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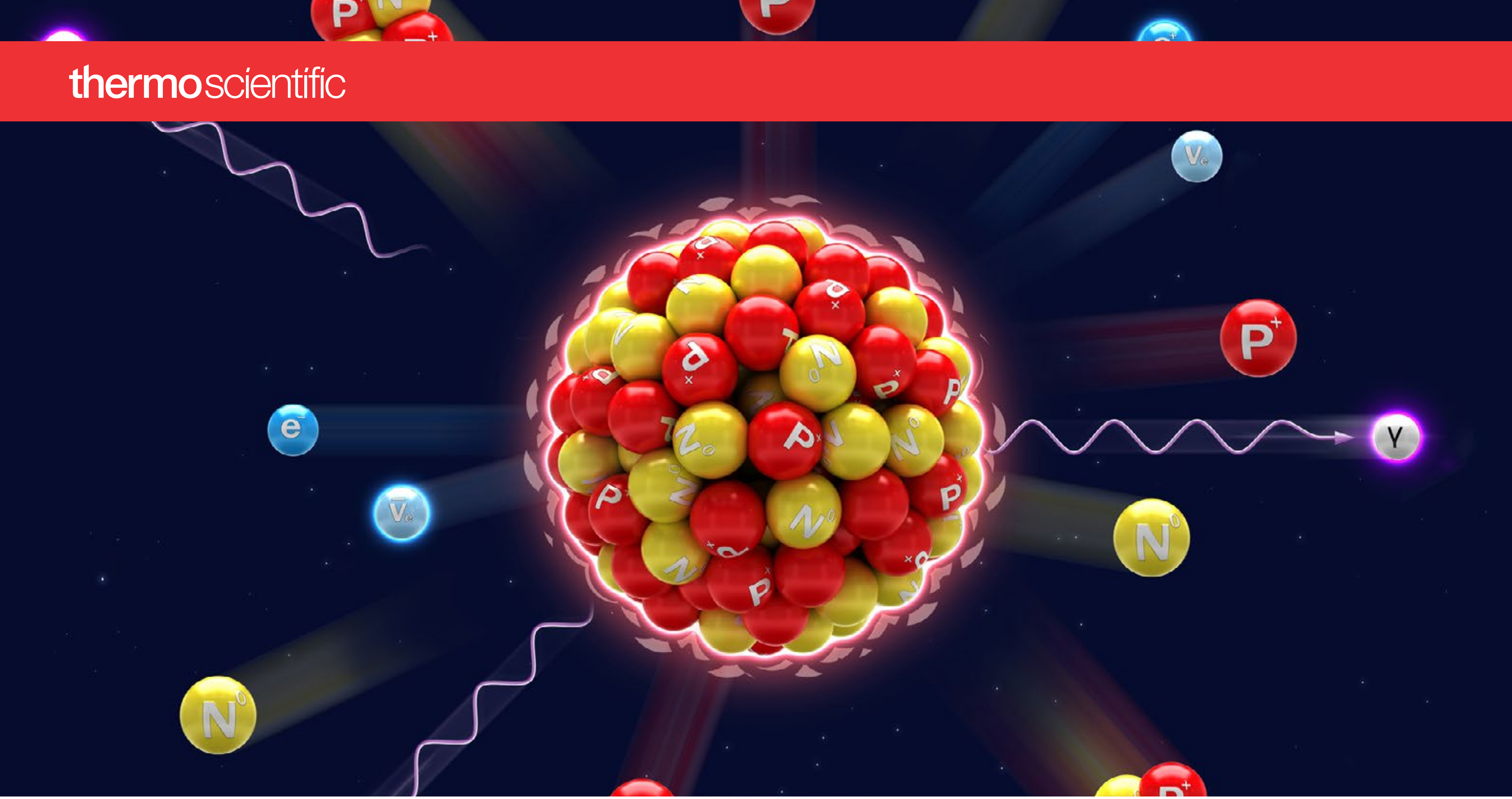

PGNAA and PFTNA technology for non-scientists

Prompt gamma neutron activation analysis
Pulsed fast thermal neutron activation

ThermoFisher SCIENTIFIC

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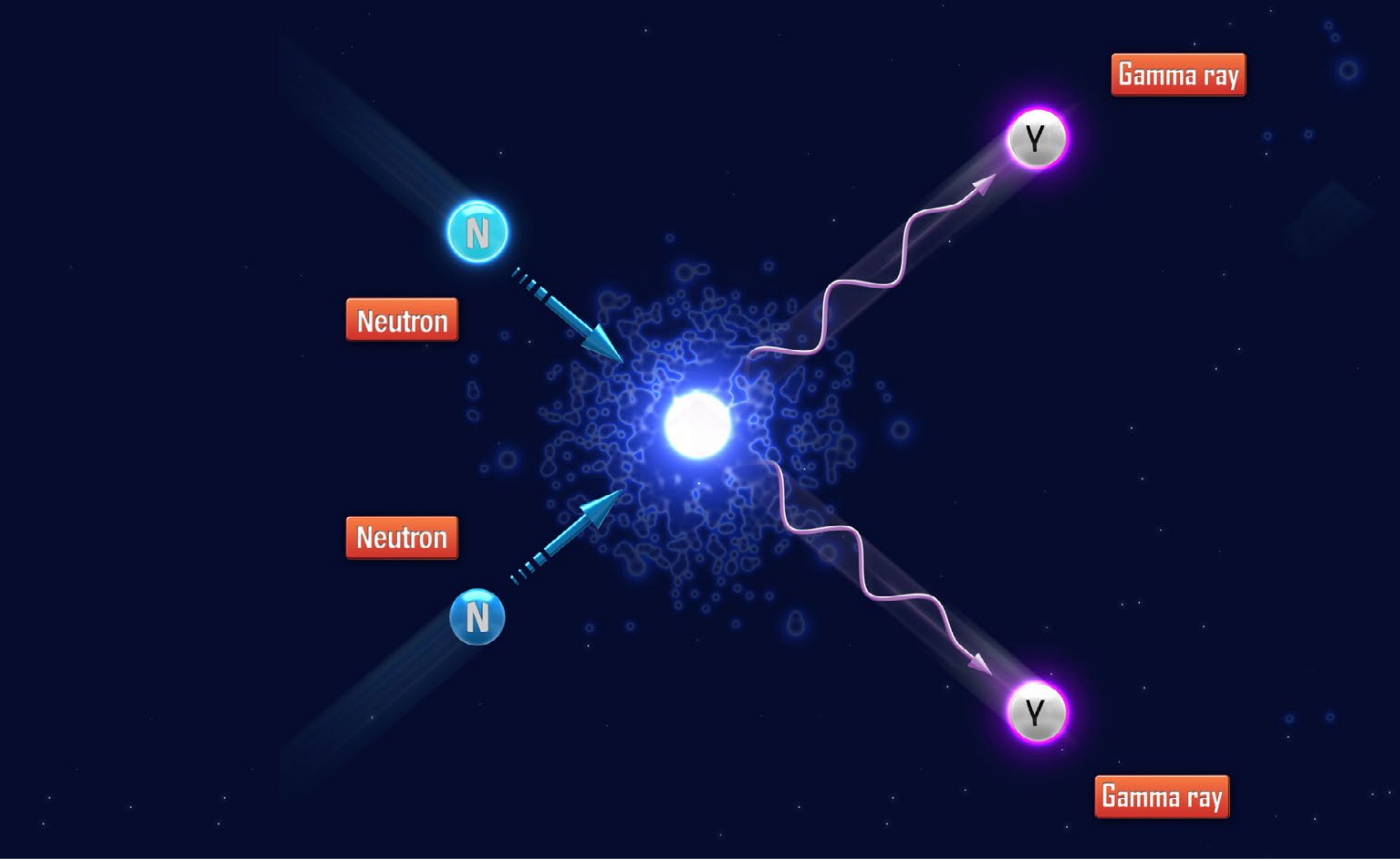

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Overview

What is PGNAA

What are PGNAA and PFTNA

Prompt Gamma Neutron Activation Analysis (PGNAA) and **Pulsed Fast Thermal Neutron Activation (PFTNA):** non-contact, non-destructive analytical techniques used in online analysis systems to determine the elemental composition of bulk raw materials.

Neutron activation analysis

Both PGNAA and PFTNA techniques are known collectively as neutron activation analysis and function by bombarding materials with neutrons. Neutrons interact with elements in the materials, which then emit secondary, prompt gamma rays that can be measured. Neutrons are highly penetrating and pass through and interact with materials (dense materials too) such as rock. This is advantageous because other techniques for analysis are only surface analysis techniques whereas with Neutron Activation Analysis pass into the materials and can measure the entire volume of materials rather than just the surface.

Gamma rays

Gamma rays are a form of electromagnetic radiation that can be measured. Similar to X-ray fluorescence (XRF), each element emits a characteristic energy signature as it returns to a stable state.

Gamma rays have the smallest wavelengths and the most energy of any wave in the electromagnetic spectrum. They are produced by supernovas and neutron stars, but can be generated by nuclear explosions, lightning, and radioactive decay. Due to their small wavelength and high energy, gamma-rays have the ability to penetrate through materials and reach the detectors after the neutron interaction within the materials creates gamma-rays.

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How neutron activation analysis works

Fingerprints

Each of the elements present in a sample produces a unique set of characteristic prompt gamma rays that are “fingerprints” for that specific element.

It all starts with the atom

Atoms are the extremely small particles of which we, and everything around us, are made. There are 92 naturally occurring elements and scientists have made more, bringing the total to 114 confirmed and at least 4 more claimed. Atoms are the smallest unit of an element that chemically behaves the same way the element does.

Atoms bond with other atoms to form a molecule. If two hydrogen atoms bonded with an oxygen atom, they would form a water molecule.

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How neutron activation analysis works

Anatomy of the atom*

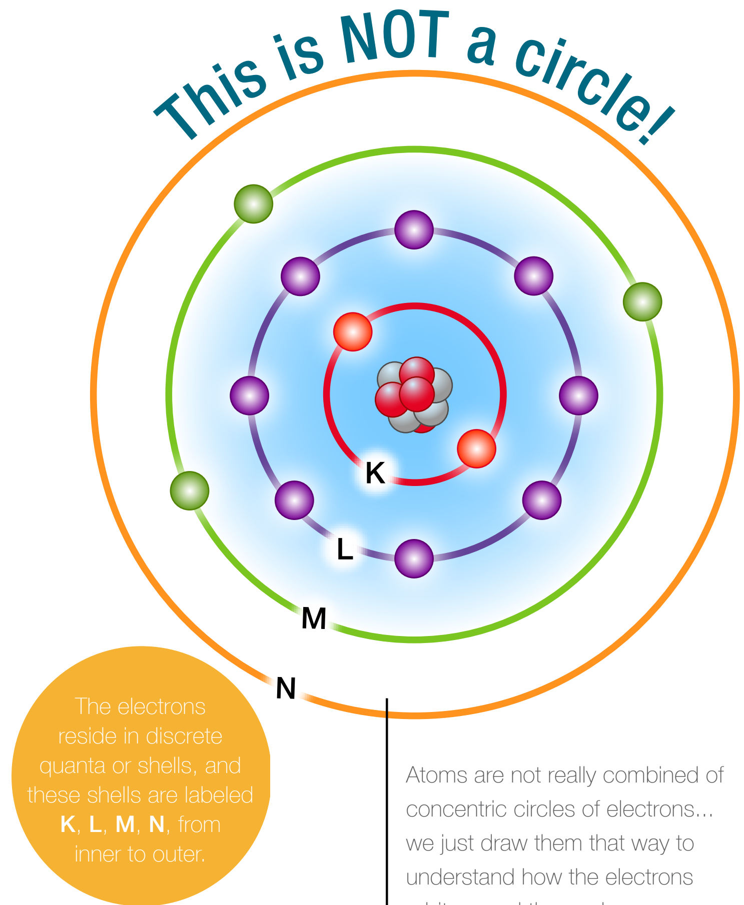
In the center of the atom is the nucleus, made up of **protons** and **neutrons**. Each proton carries a positive electrical charge, but neutrons carry no electrical charge, so the nucleus of an atom is positively charged because of its protons.

Electrons are particles that orbit the nucleus at a high speed and carry a negative charge, which balances the positive electrical charge of the protons in the nucleus. Since the total negative charge of electrons is equal to the positive charge of the nucleus, an atom is neutral.

The negative electrons are attracted to the positive protons, so the electrons stay around the nucleus in discrete shells.

When two chemicals react with each other, the reaction takes place between individual atoms at the atomic level. The outermost or covalent electrons are involved in this bonding.

The processes that cause materials to become radioactive occur within the nucleus of an atom through a change in energy state. The resultant gamma-ray represents the atom from which it was generated. On account of the this type of interaction, the form in which the atom may be bound in not relevant and the gamma-ray signature is the same for different chemical forms.



Atoms are not really combined of concentric circles of electrons... we just draw them that way to understand how the electrons orbit around the nucleus.

*this section site reference: http://www.epa.gov/radiation/understand/atom.html

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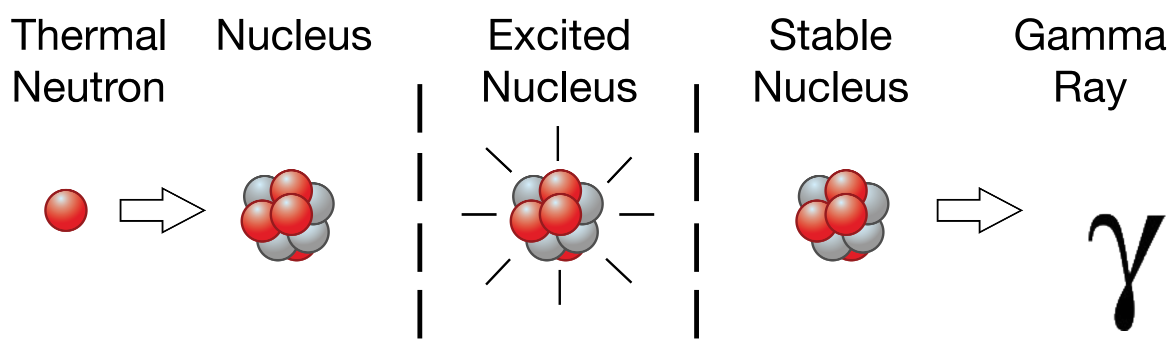
The PGNAA and PFTNA process

Prompt gamma neutron activation analysis and pulsed fast thermal neutron activation are based on a subatomic reaction between a low energy neutron and the nucleus of an atom.

1. When a thermal, or rather low energy neutron (<0.025 eV) approaches near enough to, or collides with, a nucleus of an atom, an interaction between the neutron and the nucleus takes place.
2. Energy from the neutron is transferred to the nucleus and temporarily elevates it to an excited energy state.
3. The energy is then released, nearly instantaneously, in the form of a singular or many multiple gamma rays.
4. The gamma rays produced have distinct energies associated with the atom from which it was released. (In essence the gamma-rays emitted are like a “fingerprint” of the element.)
5. The emitted gamma-rays are detected and an energy spectrum generated which can then be analyzed for elemental composition.



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The periodic table

Number of protons = Atomic Number (different for each element).

Number of electrons typically = number of protons (so that the atom is neutral).

Number of neutrons is variable and is what allows some atoms to have isotopes.

Electrons in shells closest to the nucleus are most strongly bound to the atom.Binding energy increases with atomic number. The higher the number, the higher the weight.

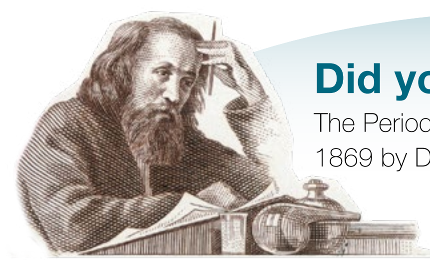
An isotope of an element has the same number of protons but a different number of neutrons.

What is an element?

An element is a chemically pure substance composed of atoms. Elements are the fundamental materials of which all matter is composed.

The elements are arranged in increasing order of their atomic weight (the number of protons in the nucleus of an atom).

1 H																	2 He
3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
55 Cs	56 Ba	57 *La	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
87 Fr	88 Ra	89 +Ac	104 Rf	105 Ha	106 Sg	107 Ns	108 Hs	109 Mt	110 **Ds**	111 **Rg**	112 **Cn**	113 113	114 **Fl**	115 **115**	116 **Lv**		
		58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu		
		90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr		



Did you know?

The Periodic Table was created in 1869 by Dmitry I. Mendeleev.

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List of periodic table elements

1 Hydrogen	H	21 Scandium	Sc	41 Niobium	Nb	61 Promethium	Pm	81 Thallium	Tl	101 Mendelevium	Md
2 Helium	He	22 Titanium	Ti	42 Molybdenum	Mo	62 Samarium	Sm	82 Lead	Pb	102 Nobelium	No
3 Lithium	Li	23 Vanadium	V	43 Technetium	Tc	63 Europium	Eu	83 Bismuth	Bi	103 Lawrencium	Lr
4 Beryllium	Be	24 Chromium	Cr	44 Ruthenium	Ru	64 Gadolinium	Gd	84 Polonium	Po	104 Rutherfordium	Rf
5 Boron	B	25 Manganese	Mn	45 Rhodium	Rh	65 Terbium	Tb	85 Astatine	At	105 Dubnium	Db
6 Carbon	C	26 Iron	Fe	46 Palladium	Pd	66 Dysprosium	Dy	86 Radon	Rn	106 Seaborgium	Sg
7 Nitrogen	N	27 Cobalt	Co	47 Silver	Ag	67 Holmium	Ho	87 Francium	Fr	107 Bohrium	Bh
8 Oxygen	O	28 Nickel	Ni	48 Cadmium	Cd	68 Erbium	Er	88 Radium	Ra	108 Hassium	Hs
9 Fluorine	F	29 Copper	Cu	49 Indium	In	69 Thulium	Tm	89 Actinium	Ac	109 Meitnerium	Mt
10 Neon	Ne	30 Zinc	Zn	50 Tin	Sn	70 Ytterbium	Yb	90 Thorium	Th	110 Darmstadtium	Ds
11 Sodium	Na	31 Gallium	Ga	51 Antimony	Sb	71 Lutetium	Lu	91 Protactinium	Pa	111 Roentgenium	Rg
12 Magnesium	Mg	32 Germanium	Ge	52 Tellurium	Te	72 Hafnium	Hf	92 Uranium	U	112 Copernicium	Cn
13 Aluminum	Al	33 Arsenic	As	53 Iodine	I	73 Tantalum	Ta	93 Neptunium	Np	113 Ununtrium	113
14 Silicon	Si	34 Selenium	Se	54 Xenon	Xe	74 Tungsten	W	94 Plutonium	Pu	114 Flerovium	Fl
15 Phosphorus	P	35 Bromine	Br	55 Cesium	Cs	75 Rhenium	Re	95 Americium	Am	115 Ununpentium	115
16 Sulfur	S	36 Krypton	Kr	56 Barium	Ba	76 Osmium	Os	96 Curium	Cm	116 Livermorium	Lv
17 Chlorine	Cl	37 Rubidium	Rb	57 Lanthanum	La	77 Iridium	Ir	97 Berkelium	Bk		
18 Argon	Ar	38 Strontium	Sr	58 Cerium	Ce	78 Platinum	Pt	98 Californium	Cf		
19 Potassium	K	39 Yttrium	Y	59 Praseodymium	Pr	79 Gold	Au	99 Einsteinium	Es		
20 Calcium	Ca	40 Zirconium	Zr	60 Neodymium	Nd	80 Mercury	Hg	100 Fermium	Fm		

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Technology

Analyzer components

PGNAA analyzers are situated directly on the conveyor belt and penetrate the entire raw material cross-section, providing minute-by-minute, uniform measurement of the entire material stream, not just a sub-sample. Surface analysis technologies such as XRF, X-ray diffraction (XRD), and other spectral analysis technologies measure limited depths and surface areas that may not be representative of the entire amount of material on the belt. With PGNAA, sample errors are reduced, and the high-frequency of analysis helps reduce variation in material quality.

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Detecting the gamma rays

PGNAA and PFTNA online analyzers detect and 'read' the gamma rays using scintillation detectors.

These detectors are composed of a high purity crystalline structure which, when exposed to gamma rays, produces photons proportional in energy to the energy of the gamma rays that enter the crystal.

1. A photon detector coupled to the crystal converts the pulses of light into electrical signals proportional in energy to the photon.

2. Sophisticated high-speed electronic circuits then amplify and process the electrical pulses, yielding a composite energy spectrum.

3. The spectrum is analyzed to determine information about specific elements.

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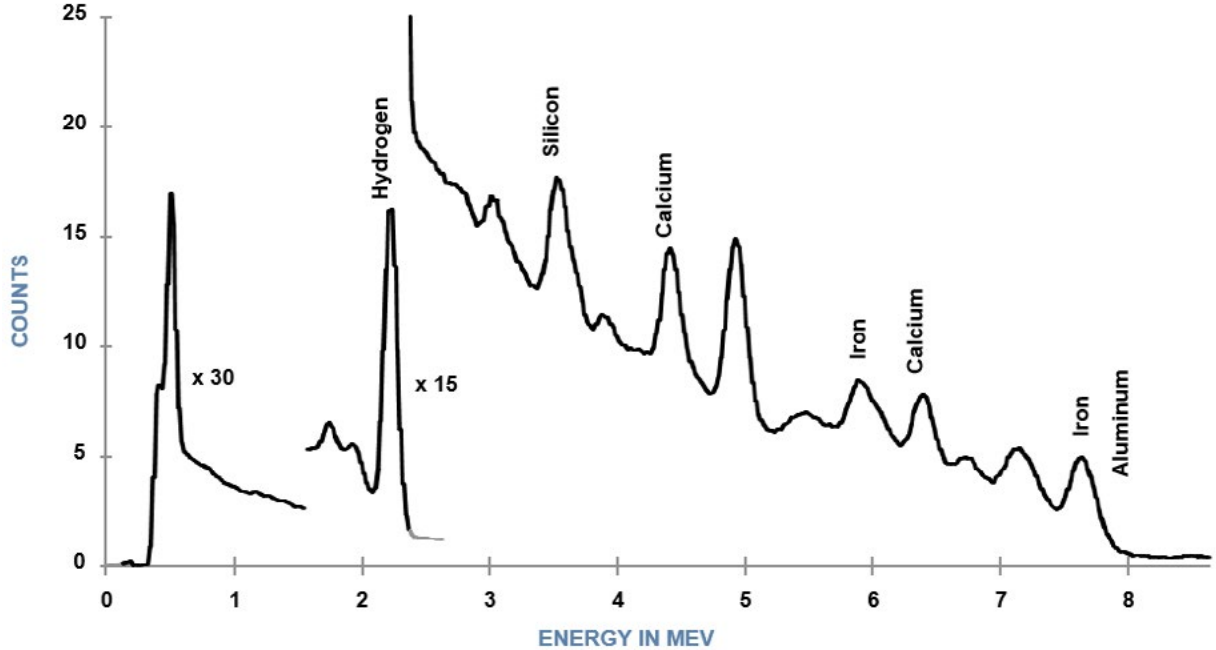
PGNAA energy spectrum

Each element has a different tendency to interact with neutrons; those elements with a high neutron cross-section are easier to measure than those with a low neutron cross-section. There must also be a sufficient amount of the element to interact with the neutrons. What is noted as the "threshold of detection" for an element is a function of the amount of material being analyzed (the percentage of the element in the material) and the tendency for that element to interact with neutrons (neutron cross-section).



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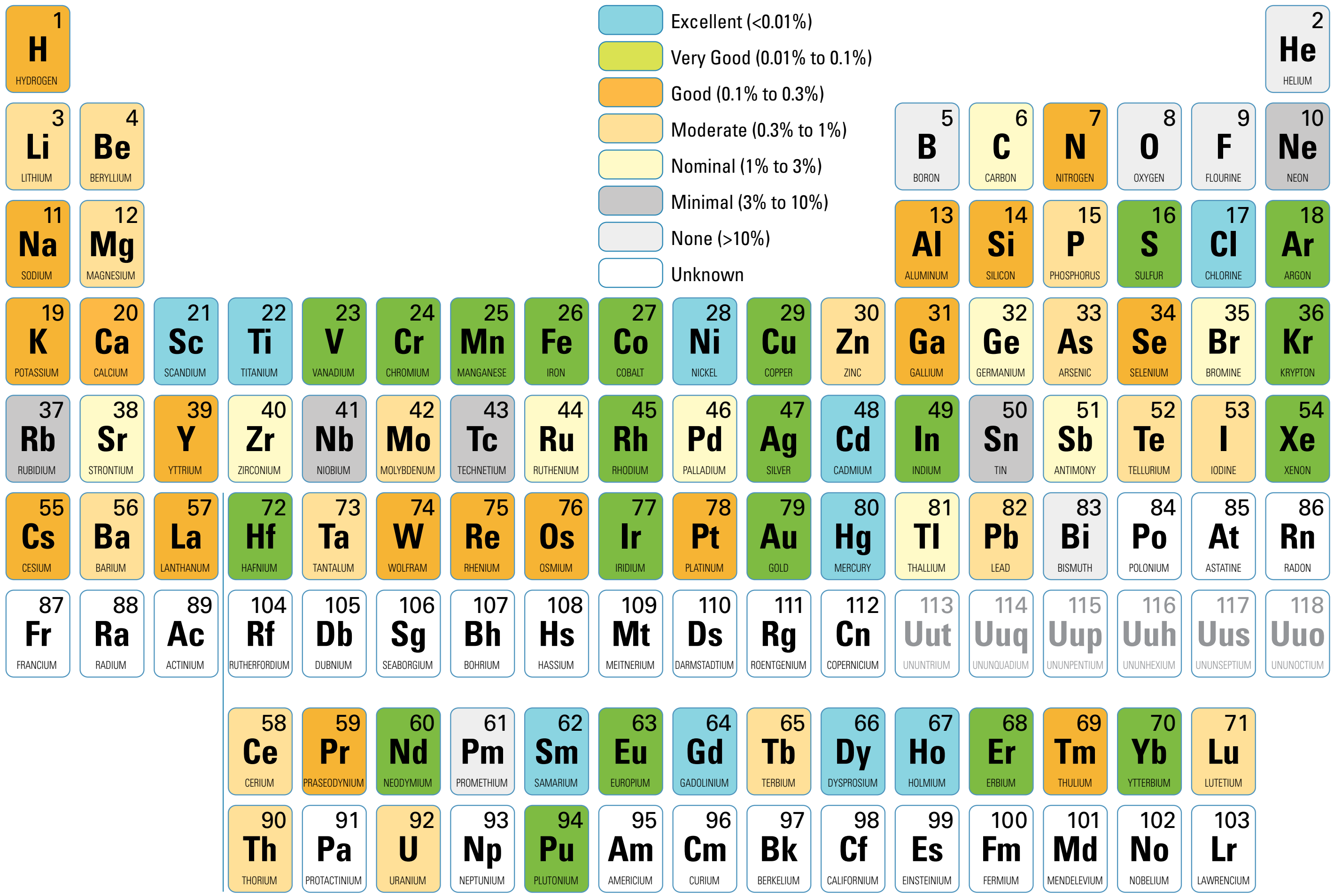
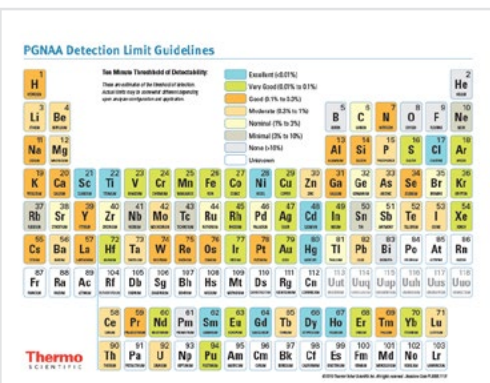
PGNAA detection limit guidelines

Ten minute threshhold of detectability:

These are estimates of the threshold of detection. Actual limits may be somewhat different depending upon analyzer configuration and application.





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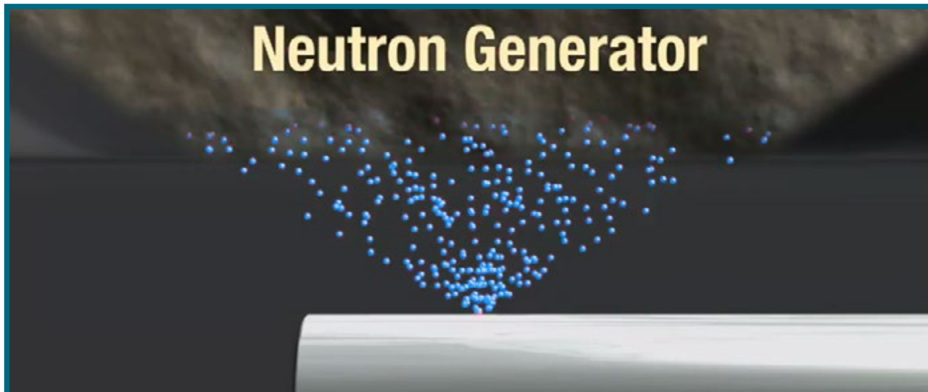
Neutron supply

Neutrons used in the analysis technique can be supplied by either a radioisotope Californium 252 (^{252}Cf) or from a neutron generator system.



Radioisotope Californium 252 (^{252}Cf)	Neutron Generator
Undergoes spontaneous fission.	Produced electrically in a special type of compact linear accelerator.
Produces neutrons that are used in the analysis process.	Isotopes of hydrogen, deuterium (^{2}H) and tritium (^{3}H), are utilized in a fusion reaction to produce the neutrons.
Average energy of 2.6 MeV and a most probable energy of 0.7 MeV.	A fairly high energy, 14 MeV, and are considered “fast” neutrons.
Energy must be reduced and most neutrons converted to thermal neutrons.	Energy must be reduced and most neutrons converted to thermal neutrons.

**When neutrons are supplied using a neutron generator, the term PFTNA is used as it describes what is taking place to allow PGNAA (see next page).*

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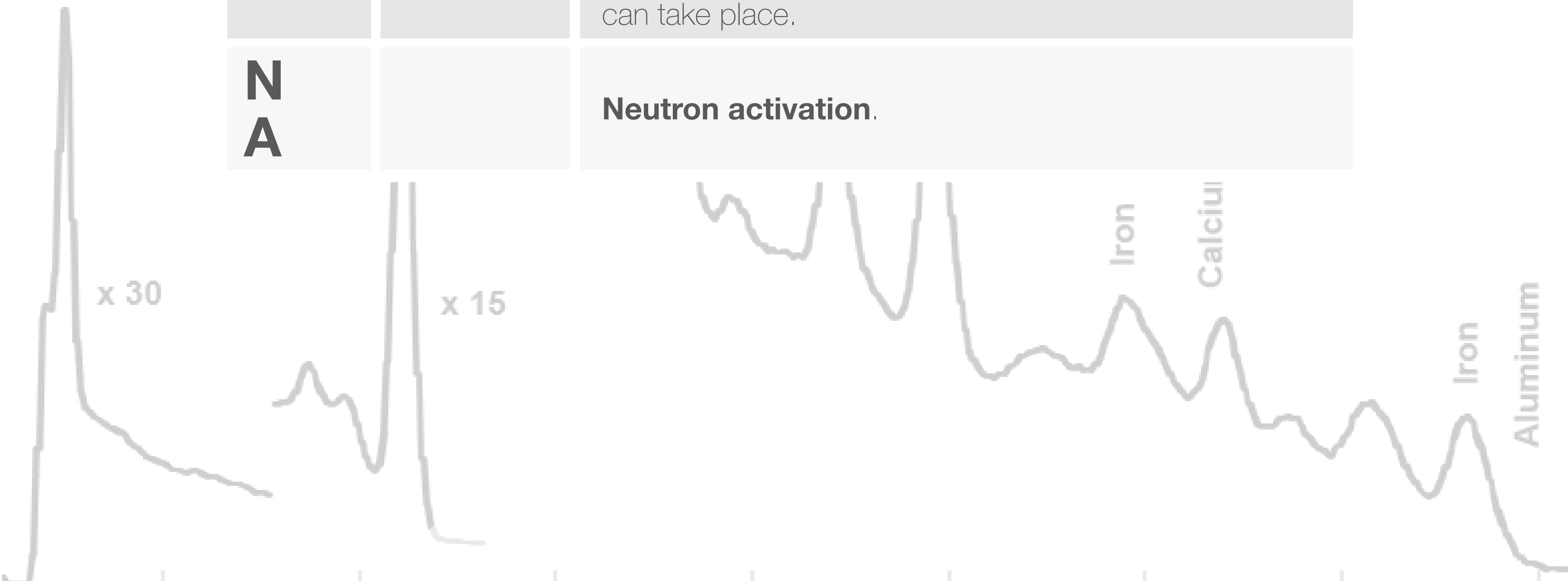
The PFTNA process

P	Pulsed	A neutron generator can be "**Pulsed**" and the time in-between pulses can sometimes also be used to measure certain elements.
F	Fast	Neutrons emitted from a neutron generator are considered "high energy" at 14 MeV and are termed "**Fast**" neutrons.
T	Thermal	The Fast neutrons must be reduced to an energy range termed "**Thermal**" neutrons so that the PGNAA process can take place.
N A		**Neutron activation**.



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Is neutron activation analysis safe to use?

Radiation

PGNAA technology uses Cf-252 or a neutron generator to produce analysis. Each of these produce low levels of radiation but reasonable effort should be made to maintain exposures to radiation as far below dose limits as practical. This is known as the ALARA (As Low as Reasonably Achievable) principle. For any given source of radiation, three factors will help minimize your radiation exposure:

Time **Distance** **Shielding**

Click here to download
the Gamma Radiation Safety guide

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Applications and equipment

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Applications

Thermo Scientific cross-belt analyzers are used in cement, coal and sintering applications as well as for processing other bulk materials such as lime, industrial minerals for refractories and blast furnace feeds, copper, iron ore, etc., to help ensure consistent material quality and process optimization.

Iron ore sintering process in steel manufacturing

The Thermo Scientific CB Omni analyzer for sinter measures sinter feed chemistry on-line and provides high-frequency (minute-by-minute or less) compositional analysis data to enable control of basicity in real time. Sinter quality begins with the proper selection and mixing of the raw materials. Inhomogeneous raw mix can affect permeability and cause an increase in fuel consumption.

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Cement applications and products

The Thermo Scientific CB Omni Fusion online elemental analyzer provides a reliable and accurate means of achieving consistent stockpile and raw mix chemistry to improve kiln efficiency and minimize production costs. This unique system provides high-frequency (minute-by-minute) compositional analysis of the raw materials used in the cement manufacturing process.

- Ease of installation
- Detector flexibility
- Flexibility in source of neutrons
- Proven solutions and support
- Legacy upgrades

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Minerals

In the mineral processing community, ore sorting and routing is a way of improving the efficiency of mining operations. The CB Omni Fusion online elemental analyzer provides high frequency online elemental analysis of an entire raw material process stream using PGNAA or PFTNA. It delivers consistent material quality, improves process efficiency and minimizes production costs in a variety of different process and mining operations, including limestone, lime, copper, iron ore, refractory & blast furnace minerals, cement production, iron ore sintering, and more.

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Coal applications and products

The Thermo Scientific Elemental Crossbelt analyzer (ECA-3) is used to control the sorting and blending of coals to maximize coal resources, reduce out-of-seam dilution and control preparation plant performance. The analyzer is designed for applications requiring process accuracy at a modest cost.

- Mounts around existing conveyor belt
- Provides high-frequency (minute-by-minute or less) compositional analysis

The Thermo Scientific Coal Quality Manager (CQM FLEX) is the ultimate analyzer with the best accuracy available, which allows you to minimize variations in coal quality, ensure contract compliance, and improve your efficiency. It is the product of choice for coal producers and utilities where real-time knowledge of coal quality is critical, including load-outs, auger samplers and power plant bunker feed systems.

- Most accurate online analyzer in the industry
- Ideal in loadouts, prep plant control and bunker feed applications
- Available with Cf-252 or neutron generator

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CB Omni Fusion online elemental analyzer

PGNAA and PFTNA is explained and illustrated in this video that shows how online raw materials are analyzed at a cement facility.

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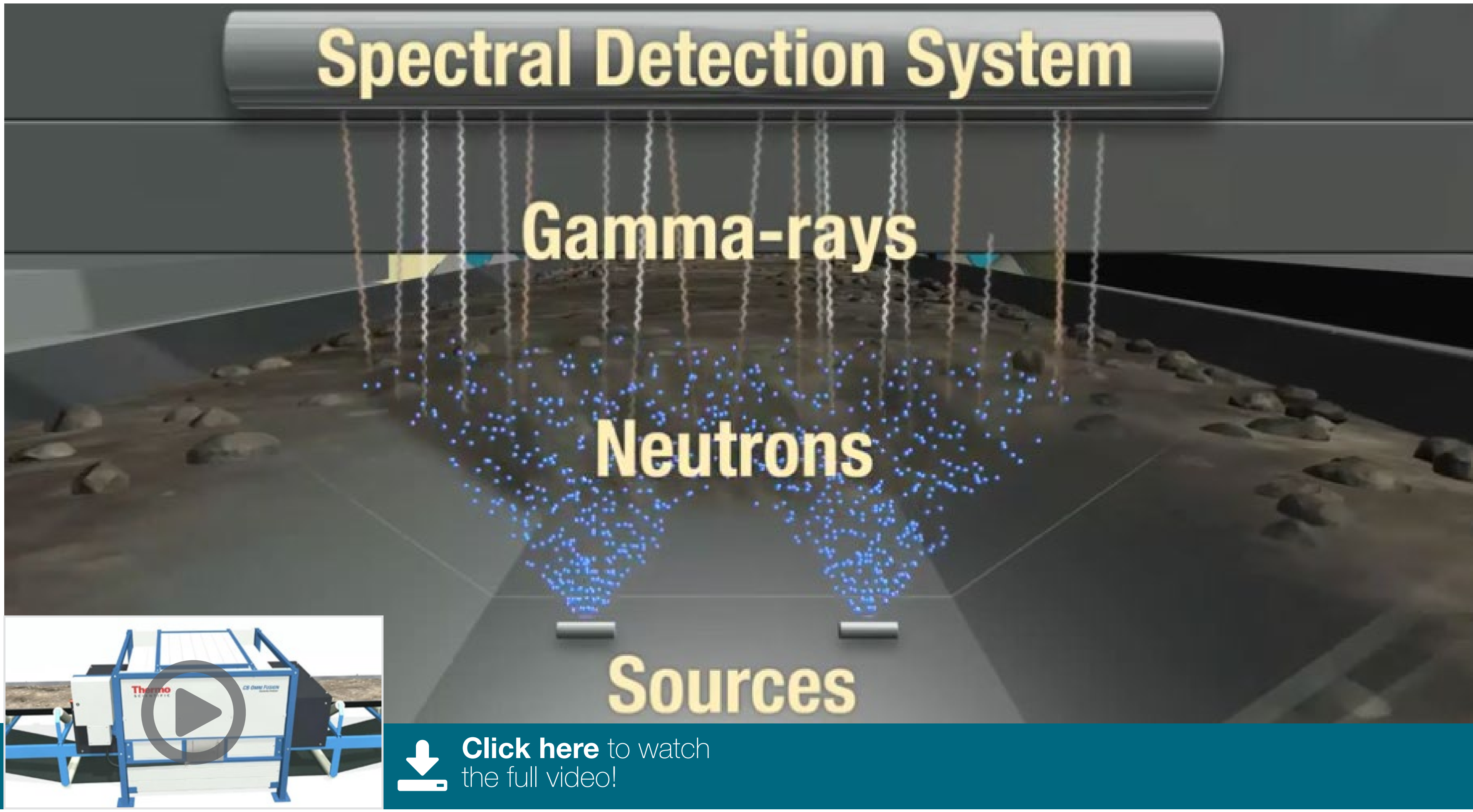

Click here to watch the full video!

Choose the system that's right for you




	CB Omni Fusion online elemental analyzer	CQM FLEX coal analyzer	ECA-3 elemental crossbelt analyzer	GS Omni analyzer
On belt analyzer	✓		✓	
Belt sizes (600 mm to 2200 mm)	✓		✓	
Sample stream analyzer		✓		✓
Elemental analysis	✓	✓	✓	✓
Coal		✓	✓	
Cement	✓			✓
Lime	✓			
Refractory minerals	✓			✓
Copper	✓			✓
Iron ore	✓			✓
Phosphates	✓			✓
Other bulk materials	✓			✓
Neutron generator capable	✓	✓		
Cf-252 capable	✓	✓		✓

Click here to access the full product selection guide

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For additional information or to request a quote, please click below.

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thermofisher.com/pgnaa-pftna

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