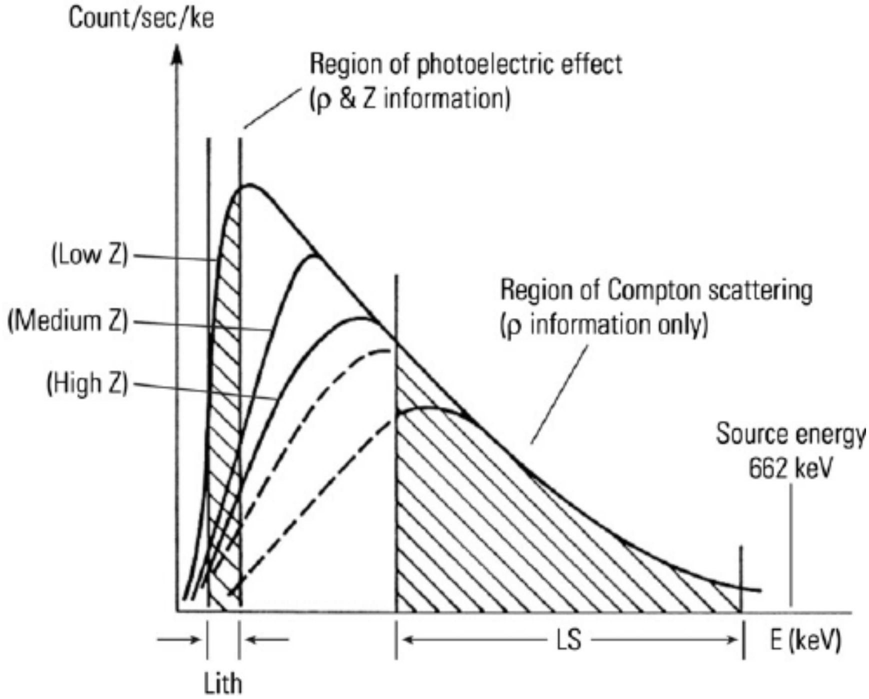
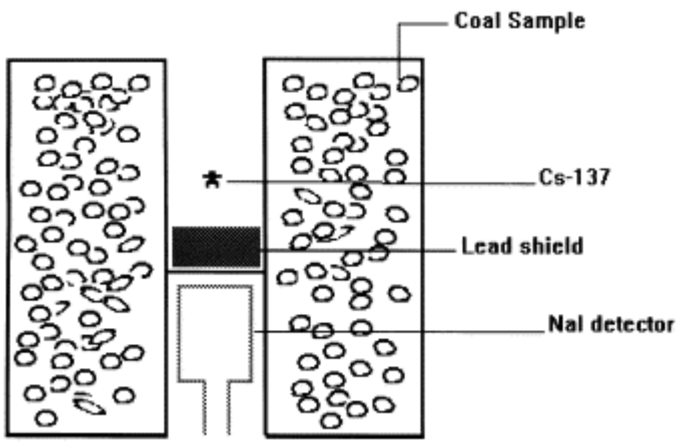
1. Gamma–gamma method

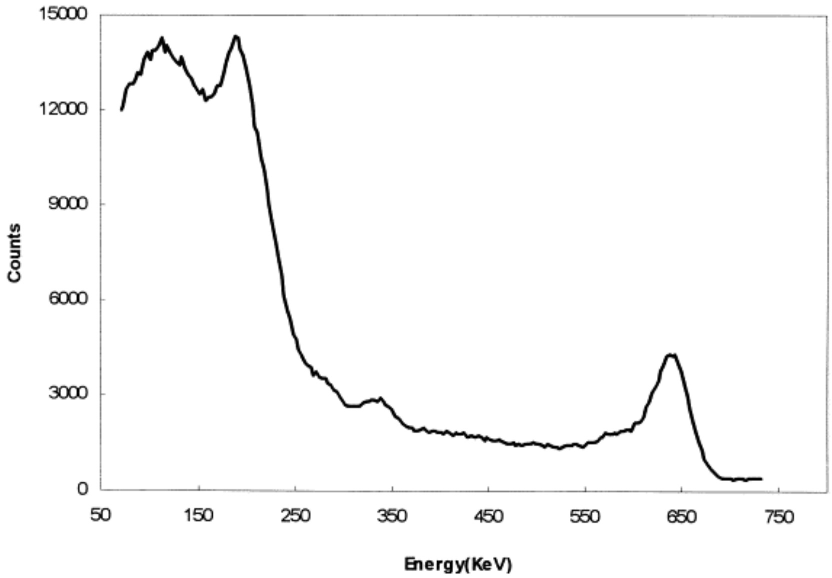


Example :

Schematic setup for coal ash measurement by the γ–γ method :



Typical spectrum of coal by the γ−γ method :



The coal ash content varies not only with density but also with the average chemical composition of the coal, expressed in $Z_{equivalent}$. The count rates in the 150–280 keV energy window is much more sensitive to the variation of the density than the chemical composition of coal.

The back-scattered γ-ray spectrum was divided into a number of spectral windows, selected in both the low and high energy regions of the spectrum.

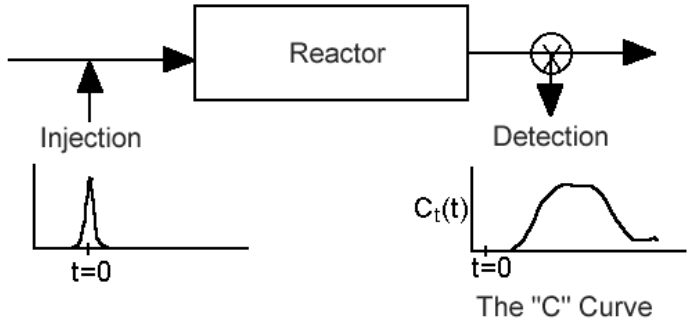
The low energy window is affected by both chemical composition, due to the photoelectric absorption for high Z elements and density, while the high energy window is only affected by the density of the coal.

Therefore a P_z ratio of count rates in the high energy to the count rates in the low energy windows was used to obtain information on changes in chemical composition …

... etc.

2. Residence Time Distribution

Inject a tracer and measure exit concentration, $C_T(t)$.

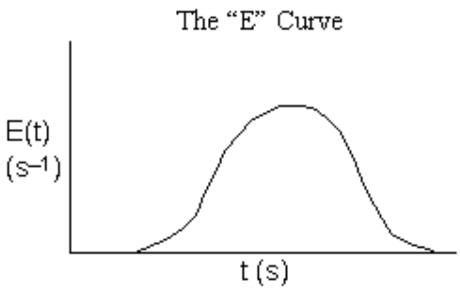


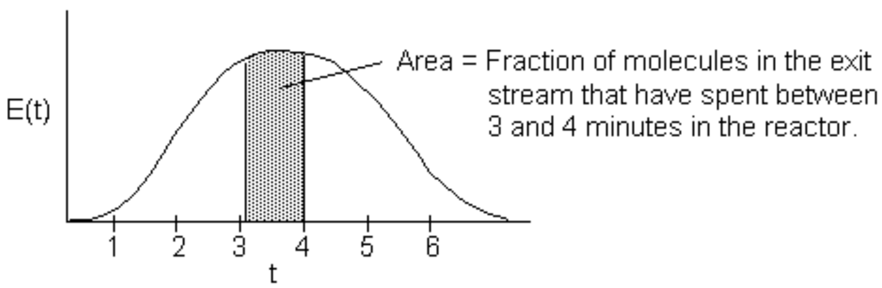
From the exit tracer concentration we can determine the following information:

- **RTD (Residence Time Distribution) Function (E(t))**

$$E(t) = \frac{C_T(t)}{\int_0^\infty C_T(t)dt}$$

$E(t)dt$ = Fraction of molecules exiting the reactor that have spent a time between (t) and (t + dt) in the reactor.





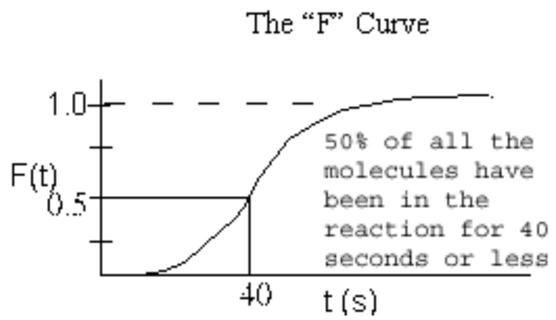
- **The Cumulative Distribution Function F(t)**

$$F(t) = \int_0^t E(t)dt$$

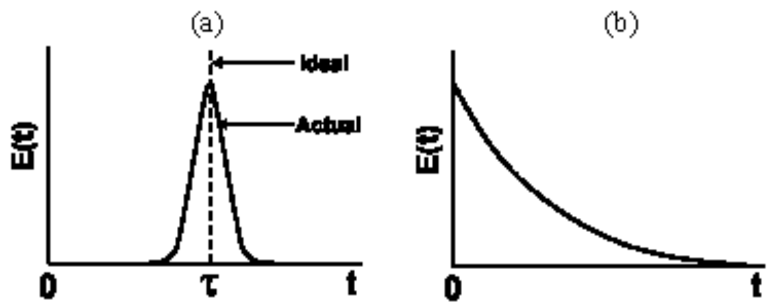
= Fraction of molecules exiting the reactor that have spent a time t or less in the reactor.

$$1 - F(t)$$

= Fraction of molecules that have spent a time t or greater in the reactor.



Diagnostics and Troubleshooting



(a) RTD for near plug flow ; (b) RTD for near perfectly mixed

... etc.

3. Zeff (or Zeq.) of water

The atomic number of a material exhibits a strong and fundamental relationship with the nature of radiation interactions within that medium. There are numerous mathematical descriptions of different interaction processes that are dependent on the atomic number, Z. When dealing with composite media (i.e. a bulk material composed of more than one element), one therefore encounters the difficulty of defining Z. An effective atomic number in this context is equivalent to the atomic number but is used for compounds (e.g. water) and mixtures of different materials (such as tissue and bone).

In many textbooks and scientific publications, the following - simplistic and often dubious - sort of method is employed. One such proposed formula for the effective atomic number, Z_{eff}, is as follows (Murty 1965):

$$Z_{\text{eff}} = \sqrt[2.94]{f_1 \times (Z_1)^{2.94} + f_2 \times (Z_2)^{2.94} + f_3 \times (Z_3)^{2.94} + \ldots}$$

where

f_n is the fraction of the total number of electrons associated with each element, and
Z_n is the atomic number of each element.

An example is that of water (H_2O), made up of two hydrogen atoms (Z=1) and one oxygen atom (Z=8), the total number of electrons is 1+1+8 = 10, so the fraction of electrons for the two hydrogens is (2/10) and for the one oxygen is (8/10). So the Z_{eff} for water is:

$$Z_{\text{eff}} = \sqrt[2.94]{0.2 \times 1^{2.94} + 0.8 \times 8^{2.94}} = 7.42$$

4. The effective doses from diagnostic CT procedures

They are typically estimated to be in the range of 1 to 10 mSv. Radiation dose from CT procedures varies from patient to patient. A particular radiation dose will depend on the size of the body part examined, the type of procedure, and the type of CT equipment and its operation.

Table 1: Radiation Dose Comparison

Diagnostic Procedure	**Typical Effective Dose (mSv)[1]**	**Number of Chest X rays (PA film) for Equivalent Effective Dose[2]**	**Time Period for Equivalent Effective Dose from Natural Background Radiation[3]**
Chest x ray (PA film)	0.02	1	2.4 days
Skull x ray	0.1	5	12 days
Lumbar spine	1.5	75	182 days
I.V. urogram	3	150	1.0 year
Upper G.I. exam	6	300	2.0 years
Barium enema	8	400	2.7 years
CT head	2	100<	243 days
CT abdomen	8	400	2.7 years

1. Average effective dose in millisieverts (mSv) as compiled by Fred A. Mettler, Jr., et al., "Effective Doses in Radiology and Diagnostic Nuclear Medicine: A Catalog," *Radiology* Vol. 248, No. 1, pp. 254-263, July 2008.
2. Based on the assumption of an average "effective dose" from chest x ray (PA film) of 0.02 mSv.
3. Based on the assumption of an average "effective dose" from natural background radiation of 3 mSv per year in the United States

5. PET/CT Scanning

Imaging with equipment that combines positron emission tomography and computed tomography (PET/CT) provides the special benefits of both in one procedure, that is, a highly sensitive imaging technique used in oncology, cardiology, neurology and in infectious and inflammatory diseases.

<u>The information from the PET scan and from the CT scan are very different but complementary to each other.</u>

The PET scan shows areas with increased metabolic activity, while the CT scan shows detailed anatomical locations. A combination of these two images together enables a doctor to tell whether a region with high metabolic activity is significant, and if so, to state definitively where that location is. Often the PET/CT is repeated to monitor the effect of treatment of a particular disease. Most commonly PET utilizes ^{18}F-FDG as a radiotracer, the short half life of which (110 min) reduces radiation exposure compared with other commonly used radionuclides such as ^{99m}Technetium (6 hours) and ^{201}Thallium (72 hours).

The radiation exposure from ^{18}F results in internal exposure to the patient and low level external exposure to other people in their vicinity. The radiation (X rays) from the CT scanner only radiates the patient and only during the CT scan. Whenever a repeat PET/CT scan is necessary, it should be performed with low dose CT.

6. How do PET/CT radiation doses compare with doses from other examinations?

A PET/CT test has two components: a PET scan and a CT, which are done together. The radiation exposure from CT has a very wide range depending on the type of the test, the area of the body scanned and the purpose of the test.

In its simplest form, a CT scan is used only for the localization of abnormalities seen on a PET scan (non-diagnostic scan). The radiation dose from such a scan can be low (e.g. an effective dose of about 7 mSv for a whole body study). However, the effective dose from a high resolution diagnostic scan can be quite high (up to 30 mSv for a whole body CT scan).

The effective dose from a PET scan is modest and depends on the activity of the injected FDG (^{18}F-Fluoro deoxyglucose) and is typically 8 mSv for adults using 400 MBq and is the same whether a part of the body or the whole body is imaged.

Major reductions in radiation doses from PET/CT scans can be achieved by modifying the acquisition parameters for CT. Conventional radiographic examinations such as chest, abdominal and bone X rays also give a radiation dose but only a fraction of that resulting from a CT examination. (*Examinations such as ultrasonography and magnetic resonance imaging (MRI) do not involve exposure to ionizing radiation*).

7. SPECT scans

SPECT scans are similar to PET scans. They use a special camera to make 3-dimensional images of inside the body. SPECT scans are effective for getting information about blood flow to tissues and chemical reactions in the body. SPECT scans are often used for diagnosing and monitoring treatment for brain tumors and cancers affecting bones.

SPECT scans are done by injecting a small amount of radioactive isotope, or tracer, into a vein. The tracer travels to places in the body where there is tumor activity. After the tracer is injected the patient will have to lie very still on the SPECT scanner table while pictures are taken.

... etc.