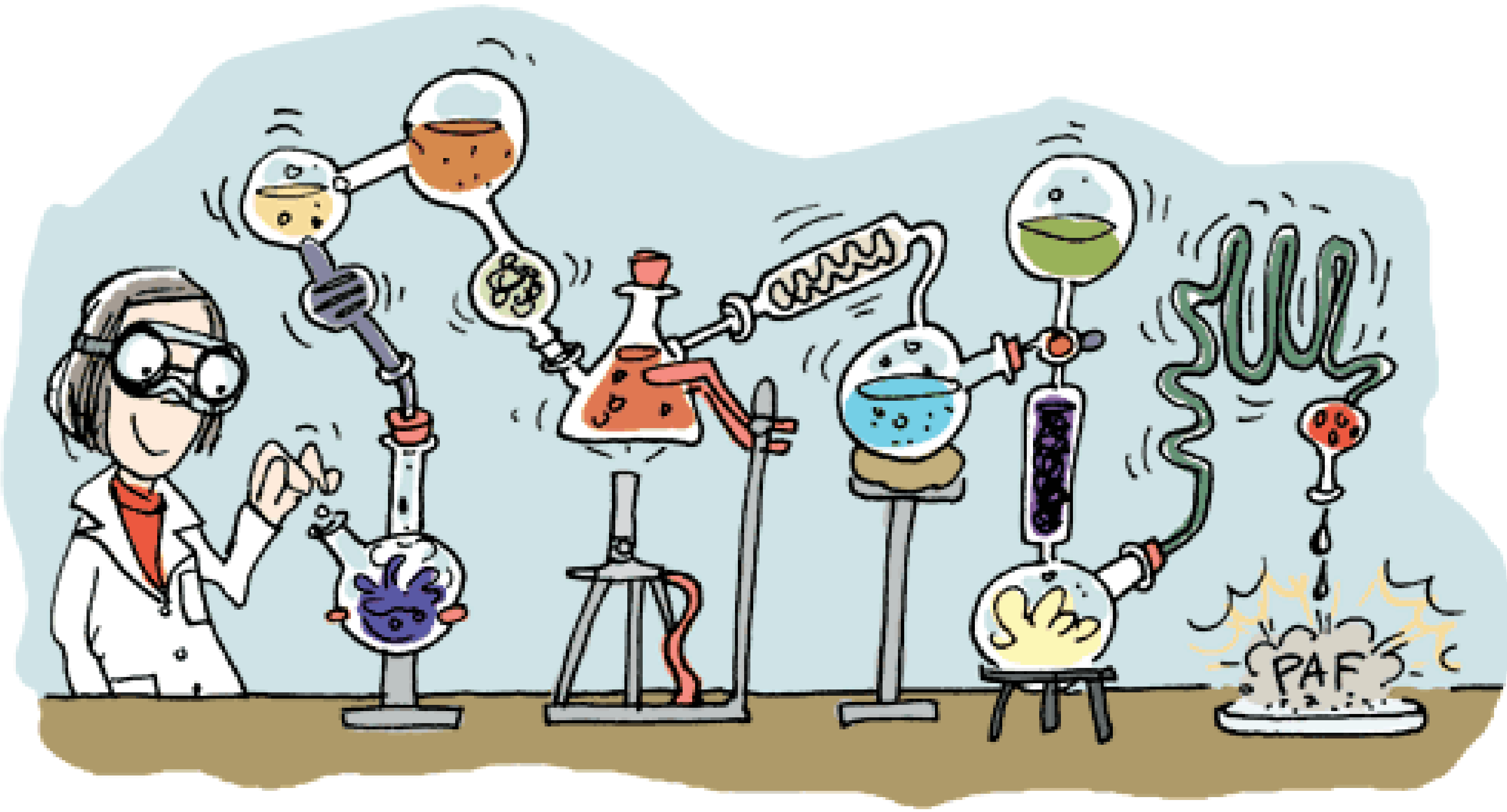
On-line analyses of mass transport using neutrons

Tor Bjørnstad
Institute for Energy Technology (IFE) and
University of Oslo

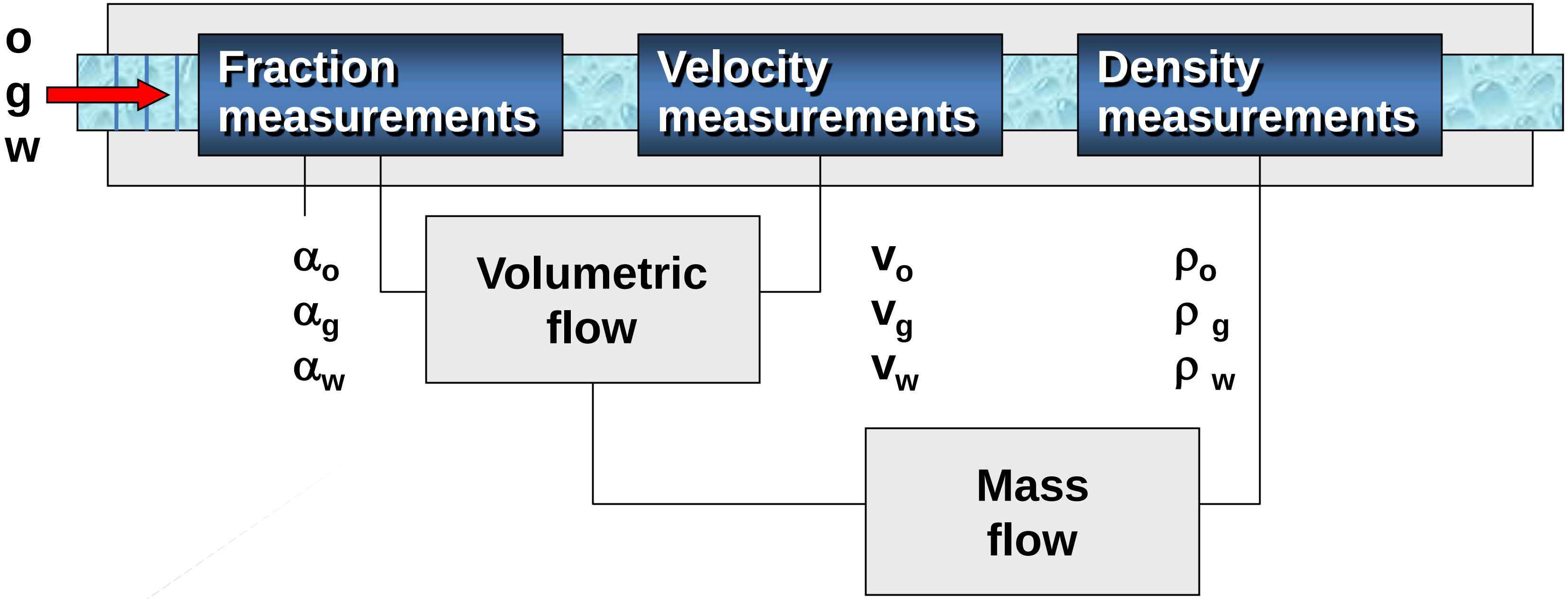
Content outline

- Nuclear methods in mass flow studies
- Neutron sources for production of short-lived radionuclides (for radiotracer synthesis)
- Neutron generator principle
- Small transportable neutron generators
- Examples of possible measurements of industrial mass flow by application of neutron generators
- Summing up

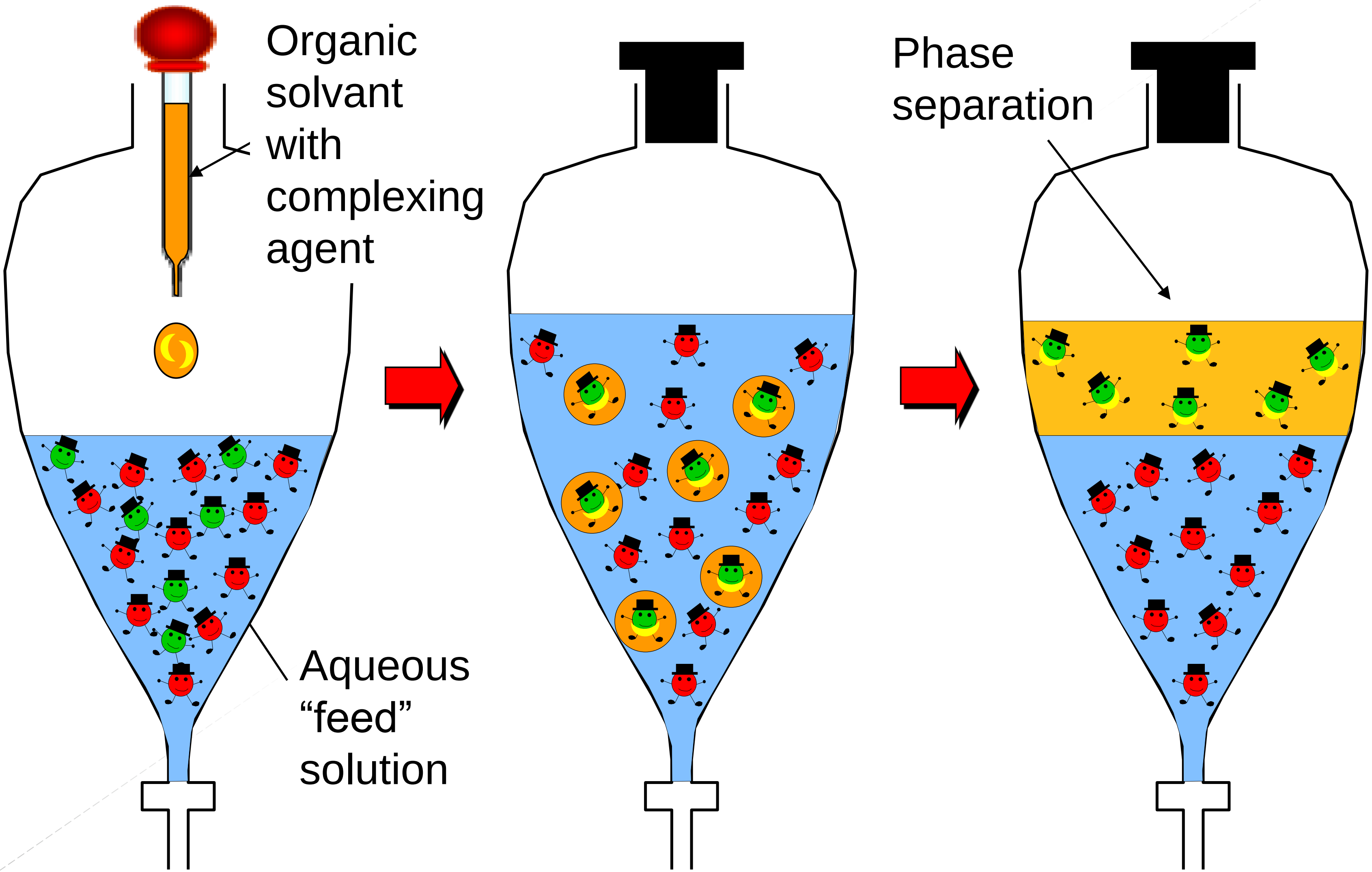
Hydrometallurgical separation techniques



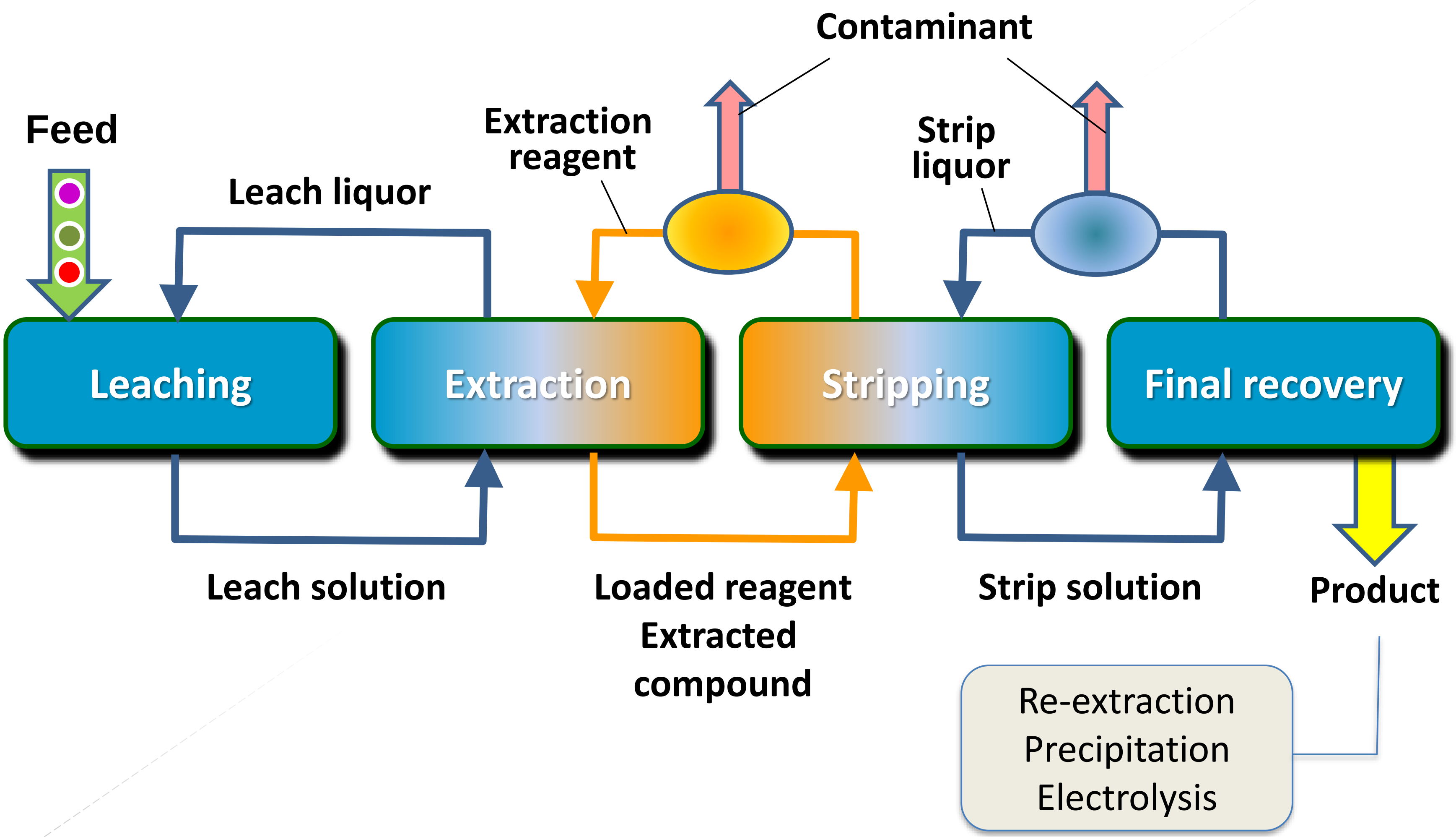
Typical components in multiphase meters



Liquid-liquid extraction

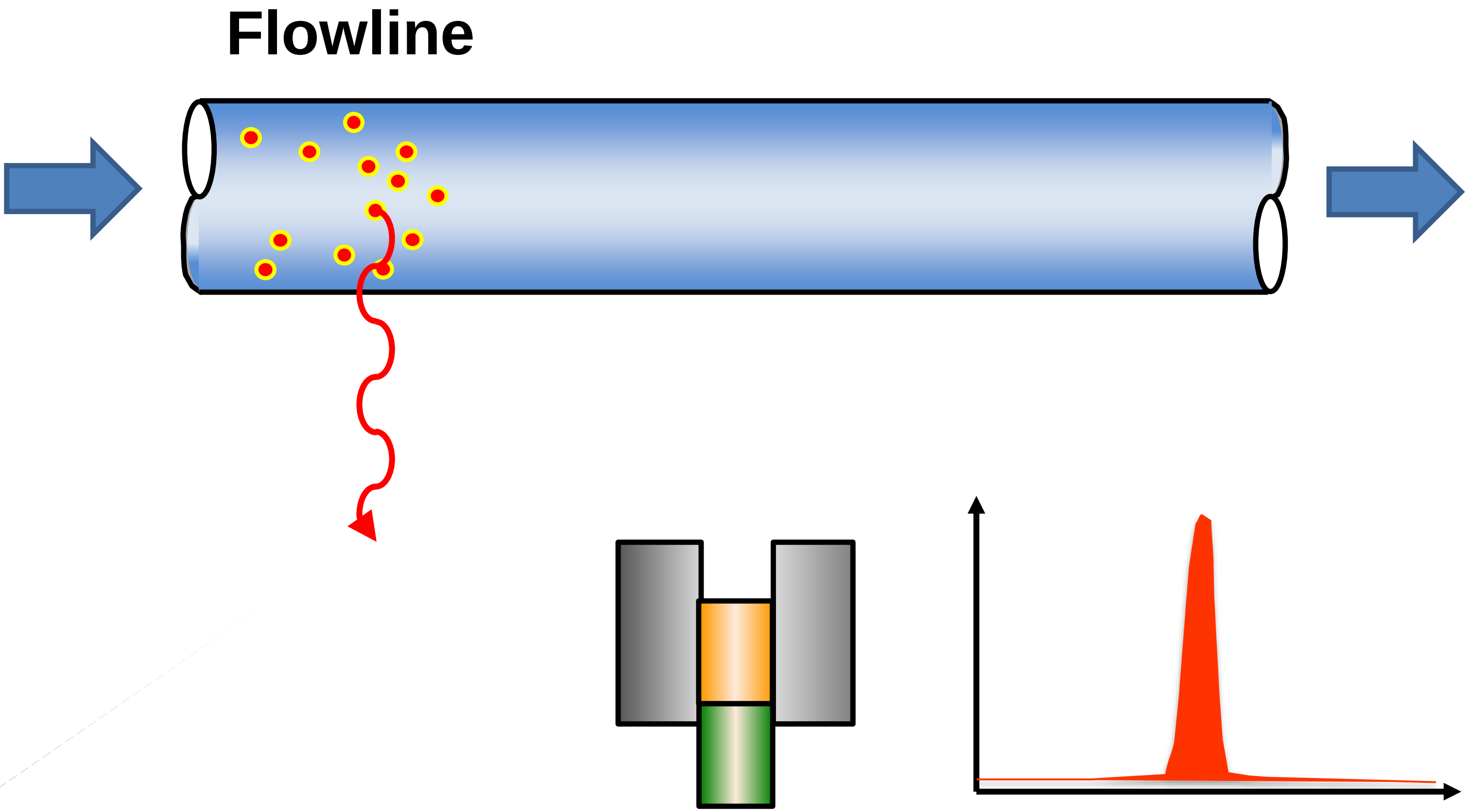


Hydro-metallurgy: Separation principle



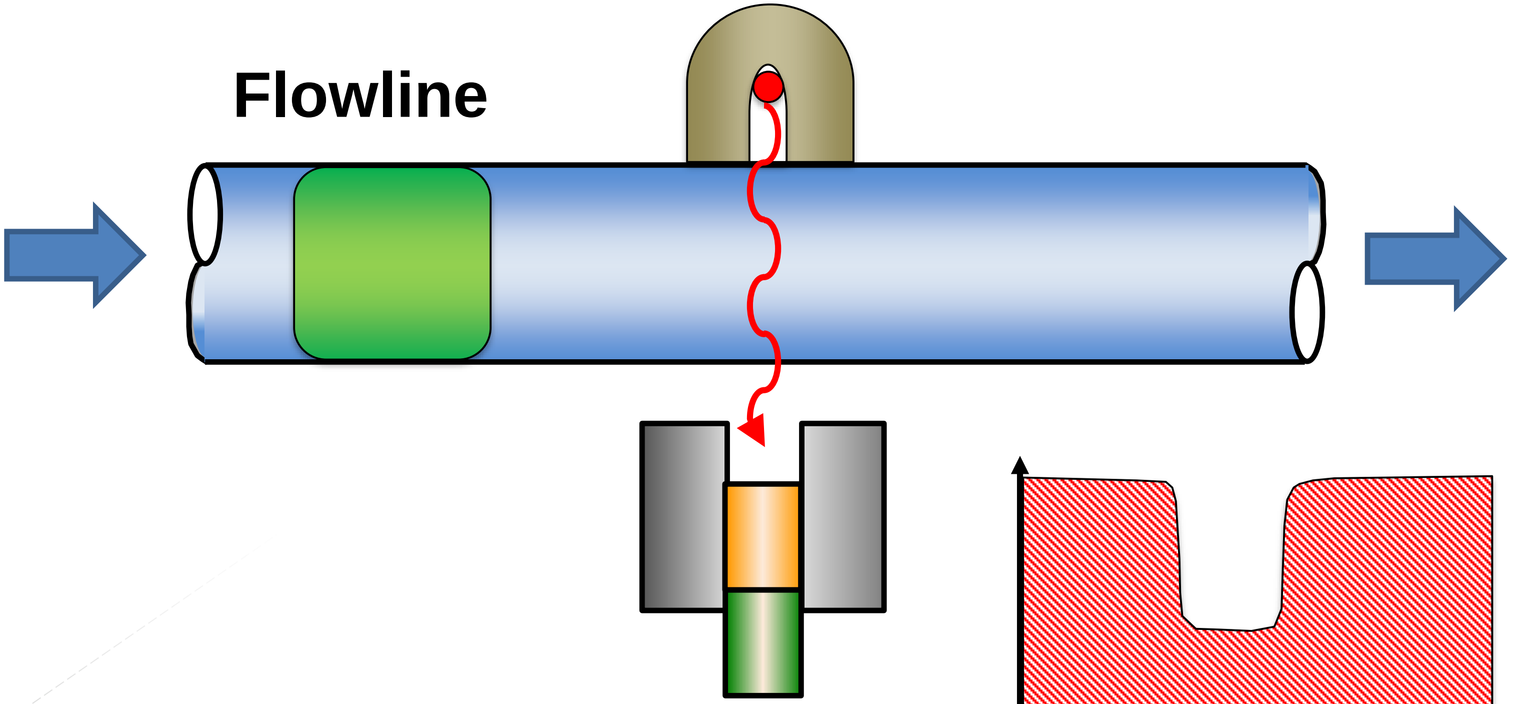
Nuclear-based radiation techniques

Gamma emission (short-lived radiotracer)



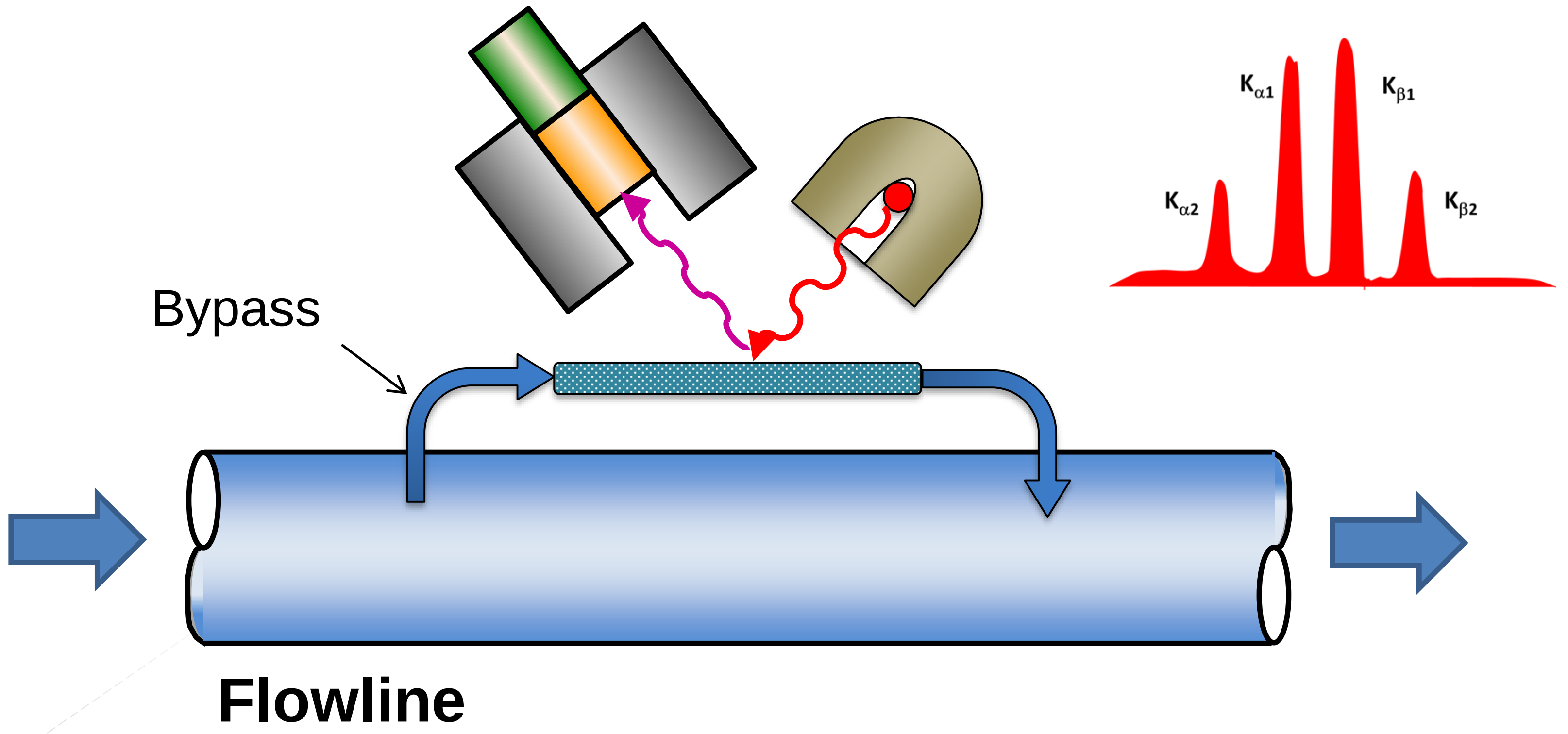
Nuclear-based radiation techniques

Gamma transmission (fixed source-detector)



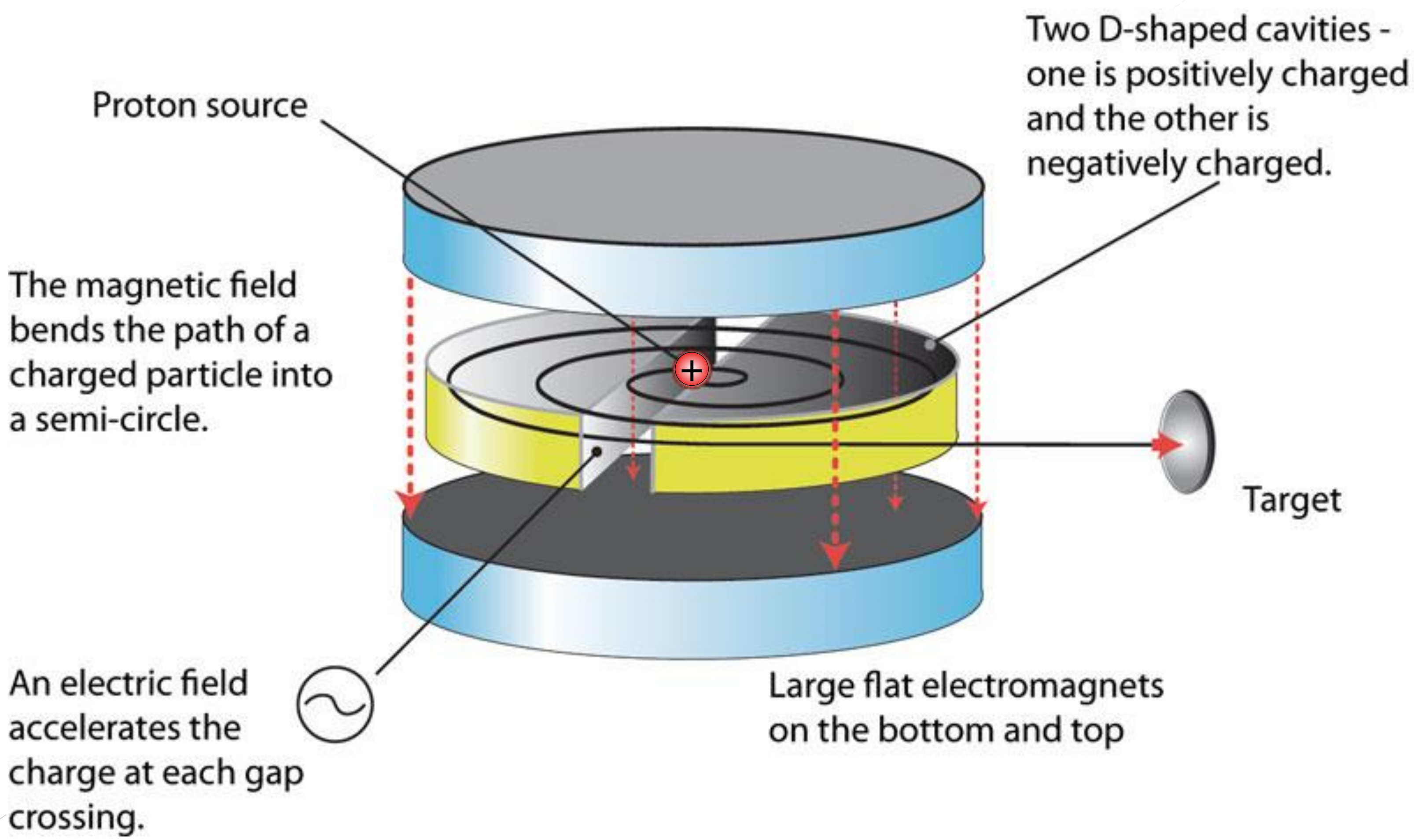
Nuclear-based radiation techniques

Gamma-induced x-ray emission



Production of radionuclides in a REACTOR

Production of radionuclides in a CYCLOTRON



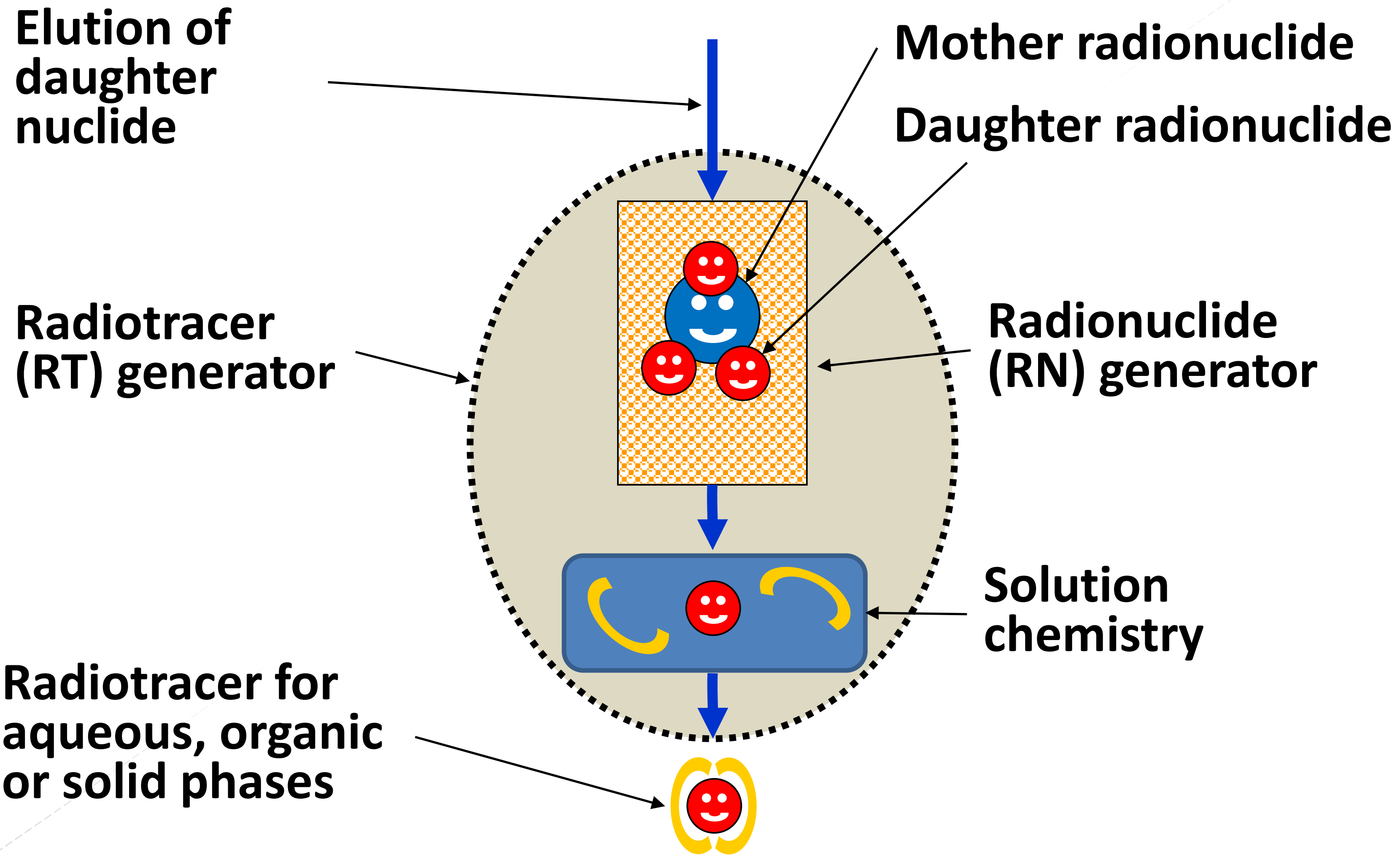
On demands....

- **Short-lived radioactively labeled tracers for liquid and solid phases at remote locations**

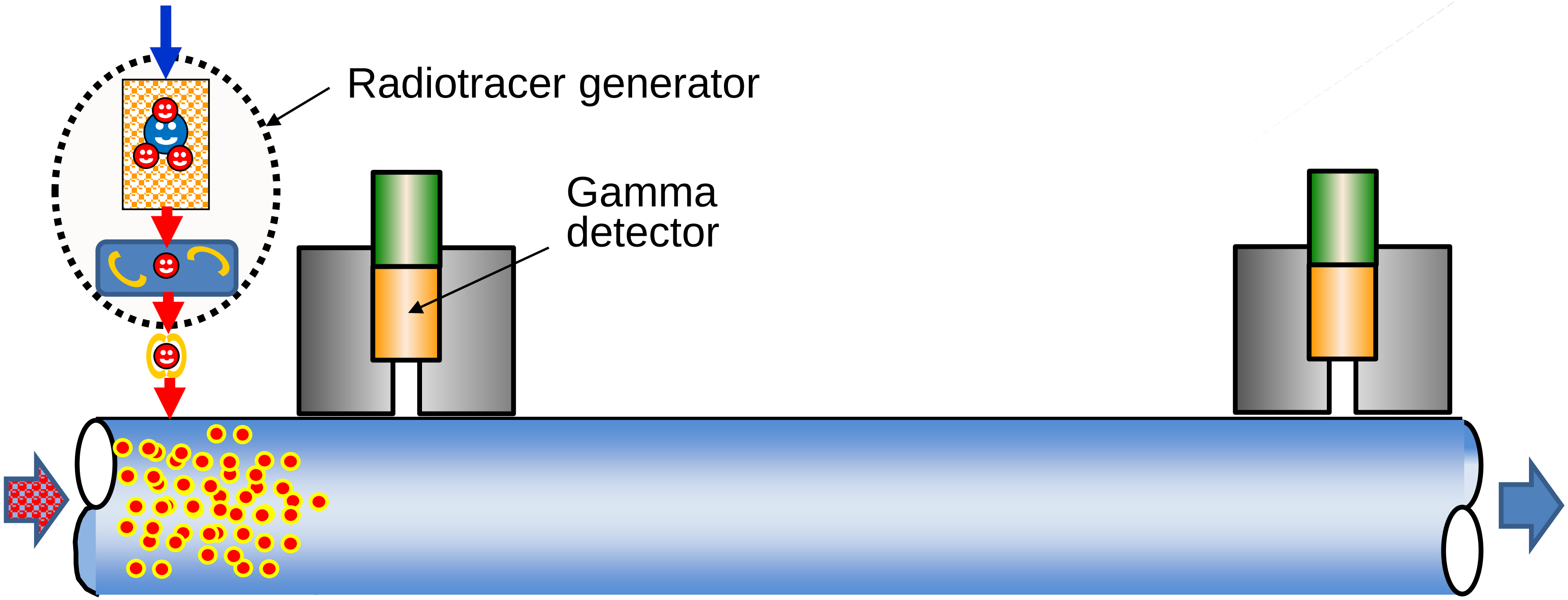
- **How to generate short-lived radionuclides?**
  - *Nuclear reactors - cannot be moved!*
  - *Particle accelerators – cannot be moved!*
  - *Isotopic/isotropic neutron sources – can be moved but not turned off!*

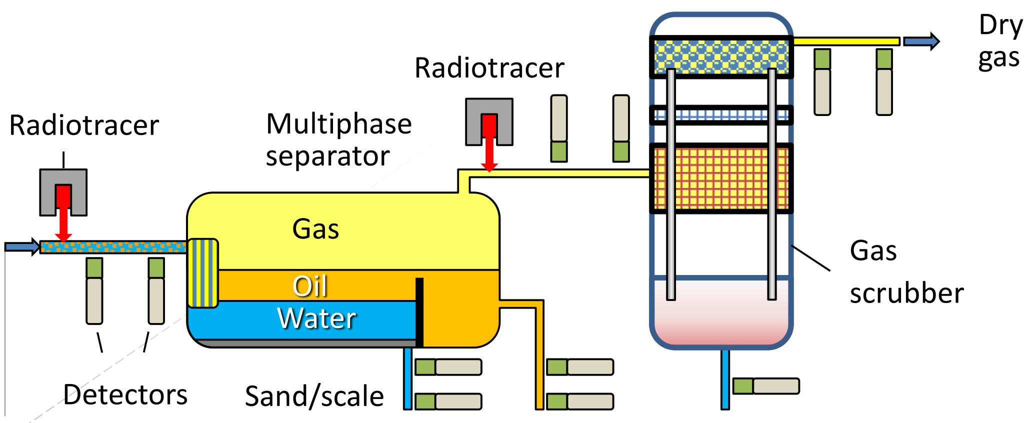
- **Are there other solutions?**

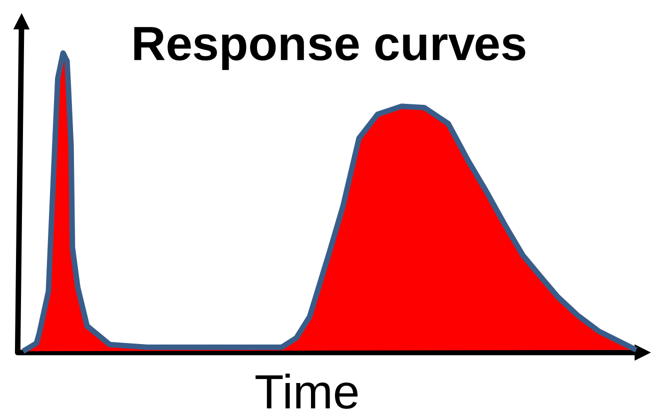
Radiotracer generator principle



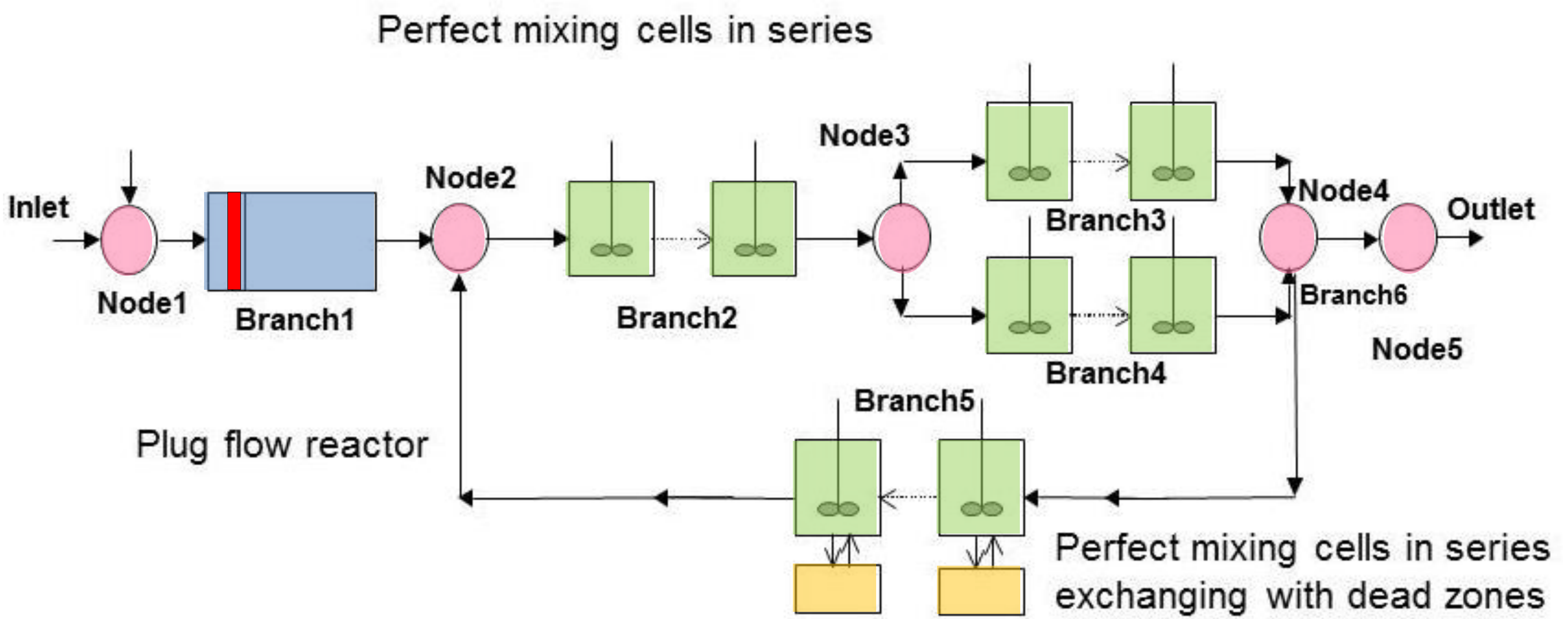
Mass transportation measurement – principle sketch







Example of complex flow structure
derived by RTD measurements

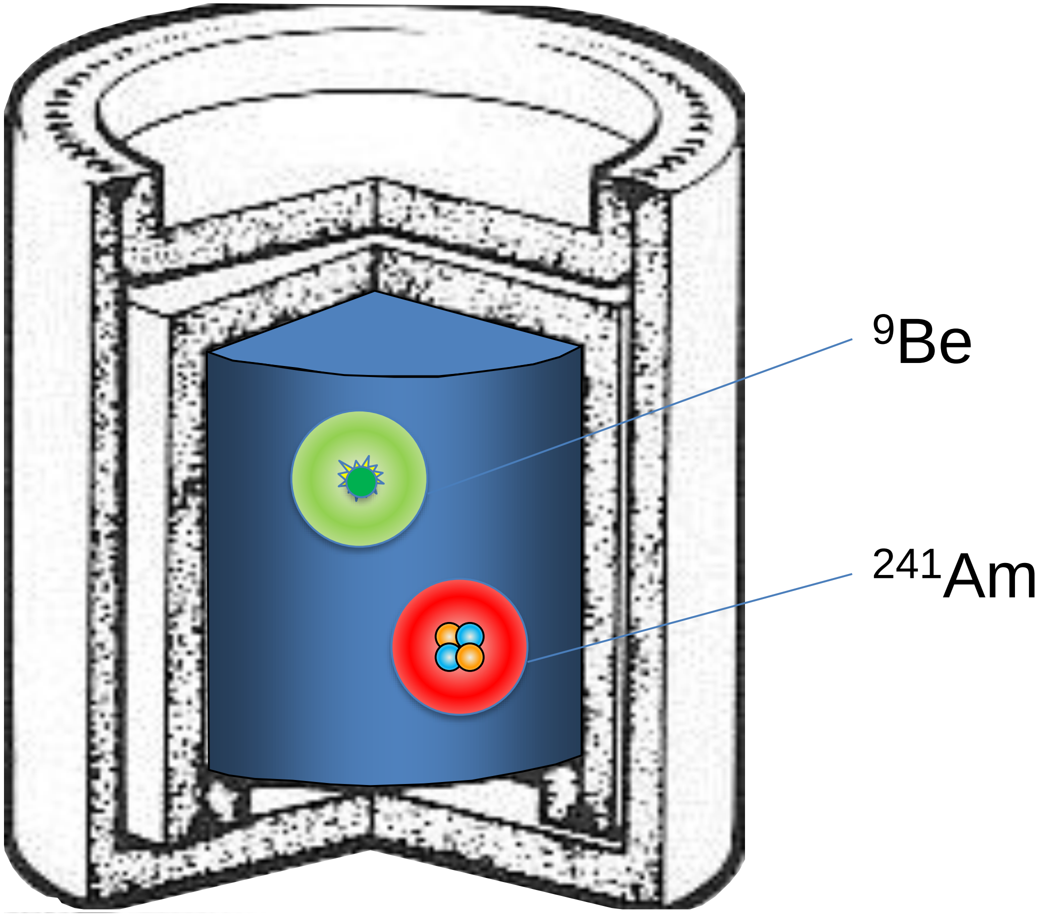


Application of Isotopic Neutron Sources

$^{9}Be + ^{4}He \rightarrow$

$^{12}C + n$

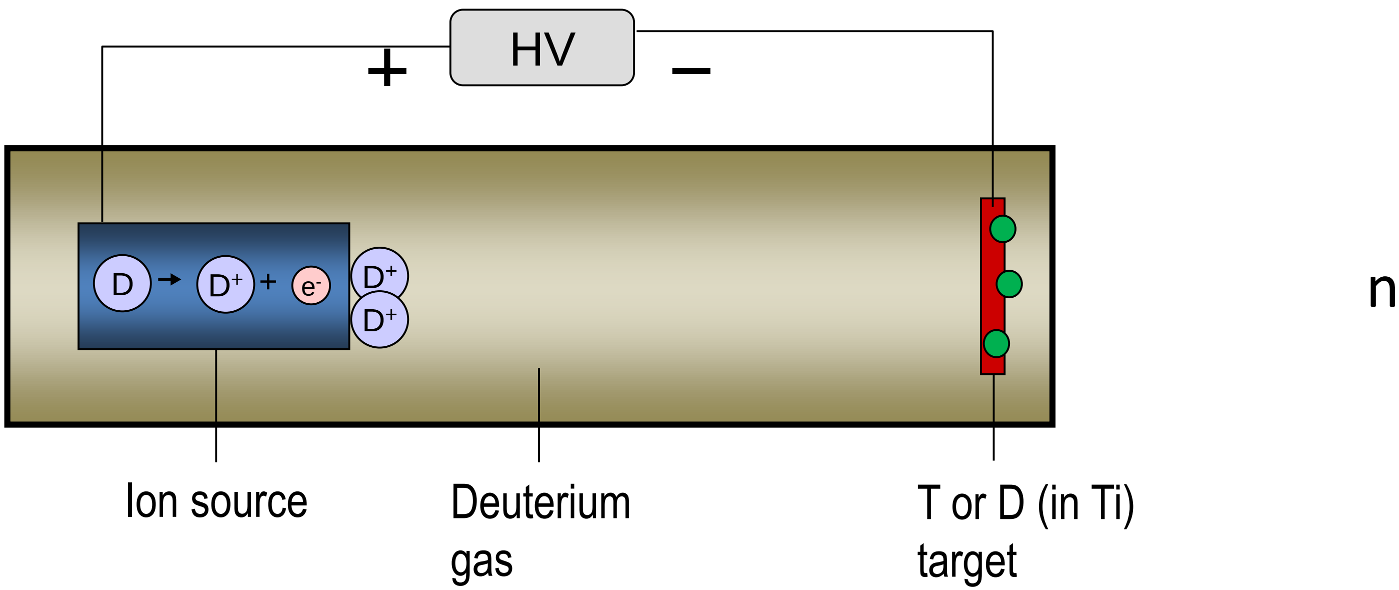
$+ 5.704$ MeV



Principle of a neutron generator

Sealed-tube neutron generator:

The principle of a neutron generator is illustrated below:

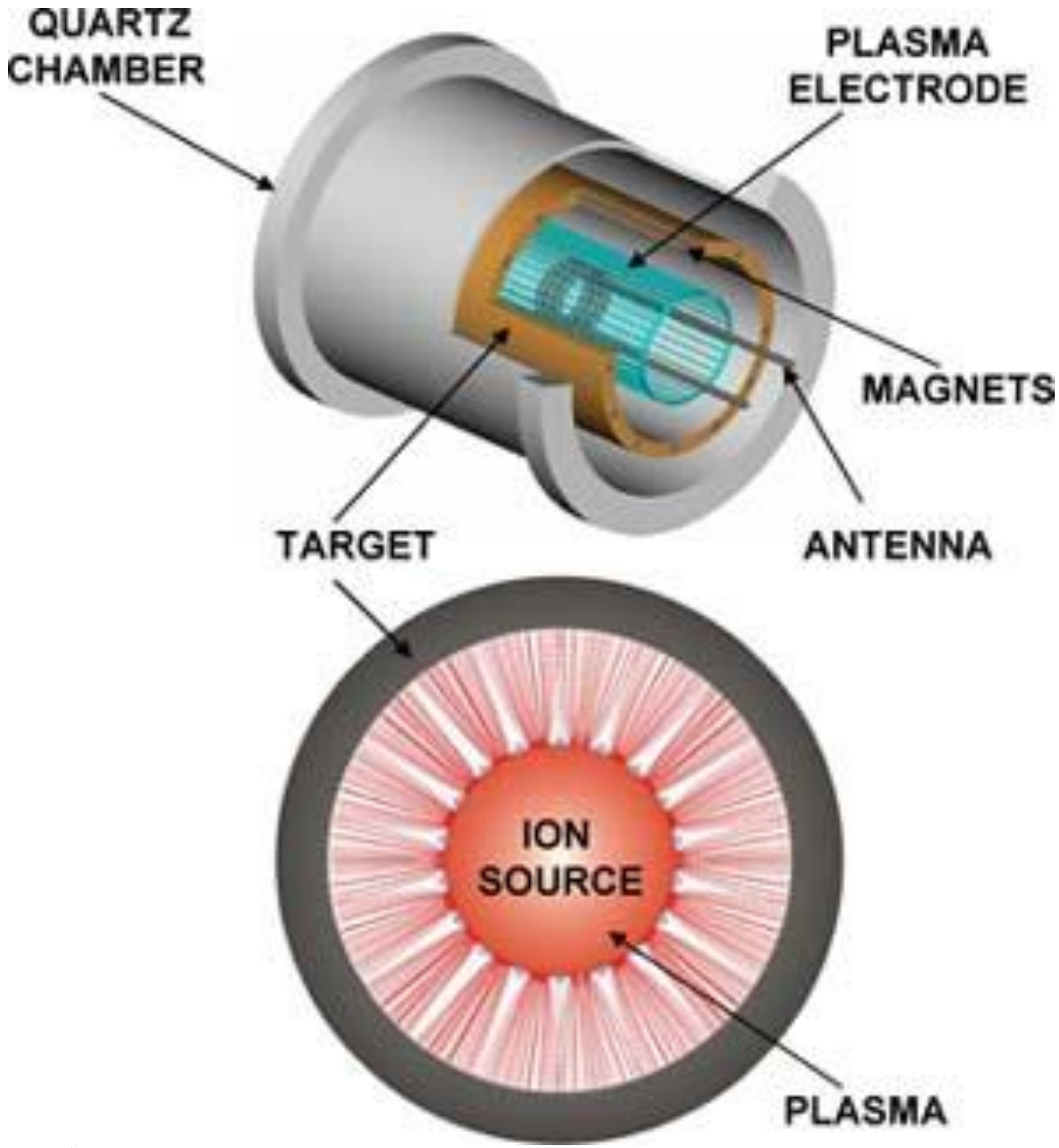


Deuterium accelerated against tritium or deuterium gives the reactions:

$$\mathbf{D + T \rightarrow {}^{4}He + n\ (14.1\ MeV)}$$

$$\mathbf{D + D \rightarrow {}^{3}He + n\ (2.5\ MeV)}$$

Sealed tube neutron generator



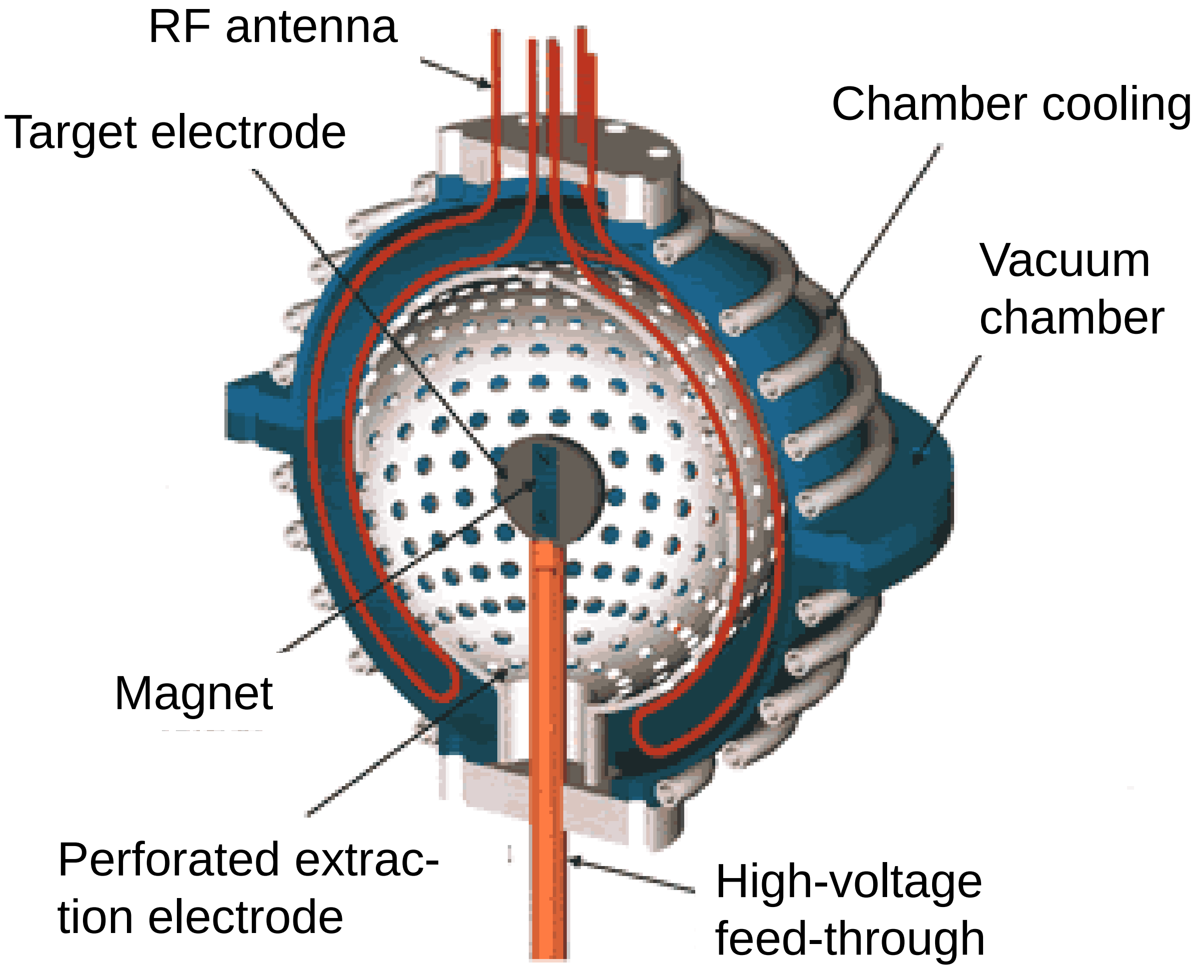
Berkeley design

Compact Spherical Neutron Generator,

IB-1675, Berkeley design

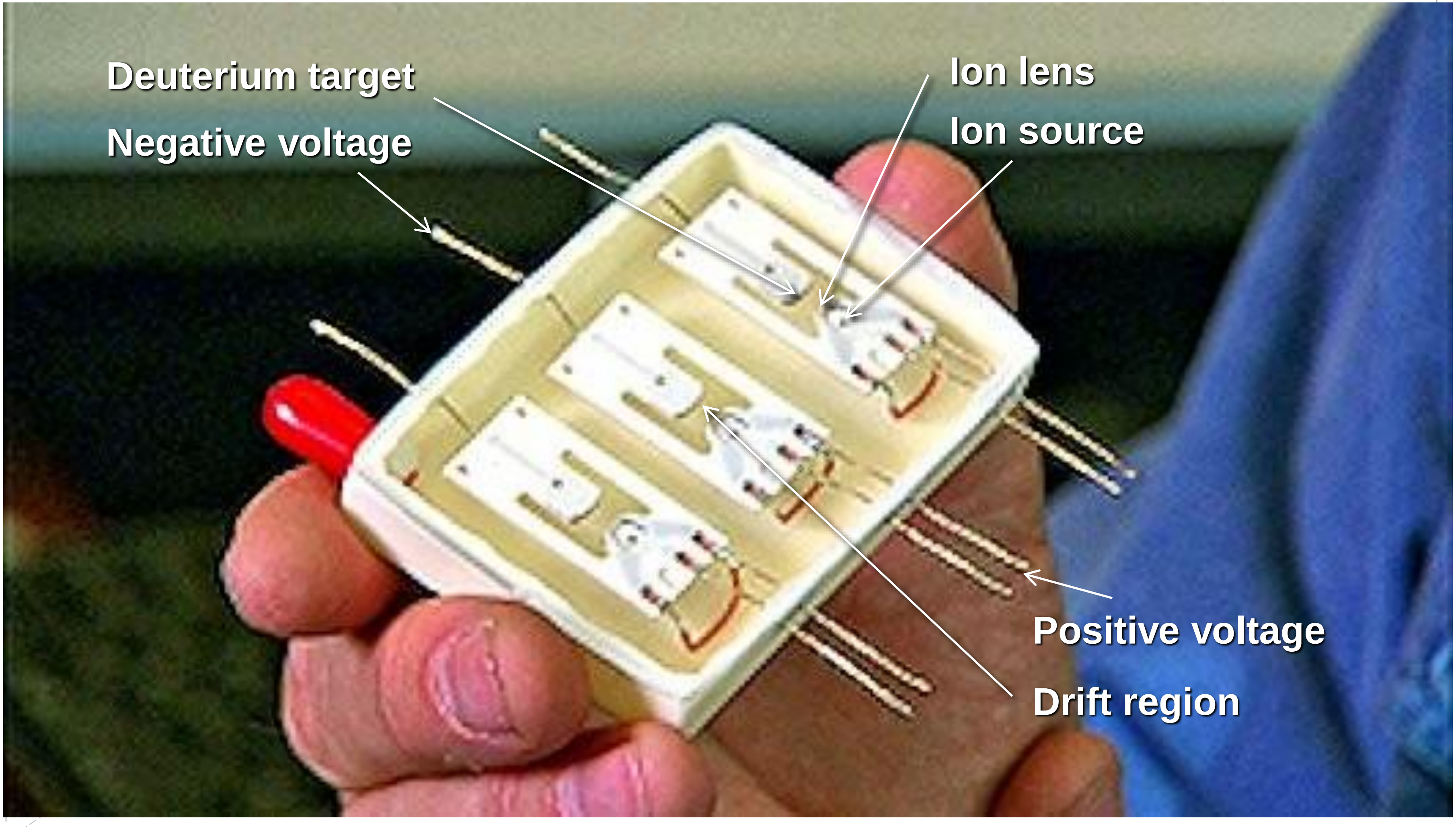
Advantages:

- High brightness
- Works like a point source
- High Flux
- High neutron field
- Safe D-D reactions



World's smallest neutron generator-

The Sandia Laboratories' Neutristor



Neutron generators (D-D and D-T)

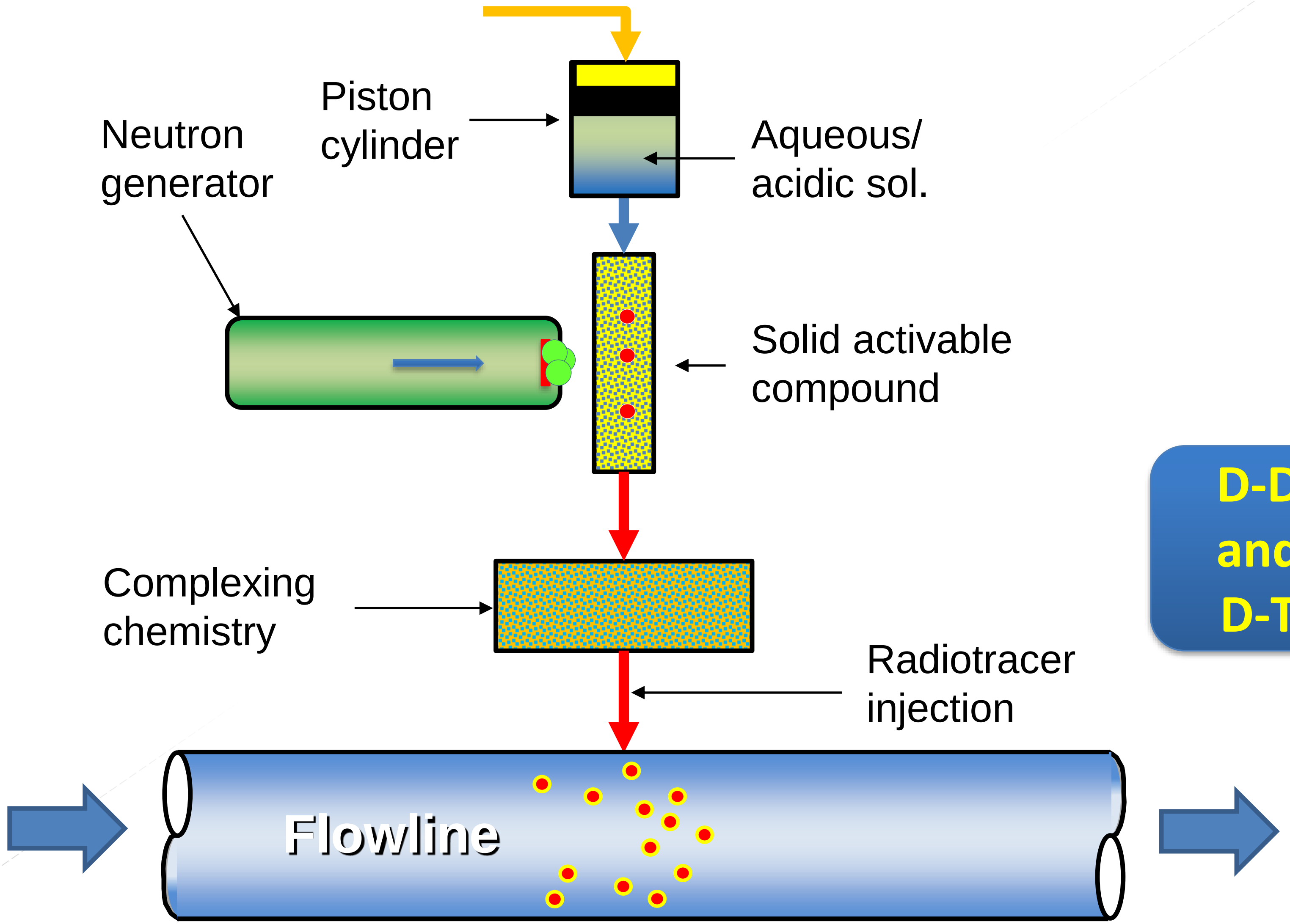
SODERN sealed tube

- Neutron Energy : 14 MeV (DT) or 2.5MeV (DD)
- Neutron yield : up to 10^{10} n/s/4πsr (DT) or 10^{8} n/s/4πsr (DD)
- Typical tube lifetime at $2{\cdot}10^{9}$ n/s/4πsr (DT) : 4000 hour

SODERN Sealed tube

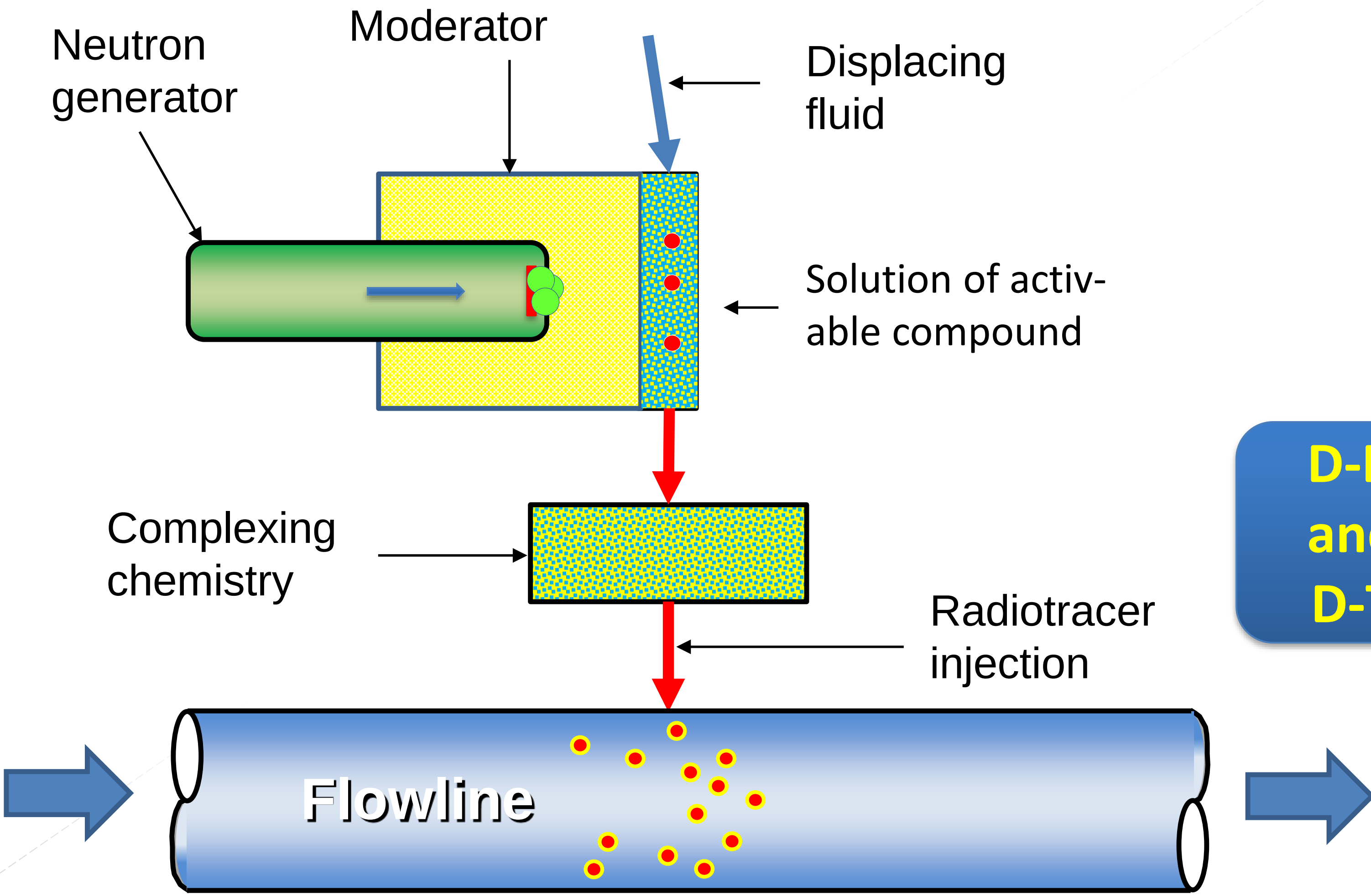
- Neutron Energy: 14 MeV (2.5 MeV for D-D)
- Neutron yield: up to $2{\cdot}10^{8}$ n/s (2.10^{6} n/s for D-D)
- Typical tube lifetime: 4000 working hours (for 10^{8} n/s)

Off-line fast neutron activation – on-line mount.



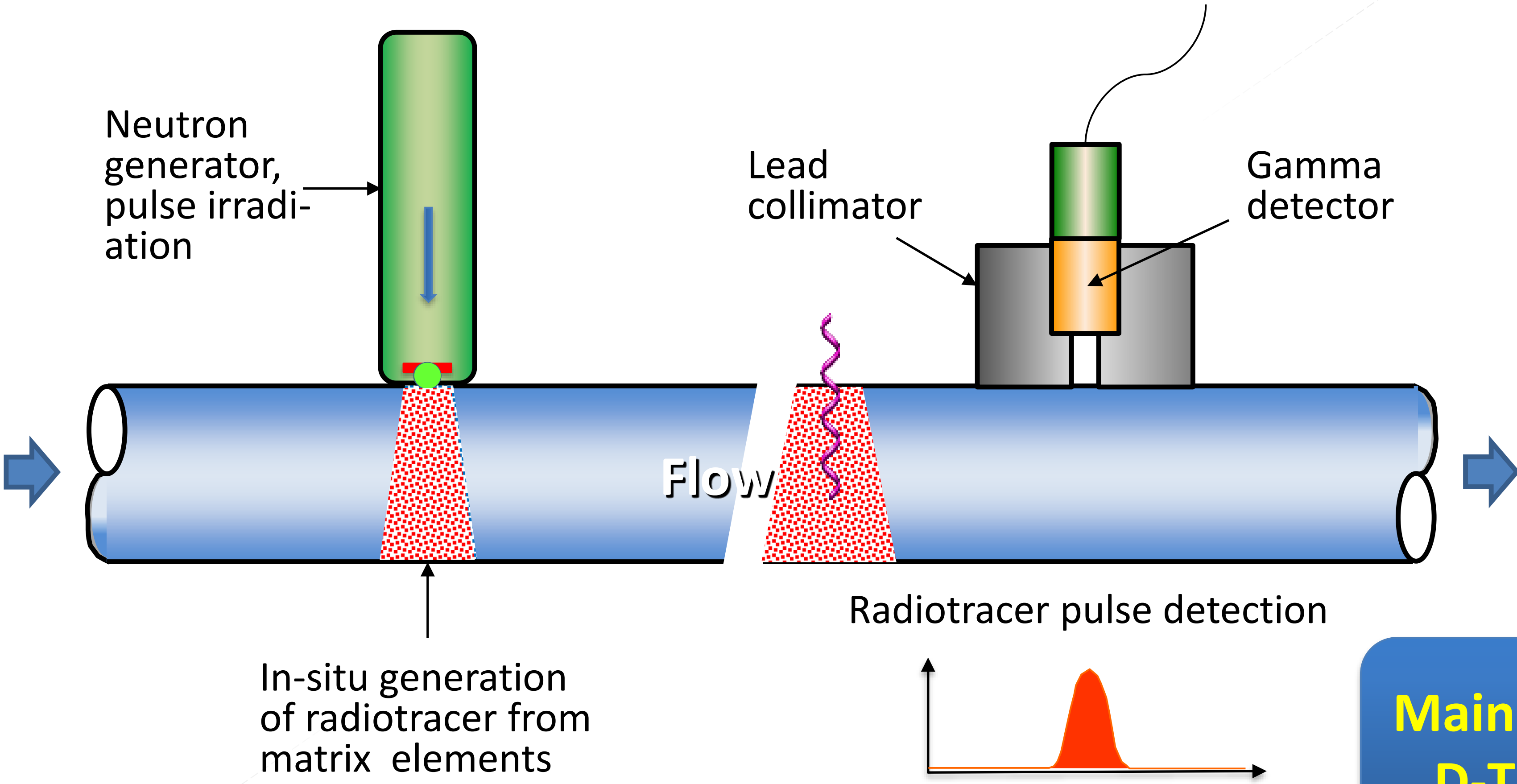
D-D
and
D-T

Off-line thermal NA on-line mount.



D-D and D-T

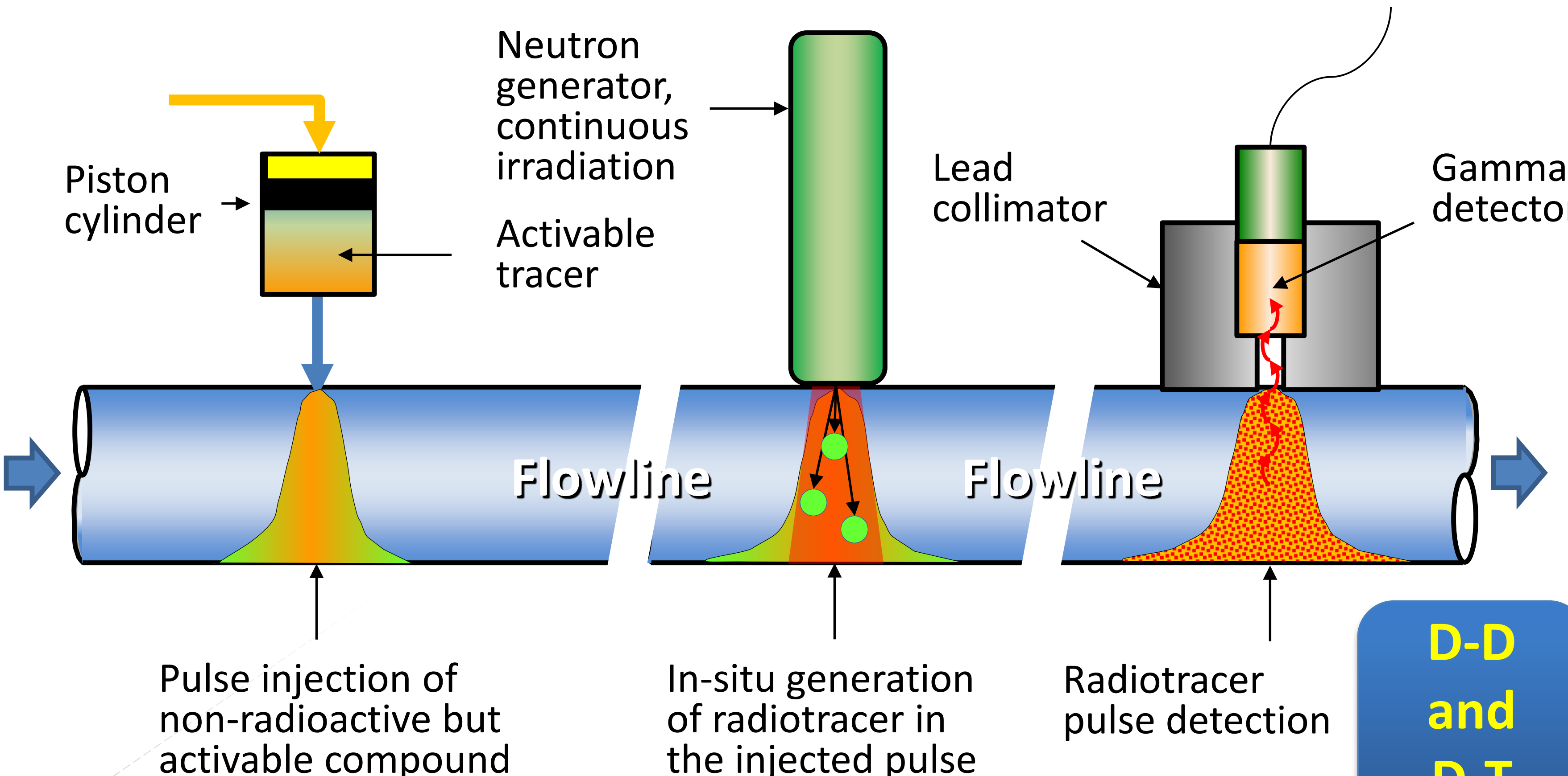
In-flow fast «pulse» NA – on-line mount.



Mainly D-T

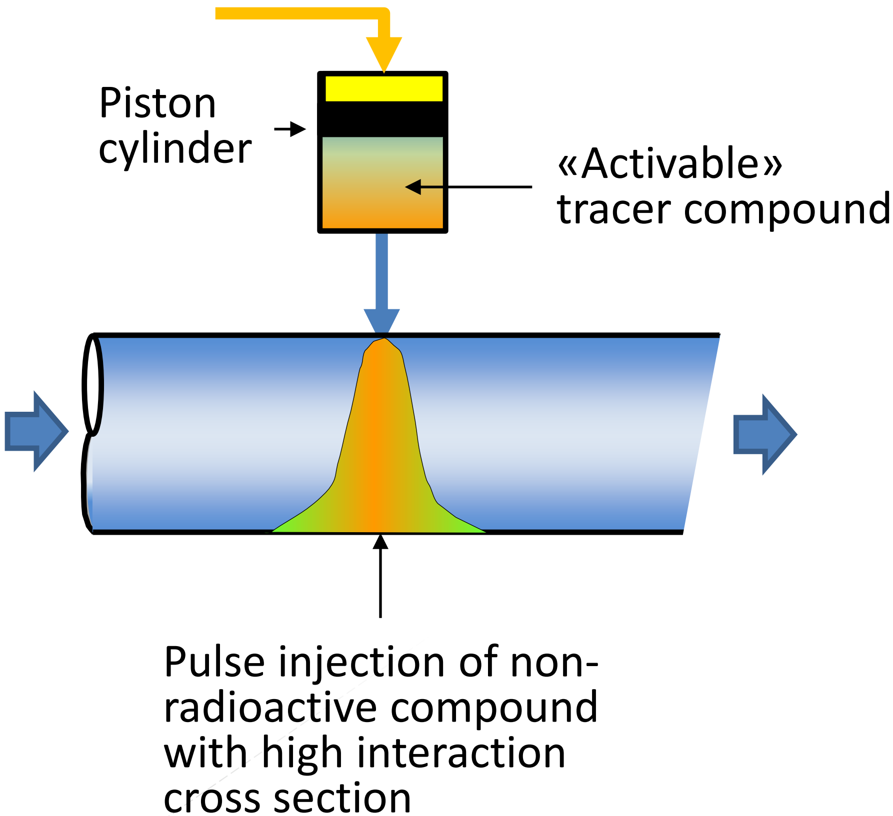
Example - irradiation of water: $^{16}O + n_{14MeV} \rightarrow$ ^{16}N (7.13 s)

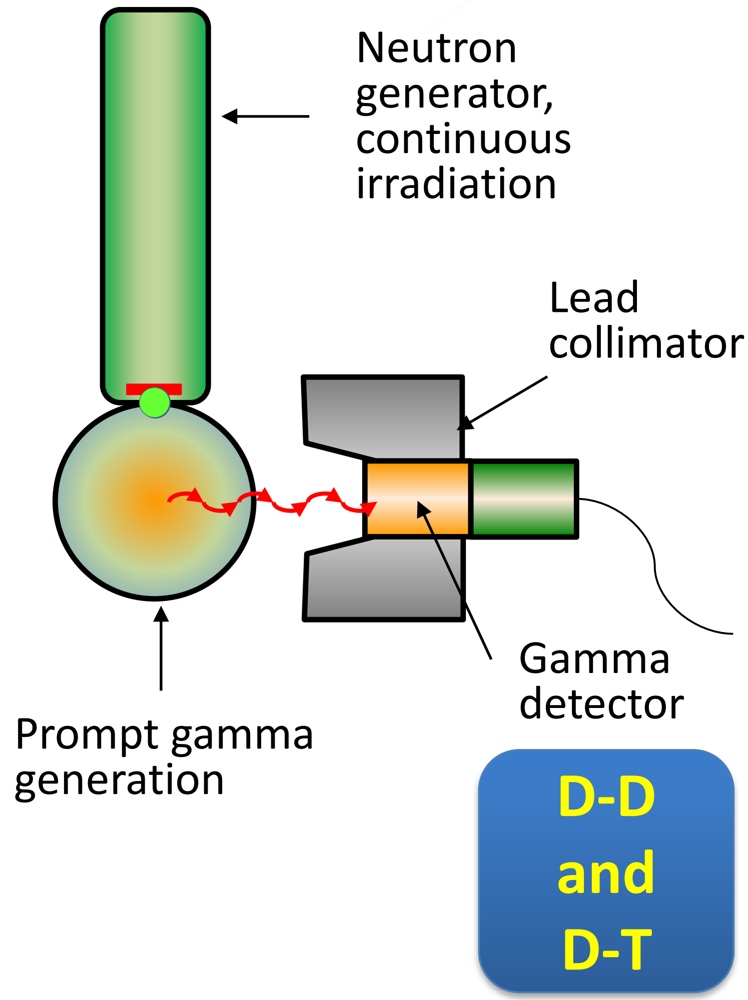
In-line tracer generation by activation of injected non-radioactive compound



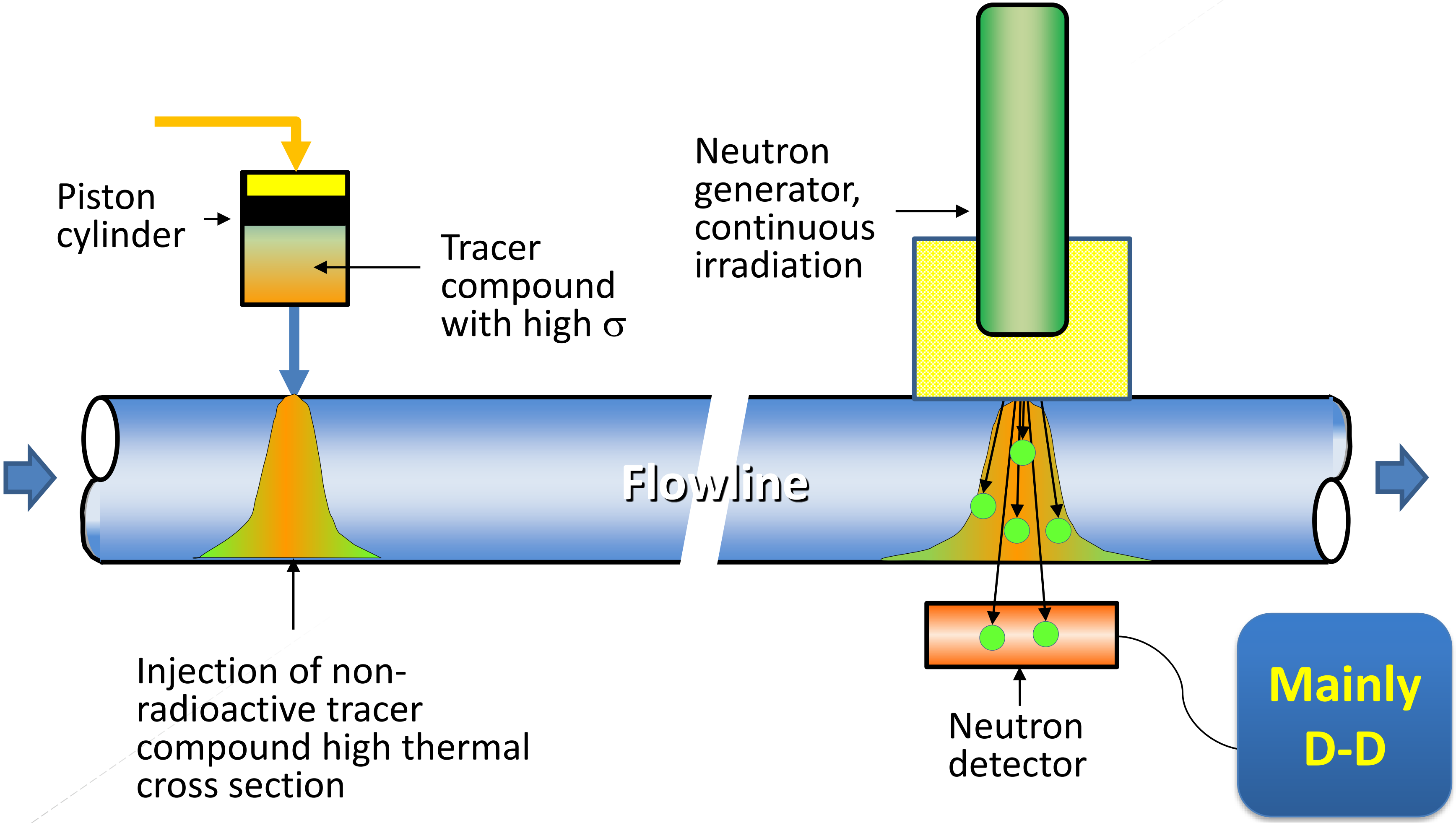
D-D
and
D-T

On-line PGNA of injected non-radioactive «tracer» compound

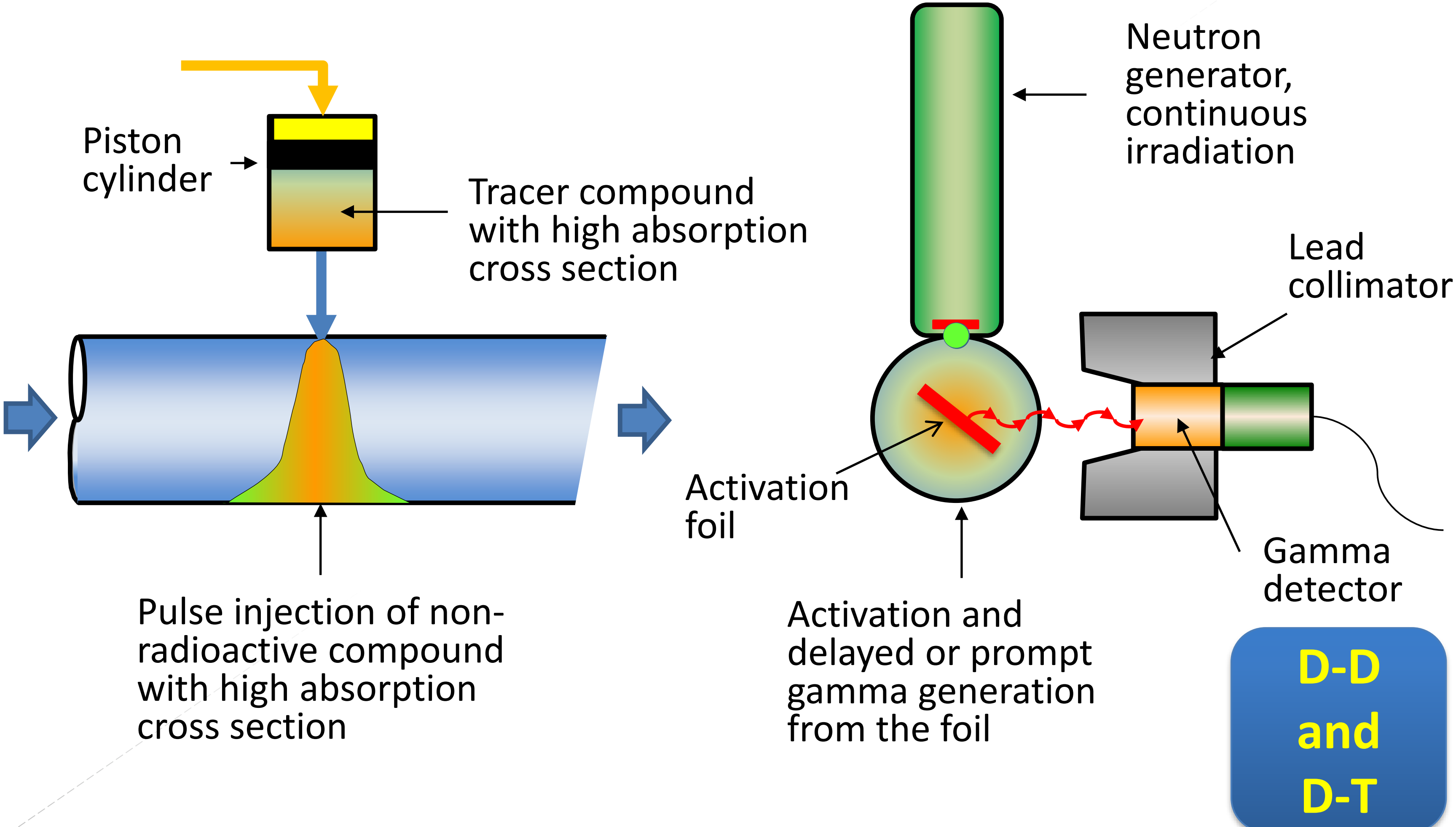




On line detection of injected non-radioactive «tracer» compound by neutron transmission



On-line detection of injected non-radioactive «tracer» compound by activation foil method



Summing up

- Availability of small transportable neutron generators makes possible, in principle, mass flow studies (RTD experiments) to be carried out on «remote» locations
- A number of neutron-based methods are possible, as outlined in the previous picture frames.
- None of these sketched methods have, as of yet, been properly examined and developed and must be regarded as «emerging technology».
- A major obstacle for further method development and general dissemination is probably the up-front investment cost.
- Major laboratories/industries should possibly lead the way and support method development to exploit the