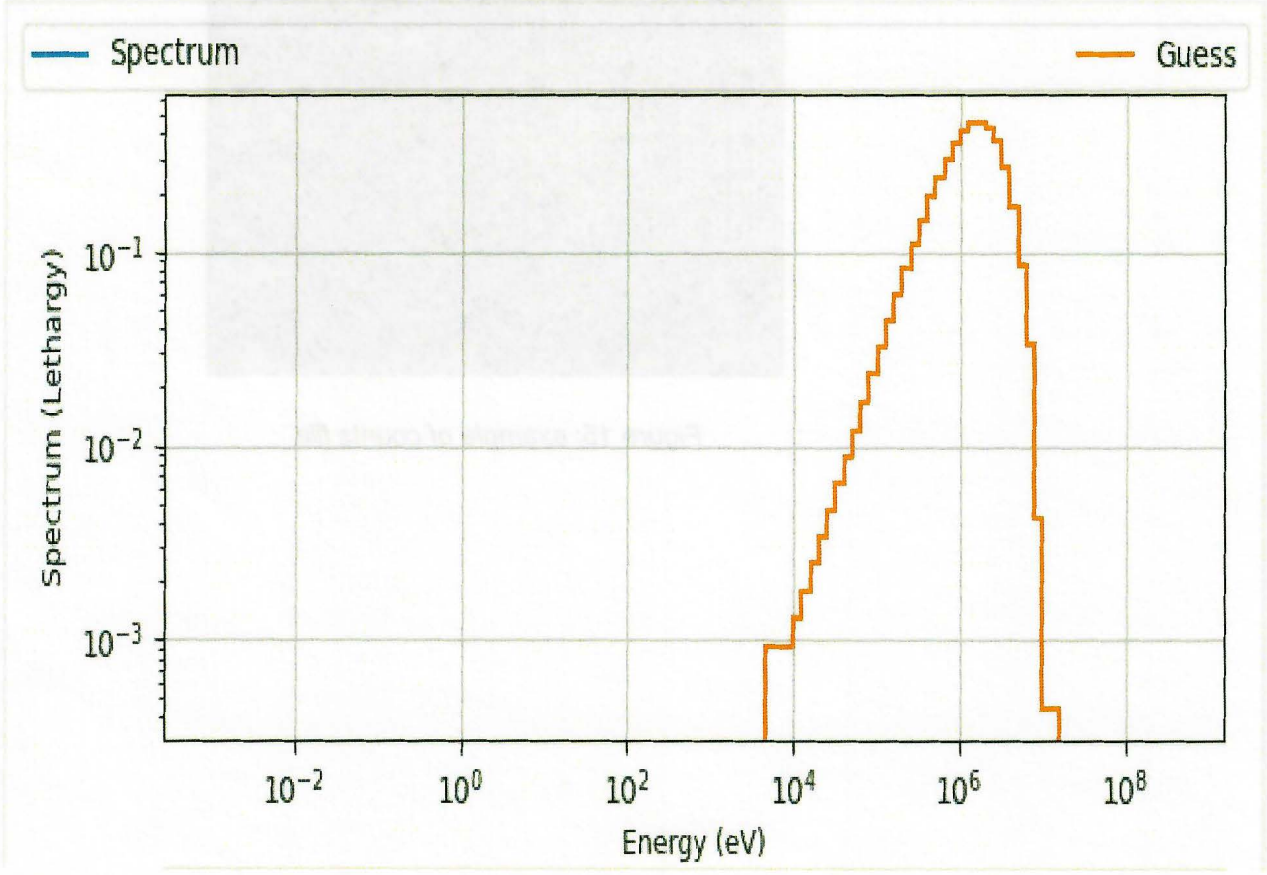



*Figure 16: live spectrum plot*

### 5.2.8 Interactive Uncertainties Editing

This page contains information about the Interactive Uncertainties Editing feature.

This feature let the user modify runtime the uncertainty on its counts. This could be useful to set some threshold on the experimental uncertainties if a determinate accuracy is desired.

This is a macro on the interface to perform runtime uncertainties edit: In this specific case, a 20% uncertainty is assigned to every Bonner Sphere. The user can modify it either writing in the appropriate box or using the arrows on on the right side of it The arrows increase or decrease the value by a 5% each click.

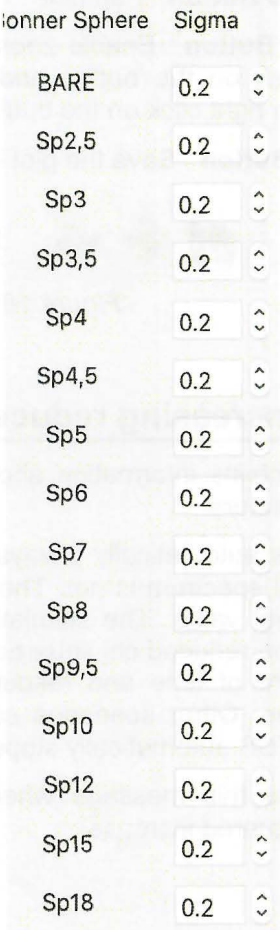



*Figure 17: uncertainties editing*

### 5.2.9 Zoom/Pan/Export plot

This page contains information about the >Zoom/Pan/Export feature.

This feature enable basical interaction with the plot. **It must not be used while the unfolding is running.**

From left to right:

- **Home Button** : Restore the view to the original one
- **Back Arrow** : Undo the last action
- **Forth Arrow** : Redo the undid action
- **Arrows Button** : Pan plot
- **Zoom Button** : Enable zoom in by drawing a rectangle holding left click on the button and zoom out by drawing a rectangle holding right click on the button
- **Save Button** : Save the plot in PNG format



*Figure 18: plot tools*

### 5.2.10 Abort on increasing reduced Chi squared feature

This page contains information about the Abort on increasing reduced Chi squared feature.

This feature is automatically always active. Suppose the guess is zero where the real spectrum is not. Then the unfolding procedure will never predict that real value. The simulation accuracy thus will not increase. This causes the reduced chi squared to increase instead of decrease. As this is a waste of time and resource, RUFUS stops automatically to prevent wastes. Other scenarios could cause reduced chi squared to increase. RUFUS automatically stops the simulation anytime.

RUFUS shows this message when the simulation is stop due to a reduced chi squared increase.

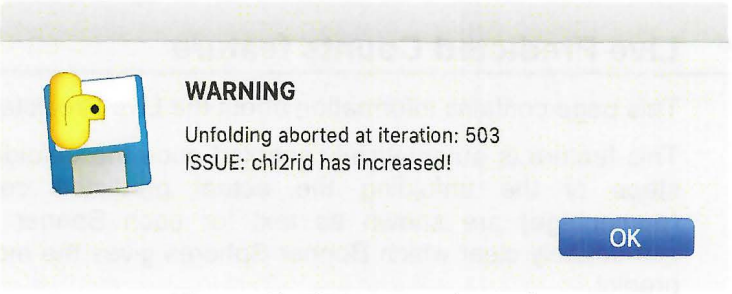



*Figure 19: Chi squared warning*

### 5.2.11 Live Residuals plot feature

This page contains information about the Live Residuals Plot feature.

This feature is automatically enabled once the unfolding starts. Evey 10 steps of the unfolding the residuals (percentage) are plot as a histogram for each Bonner Sphere. Thus, its immediately clear which Bonner Spheres gives the most difficult count to predict.

This is an example of a live residual plot (animation available only in the on-line guide).

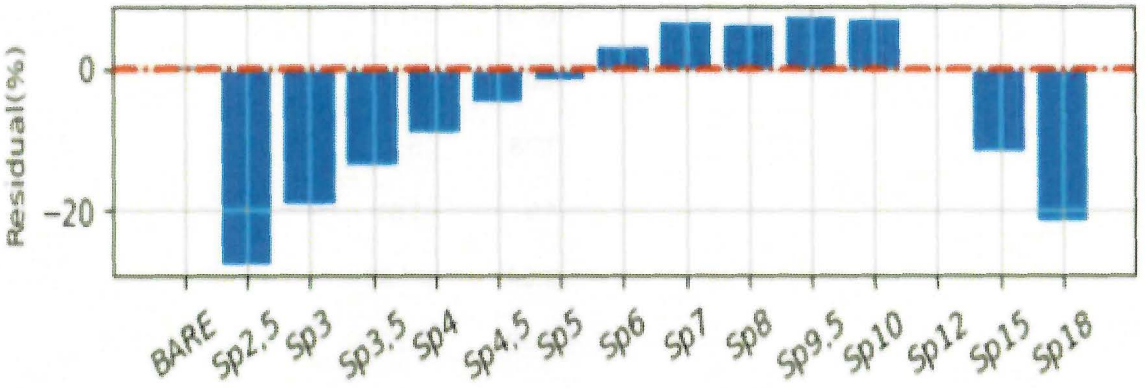



*Figure 20: live residual plot*

### 5.2.12 Live Predicted Counts feature

This page contains information about the Live Predicted Counts feature.

This feature is automatically enabled once the unfolding starts. Evey 10 steps of the unfolding the actual predicted count and residual (percentage) are shown as text for each Bonner Sphere. Thus, its immediately clear which Bonner Spheres gives the most difficult count to predict.

This is an example of a live predicted counts (animation available only in the on-line guide).

| Counts? | Res(%) |
|---|---|
| 0.0 | 2.28 |
| 0.07 | 28.01 |
| 0.21 | 19.9 |
| 0.43 | 15.04 |
| 0.73 | 11.11 |
| 1.05 | 8.01 |
| 1.38 | 5.21 |
| 1.9 | 1.61 |
| 2.24 | -1.38 |
| 2.33 | -2.35 |
| 2.2 | -4.84 |
| 2.11 | -5.46 |
| 1.64 | -3.73 |
| 0.99 | 1.25 |
| 0.6 | 8.4 |

*Figure 21: live predicted counts*

### 5.2.13 Getting Started with RUFUS

Upon starting, RUFUS shows up its main interface:

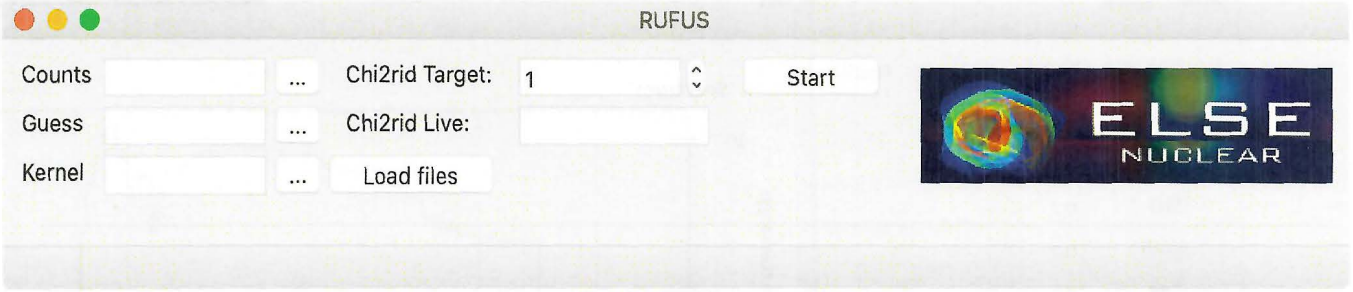



*Figure 22: RUFUS main interface*

The three stacked entry on the left side of the UI let the user load the input files. This table provides a list of input files with a short description and a link to a more throughtful explanation of their specific format.

| Input files | Descriptions |
|---|---|
| Counts File | contains the experimental counts and uncertainties |
| Guess File | contains the guess spectrum for the experimental counts |
| Kernel File | contains the sensitivity kernel of the experimental setup |

Once the desired input files have been chosen, the user must click the **Load** button.

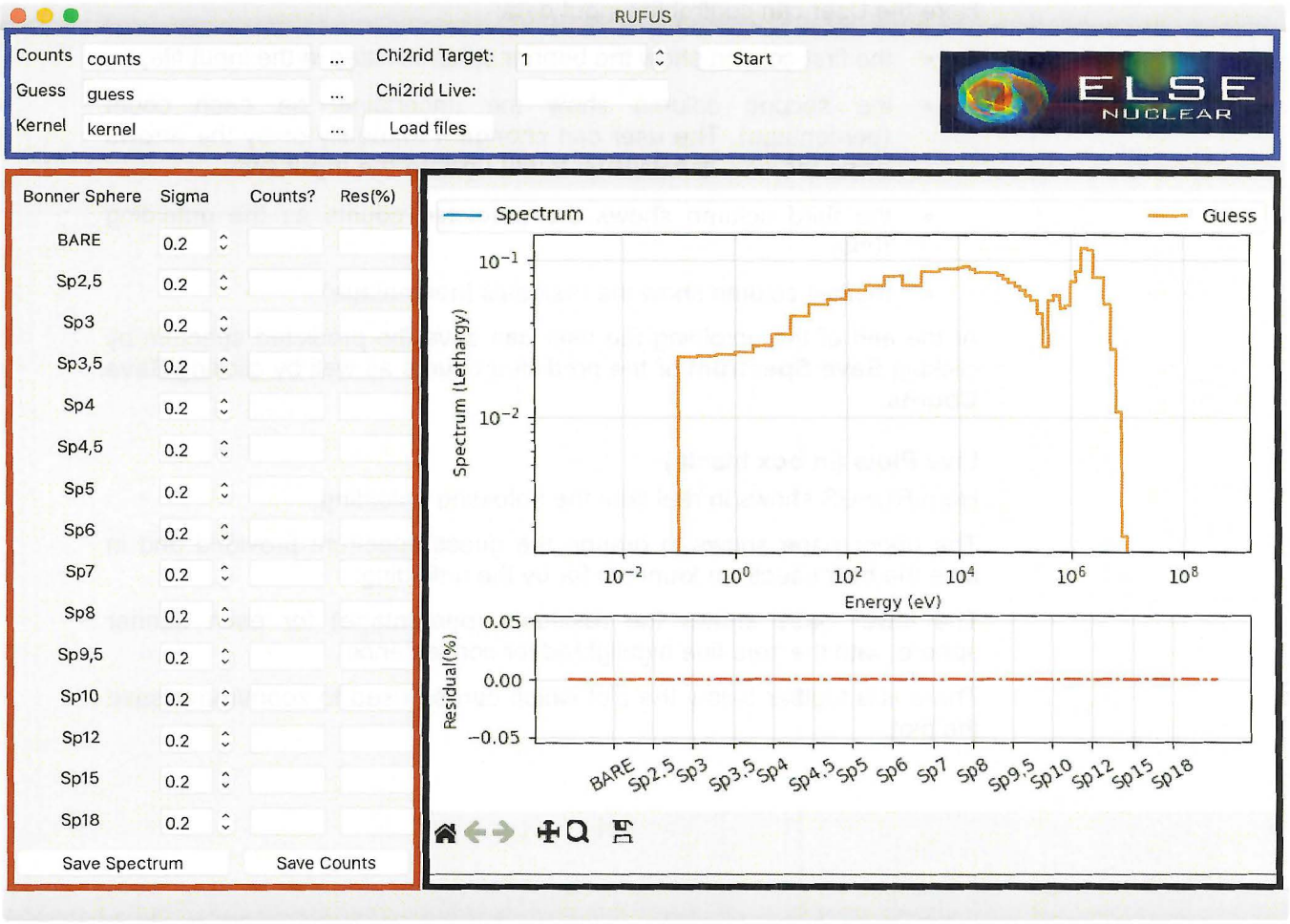
**Be careful to click Load every time the input files change, otherwise RUFUS will work with the previously loaded input files.**

Once input files are loaded, RUFUS will show a window like this:




*Figure 23: RUFUS main window*

Let's split in three main part what you see:




**Controllers (in box blue )**

Here the user can control unfolding:

- the user can change the input files following the above procedure;
- the user can choose the reduced Chi square target for the unfolding, by writing it or using the arrows aside the box;
- the user can see the istantaneous value of reduced Chi square as the unfolding proceeds;
- the user can start the unfolding by pushing **Start** ;
- while the unfolding is running, the user can stop it any time by pushing **Stop** , which appears only during the unfolding as replacement of the start button

**Bonner spheres parameters (in box red )**

Here the User can control the input data:

- the first column show the bonner spheres listed in the input file;
- the second column show the uncertainty on each count (percentage). The user can change it manually or by the arrows aside the box. **WARNING: It will update the input file** ;
- the third column shows the predicted counts as the unfolding runs;
- the last column show the residuals (percentage)

At the end of the unfolding the user can save the predicted spectum by clicking **Save Spectrum** or the predicted counts as well by clicking **Save Counts.**

**Live Plots (in box black )**

Here RUFUS shows in real time the unfolding unfolding.

The upper pane shows in orange the guess spectrum provided and in blue the best spectrum found so far by the unfolding.

The lower pane shows the residuals (percentage) for each bonner sphere, with the zero line highlighted for convenience.

There is a toolbar below the plot which can be used to zoom/move/save the plot.

# Section 6
# **Maintenance**

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## 5.1 Calibration and ordinary maintenance

The content of this chapter refers to the calibration and maintenance activities to be performed by the customer during normal operation of the BSS.

Calibration and recalibration of the BSS must be performed by following the instructions given below.

ELSE NUCLEAR recommends recalibration at intervals no greater than twelve months. Check the appropriate national regulations to determine required recalibration intervals.

The BSS must be calibrated in neutron ambient dose equivalent, H*(10), rate. Unless otherwise specified, the BSS is calibrated in neutron H*(10) rate at the factory.

Before starting the calibration process, be sure that the correct switching on procedure has been correctly followed.

Each detector of the BSS must be exposed to the neutron source with its active centre located at the centre of the irradiation field. The active centre of the detectors is located at half height of the moderating assembly (which needs to remain the same through all the calibrations). Pay attention to the fact that the minimum distance between the neutron source and the moderating assembly surface must be at least equal to three times the height of the moderating assembly itself in order to guarantee neutron field uniformity. In the event that the new calibration factor after recalibration is not within ± 10% of the old one, the detector is defective and requires repair.

Ordinary maintenance consists of keeping the BSS clean and periodically checking the cable connections and the status of the connectors themselves in order to avoid malfunctioning due to leakage currents. The BSS may be cleaned with a damp cloth, by using only water as the wetting agent. Do not immerse the BSS or any of its components in any liquid, as this may cause an irreversible damage to the electronics. Follow the switching off procedure in order to turn the BSS off before starting the cleaning procedure.

## 5.2 Service

The content of this chapter refers to the maintenance activities to be performed by the ELSE NUCLEAR's personnel during regular

interventions foreseen in the maintenance contract (if any) or by the customer specifically authorized to do so by ELSE NUCLEAR.

A more detailed description of the operations here listed is provided in the maintenance contract (if any).

- Check of HV presence and stability
- General check of all the internal power supplies
- Check of the signal level in presence of background radiation
- Good functioning check through the software and/or other applicable procedures
- Dust and dirt on the connectors and in general on electronics elements can generate current losses, altering the measurements and eventually damaging the instrument. Therefore, a cleaning check is required



**Before cleaning the instrument, make sure that it is disconnected from any external power supply (following the proper procedure described in Components connection).**

- Check of the alarm settings
- Check of the functional parameters and algorithm

### 5.2.1 General safety notes

Do not plunge the instrument into liquids: it is not waterproof. Liquids could damage the circuits. Keep the unit clean and free from dirt and contamination.

Do not use chemical detergents.

Use a soft and clean cloth.

Do not use powdered or abrasive solvents on any part of the instrument.

### 5.2.2 Repairs

Do not try to repair this instrument by yourself. Contact ELSE NUCLEAR for any repair related for example to the following events:

- Damaged cables
- Device was exposed to water

- Device does not operate properly although instructions of this manual have been followed
- Damaged device



**Do not send a contaminated instrument for repair or calibration under any circumstance.**

If the instrument requires servicing, please contact ELSE NUCLEAR Service Department at the following address:

| | |
|---|---|
| **Society** | ELSE NUCLEAR s.r.l. |
| **Address** | Via Dante Alighieri, 16<br>21052, Busto Arsizio (VA)<br>ITALY |
| **Telephone** | +39-0331 620533 |
| **Fax** | +39-0331 620533 |
| **E-Mail** | info@elsenuclear.com |

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# Section 7
# **Technical data**

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## 6.1 Detectors

- He-3 spherical proportional counter
- Typical sensitivity: 0.25 cps/μSv/h (when housed in the 8" sphere)
- Housing: HDPE cylindrical inserts for fitting the detectors in the spheres

## 6.2 Bonner spheres

The standard set (which reproduces the worldwide standard PTB NEMUS configuration) includes the following moderators for the proportional counters:

- HDPE moderator: Ø 3", Ø 3.5", Ø 4", Ø 4.5", Ø 5", Ø 6", Ø 7", Ø 8", Ø 10", Ø 12", Ø 15", Ø 18"

## 6.3 Operational acquisition & display software

- Independent data acquisition from each electronic module
- Visualization of each detector counts and status, real-time updating (every second)
- Either manual or automatic Start/Stop with user-settable integration time
- Synchronized Start/Stop commands for all the acquisition inputs
- Graphical display of acquired/archived data
- Data export and storage in ASCII format files

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| DOCUMENT REVISION TABLE | | |
|---|---|---|
| **REV. #** | **DATE** | **REVISION OBJECT** |
| 00 | 11/01/2021 | First emission |
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