MIRION TECHNOLOGIES

Application Note

InSpector™ 1000-based CZT Package for Nuclear Power Plant Isotope Mix Analysis

A collaboration between Mirion/Canberra and EDF, owner of 58 Operating Reactor units in France.

CANBERRA ⟷ EDF

Background on the InSpector 1000 Digital Hand-Held Multichannel Analyzer

A Canberra™ InSpector 1000 Digital Hand-Held Multichannel Analyzer was introduced in 2003. It is a portable spectrometer that is capable of measuring dose-rate with an internal GM detector as well as making dose-rate, nuclide identification and activity measurements with an external gamma scintillation detector probe. An optional, external neutron probe is also available that can be used in parallel with the gamma probe.

IN1K with IPROL-1

The InSpector 1000 unit is available with a large variety of detachable and interchangeable external probes of various sizes and resolution:

- IPRON-1: 1” x 1” NaI(Tl) for difficult accessible areas
- IPROS-2: 2” x 2” NaI(Tl) – Temperature Stabilized for most applications when isotope mix is rather simple
- IPROS-3: 3” x 3” NaI(Tl) – Temperature Stabilized for very low background environmental measurements
- IPROL-1: 1.5” x 1.5” LaBr – Temperature Stabilized for more complex spectral analysis, thanks to its improved resolution (twice better than NaI(Tl))
- IPRON-N – Optional neutron probe for security applications

IPROS-3

IN1K with IPRON-N and IPROS-2

The existing gamma probes are able to generate spectra with optimum quality up to a dose-rate between 25 and 70 µSv/h (2.5 to 7 mrem/h), depending on the size of the probe. This dose-rate limit is considered low for a nuclear power plant when the measurement is near reactor coolant piping. High dose-rates in this area require heavy collimation of the probe which is not always easy to deploy.

Also, many utilities perform ISOCS™ measurements with germanium-based detectors and even heavier shielding and collimation – all transported on a cart. These systems provide extremely precise and absolute measurements when characterizing many critical areas in the plant. However, their use requires additional time for deployment, and some areas are very difficult to access with a cart-based system such that the measurements are not always practical or even possible to perform.

Introduction of the InSpector 1000/CZT Package

These two critical requirements, ***minimal time for deployment with a small, compact spectrometer and ability to perform nuclide identification measurements in a high dose-rate area***, drove Mirion to develop a Cadmium Zinc Telluride (Cd-Zn-Te or CZT) package to go with the existing InSpector 1000 analyzer. While still having good resolution compared to a scintillation detector, CZT detectors are much smaller and less sensitive than scintillation or HPGe detectors and can be operated at room temperature. These features make them perfect for taking gamma spectroscopy measurements in cramped, high dose-rate areas.

The new InSpector 1000/CZT Package includes:

- InSpector 1000 unit
- CZT interface that clips onto the side of the InSpector 1000 unit
- Series (based on expected dose-rate) of color-coded CZT probes that connect to the CZT interface:
  - 5 mm^3 for Dose-rate from 50 mSv/h to 200 mSv/h (5 rem/h to 20 rem/h). ***This probe is optional.***
  - 20 mm^3 for Dose-rate from 10 mSv/h to 50 mSv/h (1 rem/h to 5 rem/h)
  - 60 mm^3 for Dose-rate from 0.1mSv/h to 10 mSv/h (10 mrem/h to 1 rem/h)
  - 500 mm^3 for Dose-rates < 3 mSv/h (300 mrem/h). ***This probe is optional.***

The first three probes (5, 20 and 60 mm^3) have the same external dimensions, allowing the same optional collimator to be used if necessary.

- A 20-meter length cable maximum (optional 5 and 10 meter lengths are also available) to position the InSpector 1000 unit and user far enough from the measurement for ALARA and general safety purposes

- RADMAP software running on a laptop (may be provided by user) with a very simple user interface in order to analyze spectra once they are transferred from InSpector 1000 memory
- Carrying case for all above listed material plus the laptop computer

- An optional collimator is also available to fit 5, 20 and 60 mm^3 probes when the dose-rate in the measurement area is too high for an unshielded probe. The collimator can connect to the top of a standard tripod. Our experience has shown that the collimator is rarely needed. Selection of the proper sensitivity probe is all that is usually required.

What application can benefit from portable InSpector 1000-CZT gamma spectrometer?

A Nuclear Power Plant has to deal with contaminations daily during operation, before and during outages. Uncontrolled contamination can delay the outage start-up and prolong maintenance operations (each additional day of outage adds a significant cost). Contaminations impact heavily on the life cycle of the site. This explains why most of the Chemist and Health Physics teams are searching for contaminants.

We can identify four main focuses:

1. Identify the origin of high dosimetry levels: what are the radio-nuclides and where do they come from?
2. Characterize qualitatively pollutions (contaminants)
3. Identify the cause of these pollutions
4. Follow-up of the cleanup process efficiency

Removing contamination is not the real final goal of utilities. All of them work to identify and remove contamination, but they also need to understand its origin to remove it definitely, if possible. Each isotope/material behaves specifically to its chemistry. It can be very mobile with water movement or stick on cold areas of the pipe making the analysis of the contamination's origin a real challenge.

These isotopes can have various origins with variable impact on the loop's chemistry and dose-rates.

Identifying the origin of high dosimetry:

Below are examples of some typical isotopes that are present in the primary loop:

^{60}Co comes from ^{59}Co activation that is used in valves or pumps and also exist as impurity in alloys (like Stainless steel) used to build primary loop elements like steam generator tubes. It can be seen as particles coming from mechanical degradation of Cobalt based alloys or in ionic form because of the corrosion of Cobalt alloys. Such Cobalt particles are very small (typically from about 2 μg for 70 μm diameter) and can easily generate a dose-rate of 10 mSv/h (1 rem/h) at 50 cm (20 in.) distance. They have a tendency to migrate to lower levels (or dead area) in the loops but are very mobile and can move in the pipes following water behavior.

^{58}Co exists as a soluble and insoluble particle. It comes from ^{58}Ni activation that is used in nickel alloys that is corroded. Presence of ^{58}Co is often the sign of a bad oxygen injection process to clean-up the loops.

^{110m}Ag comes from neutron activation of ^{109}Ag present in control bars made of Silver-Indium-Cadmium or in specific joints. This isotope can also highlight a Cadmium filter replacement or a problem with a destroyed resin.

^{51}Cr comes from high level of chromium alloys like stainless steel in the primary loop. This isotope usually reveals oxidant injection in primary loop but can also be the consequence of filter degradation. Its impact on dose-rate is considered very low because of it low energy gamma ray and short half-life.

Characterize qualitatively pollutions (contaminants) and identify the cause of them:

A gamma spectroscopy analysis provides sufficient information about deposit composition in order to apply the correct contamination clean-up on the pipe and also to investigate the cause of that contamination. These instruments do not require any contamination sampling that can generate significant dose to workers. The spectroscopic probe is placed directly on the pipe and is easy to operate remotely.

Follow-up of the cleanup process efficiency:

A gamma spectroscopy system provides a good result of the clean-up efficiency when the process has been selected to focus on a specific isotope. A measurement of isotope relative contribution of the remaining contamination will demonstrate the good operation on the specific nuclide (e.g. follow-up of the ^{110m}Ag presence in pipes during clean-up, successful elimination of ^{60}Co hot spots, etc.).

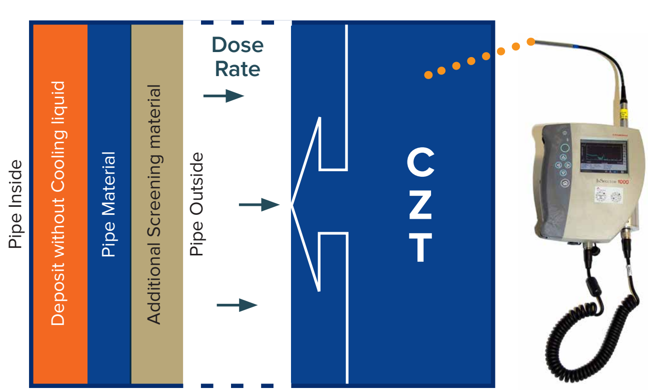
How does the portable InSpector 1000-CZT solve the problem?

The CZT Package is a good answer for *in situ* relative isotope mix analysis where there is no need for absolute quantification of different components at the plant.

Primary Coolant Analysis in a PWR Plant:

For primary loop coolant analysis, chemistry labs usually analyze the soluble isotopes by liquid "grab" sampling. But this only gives part of the picture since insoluble isotopes remain deposited in the coolant piping. Therefore, the measurement needs to be made at the pipe itself with consideration as to whether the sample pipe is full or empty of coolant.

The direct measurement of the pipe gives the isotope contribution to the dose-rate and an attenuation calculation that takes into account the screening material (pipe material and any other material around the pipe). This type of measurement can provide the chemist with the isotopic contribution from the deposit inside the pipe.



Isotopic analysis of residual contamination in pipes also provides key information about the migration of various elements into the cooling system. This information is often useful for determining the status and relative health of the reactor vessel and cooling system components. It can also provide the outage team with decontamination efficiency during the oxygen injection phase that is critical for a good clean-up. A good understanding of the isotope mix helps to correctly define the decontamination process and focus on isotopes of interest to reduce the chemistry impact on the pipe material and also reduce the resulting dose-rate at the working area.

As an example, abnormal ^{60}Co contamination of valves can be mitigated by changing the filtration level to better capture the isotope once it has been identified by RADMAP analysis. Also, we have seen resin break during oxygen injection which can result in significant ^{110m}Ag contamination. The clean-up consists of using a dedicated macro porous resin to capture the colloid form of the isotope. If the HP team is not able to identify ^{110m}Ag early in the process, migration of the isotope can heavily contaminate the entire cooling system with a major dose impact on workers. Finally, ^{124}Sb and ^{51}Cr can reveal a certain type of corrosion in the system, although they usually have a weak impact on dose-rate.

Turbine check in a BWR plant:

A relative isotope mix measurement can reveal plate-out problems in a BWR plant by showing a different ratio of isotopes in the high pressure turbine piping versus the low pressure turbine piping. Analyzing the moisture separators and looking at ^{54}Mn to ^{60}Co ratios is a common check that is done to see if activity is plating out on the low pressure side.

Specific increase of Contamination after Steam Generator replacement:

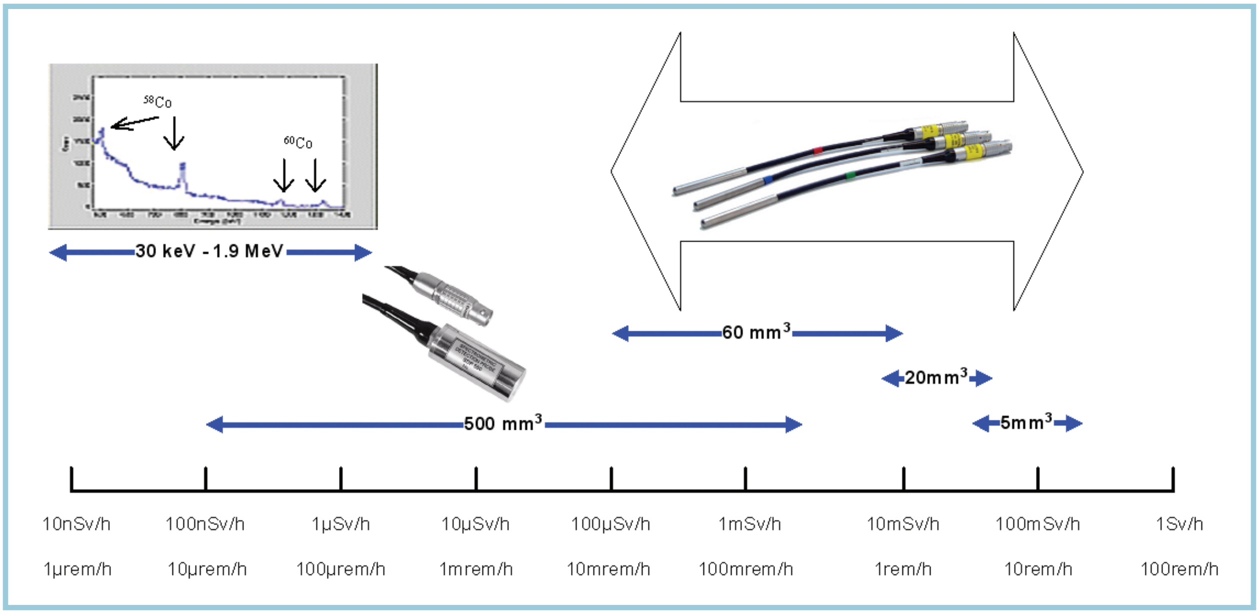
Replacement of a vapor generator in the loop can generate significant contamination of ^{58}Co and a regular follow-up of this isotope with adequate clean-up action can prevent the entire loops from being contaminated. Therefore, InSpector 1000-CZT package can be used proactively when the user expects something to happen and deploy a preventive action plan to mitigate the negative impact.

Qualitative analysis of dose-rate:

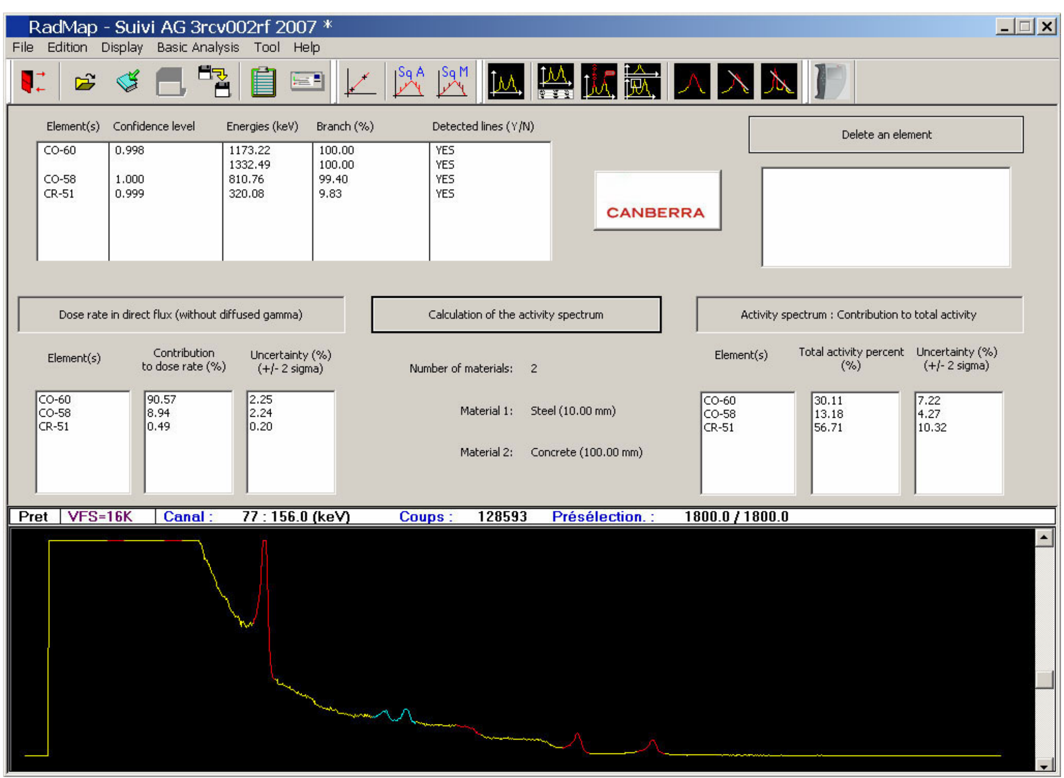
Measurement of isotope contribution to dose-rate provides the Heath Physics team with qualitative information. This helps the HP team to better react and screen a hot spot accordingly with "just enough" protection shielding. CZT spectral analysis is a good tool to minimize the effort needed for optimum protection.

How does the InSpector 1000/CZT Package serve applications in Nuclear Power Plants?

The CZT detector-based InSpector 1000 Package covers the 30 keV – 1.9 MeV energy range and dose-rates up to 200 mSv/h (20 rem/h) in contact with the measurement point. Typical acquisition time is 1,000 seconds.



Analysis is performed on the associated laptop computer using RADMAP software, designed in cooperation with EDF (French NPP owner/operator of 58 reactor units). EDF is using one InSpector 1000-CZT package per nuclear site for contamination analysis). The software is dedicated for the Health Physics team and does not require any extensive spectrometry expertise. The user interface is very simple to use, and automatic analysis sequences have been created to generate a comprehensive result with minimum user interaction.



The RADMAP screen displays three key sections. From top to bottom, they are:

1. Spectrometry initial analysis result with all isotopes found
2. Isotope contribution to dose-rate (left side) and to deposit (right side) with screening material selection in the center
3. Spectral display to ensure peak identification was performed correctly

A top line of dedicated control icons are available to: set specific regions of interest in case of a manual analysis, change display layout (log/Lin, full screen spectrum, peak label toggle) and to transfer spectra from the InSpector 1000 unit to the laptop. A spectrum can always be re-calibrated for energy to ensure a good quality analysis.

The RADMAP application software also generates an analysis report in a text-editable file. It summarizes all information related to the specific measurement:

Analyzed file: AG110m Follow-up 2007

SAMPLE INFORMATION

Sample title:	InSpector 1000 spectrum
Operator name:	user 1
Sample description:	AG110m follow-up
Detailed description:	following activity >1 GBq
Probe type:	CZT 0060
Exposition:	2.5 mSv/h
Date:	10/12/2007 11:00:16
Collimator:	No collimator
Circuit state:	Circuit in water
Measure live time:	1800.00 sec.
Dead time:	1.79%

ANALYSIS RESULTS

Elements	Confidence level	Energies (keV)	Emission percent	Detected
CO-60	0.998	1173.22	100.00	YES
		1332.49	100.00	YES
CO-58	1.000	810.76	99.40	YES
CR-51	0.999	320.08	9.83	YES

REMOVAL OF ANALYSIS ELEMENTS

No removed element

CONTRIBUTION TO DOSE RATE IN DIRECT FLUX

Element	DER contribution in direct flow	Uncertainty (±2 sigma)
CO-60	90.57%	±2.25
CO-58	8.94%	±2.24
CR-51	0.49%	±0.20

ATTENUATION BY MATERIALS

Material 1: Steel (10.00 mm)
Material 2: Concrete (100.00 mm)

ACTIVITY SPECTRUM

Element	Total activity contribution	Uncertainty (±2 sigma)
CO-60	30.11 %	±7.22
CO-58	13.18 %	±4.27
CR-51	56.71 %	±10.32

The CZT-REPORT is a second piece of software that regroups a series of analysis into a summarized Excel spreadsheet, focusing on a limited list of isotopes that represent the main concern in Nuclear Power Plants. These isotopes include fission products and other major contaminators: ^{60}Co, ^{58}Co, ^{110m}Ag, ^{124}Sb, ^{122}Sb, ^{51}Cr, ^{59}Fe, ^{54}Mn, ^{131}I and ^{137}Cs.

Two separate Excel Worksheets display the isotope mix at the chosen locations in dose-rate and in repository activities in a simple, easy to understand format:

PLANT: NPP #1 | **TR:** 2 | **UNIT STATUS:** Stop | **CYCLE:** 3 | **DATE:** 10/12/2007
Building Location: | **Auxiliary:** no | **Fuel:** no | **Reactor:** yes | **OTHER:**

TEST 1

CZT SPECTROMETRIC MEASURES — %DOSE EQUIVALENT RATE

"Localization & Measure characteristics"					%DER BY RADIOELEMENT										
Measure point	Date	Hour	Collimated	Circuit in water	mSv/h	CO-58	CO-60	AG-110m	SB-124	SB-122	CR-51	FE-59	MN-54	I-131	CS-137
InSpector 1000 spectrum	10/12/2007	11:00	No	Yes	2.5	8.94	90.57				0.49				
Gate 3	21/01/2008	11:12	Non	Oui	3.76		99.42				0.58				

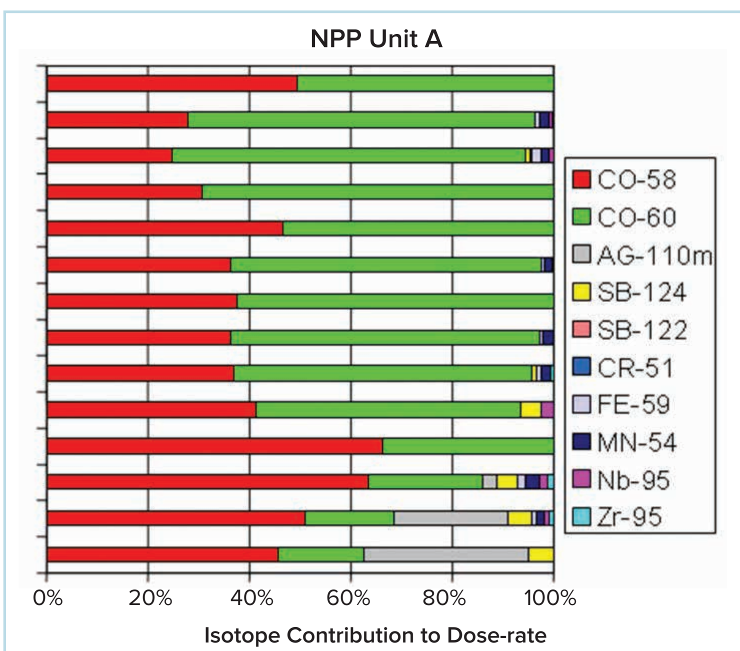
PLANT: NPP #1 | **TR:** 2 | **UNIT STATUS:** Stop | **CYCLE:** 3 | **DATE:** 10/12/2007
Building Location: | **Auxiliary:** no | **Fuel:** no | **Reactor:** yes | **OTHER:**

TEST 1

CZT SPECTROMETRIC MEASURES — %REPOSITORY ACTIVITIES

"Localization & Measure characteristics"					%ACTIVITY										
Measure point	Date	Hour	Collimated	Circuit in water	mSv/h	CO-58	CO-60	AG-110m	SB-124	SB-122	CR-51	FE-59	MN-54	I-131	CS-137
InSpector 1000 spectrum	10/12/2007	11:00	No	Yes	2.5	13.18	30.11				56.71				
Gate 3	21/01/2008	11:12	Non	Oui	3.76						100				

A graph can easily be generated of the results using Excel tools to follow-up. See example below.



Benefits of the InSpector 1000/CZT Package for the application include:

	FEATURES	ADVANTAGES	BENEFITS
InSpector 1000/CZT Hardware	Various sizes of CZT probe: 5, 20, 60 & 500 mm^3	Select the best probe for the dose-rate Good measurement FWHM	One instrument covers all *in situ* situations for immediate response in the field Better complex spectrum analysis than NaI detectors Worker dose reduction
	Cables 5, 10 or 20 meters	Place the probe close to the source and keep a safe distance away to control the unit	Allows the instrument to be used in tight spaces with the operator in a more open area
	Compact and easy to transport	Always available and rapidly deployed	Facilitates measurements that were much more expensive or impossible to make in the past
RADMAP Software	Measures isotopes' contribution to dose-rate	Dose-rate analysis with better knowledge of the source(s) of the dose	More effective design of shielding for worker protection Minimum additional effort for a more results-based ALARA approach
	Measures isotopes' contribution to activity	Chemical interaction analysis with identified isotopes	More focused decontamination with immediate feed-back of results Provides key information for structure life extension

Technical information

CZT probes:

Each probe is mounted with 270 mm (10.6 in.) cable length and LEMO® connector that connect on CZT interface.

Probe Name	CdZnTe Detection Volume	Typical Resolution for ^{137}Cs (662 keV)	Probe diameter	Probe length without cable
CZT-005S	5 mm^3	10 keV	8 mm – 0.31 in.	89 mm – 3.5 in.
CZT-020S	20 mm^3	10 keV	8 mm – 0.31 in.	89 mm – 3.5 in.
CZT-060S	60 mm^3	15 keV	8 mm – 0.31 in.	89 mm – 3.5 in.
CZT-500S	500 mm^3	20 keV	24 mm – 0.95 in.	58 mm – 2.28 in.

Ordering references

EM88862	IN1K-CZT-PACK/E	IN1K-CZTpackage, – InSpector 1000 IN1K with Genie™ 2000 S504C and S501C – Interface electronic for CZT probes – 60 mm^3 CZT probe CZT-060S – 20 mm^3 CZT probe CZT-020-S – RADMAP software English version – 20 meter cable for probe connection to CZT interface – Carrying case with precut foam holes for laptop computer and all above items	including
EM88860	IN1K-CZT-PACK/F	IN1K-CZTpackage, – InSpector 1000 IN1K with Genie 2000 S504C and S501C – Interface electronic for CZT probes – 60 mm^3 CZT probe CZT-060S – 20 mm^3 CZT probe CZT-020-S – RADMAP software French version – 20 meter cable for probe connection to CZT interface – Carrying case with precut foam holes for laptop computer and all above items	including
EM80020 EM80019 EM80018 EM88863	CZT-005S CZT-020S CZT-060S CZT-500S	5 mm^3 CZT probe 20 mm^3 CZT probe 60 mm^3 CZT probe 500 mm^3 CZT probe	for IN1K-CZT for IN1K-CZT for IN1K-CZT for IN1K-CZT
EM83878 EM83877 EM80215	CZT-CABLE-5 CZT-CABLE-10 CZT-CABLE-20	5 meters cable 10 meters cable 20 meters cable	for IN1K-CZT for IN1K-CZT for IN1K-CZT
EM81955	CZT-CASE	Carrying case with precut foam holes for laptop computer and all CZT items	
EM88867	CZT-COL	Collimator for 5, 20 or 60 mm^3 CZT – 20 mm of lead with 3 mm copper liner – 6 mm hole with 15° cone opening – Stainless steel finishing, 2 mm thickness – threaded insert for tripod	probes
EM88868	CZT-TRIPOD	Tripod – allow use of CZT collimator	

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