An introduction to Neutron Resonance Densitometry
(Short Summary)

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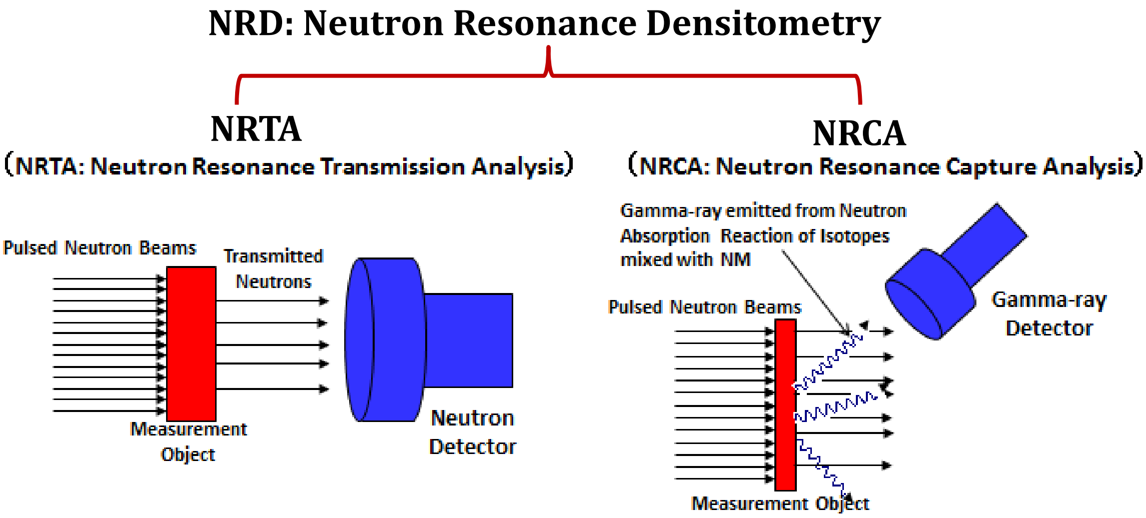
What is NRD and what can be quantified by NRD?

- **NRD is <u>a non-destructive analysis method to quantify the amount of special nuclear materials (U/Pu) in samples with unknown elemental and isotopic composition, such as melted fuel debris generated in severe accidents of nuclear reactors.</u>**
- **NRD is also a non-destructive mass spectrometry method.**

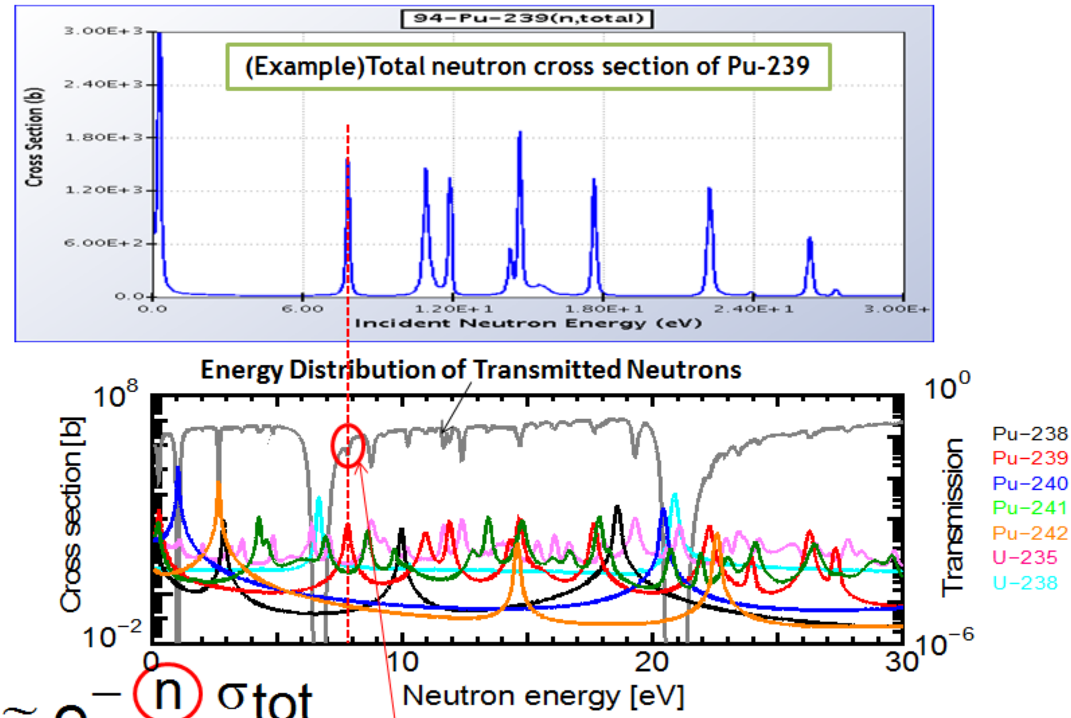
Neutron Resonance Densitometry (NRD) is a method based on a combination of NRTA (Neutron Resonance Transmission Analysis) for determining the abundance of of U/Pu and NRCA (Neutron Resonance Capture Analysis) for identifying neutron absorbing nuclides. The results of NRCA are used to correct NRTA data and improve the accuracy of NRTA. (Both NRTA and NRCA rely on the use of TOF (Time of Flight) measurement.)



NRTA: Quantification of (U/Pu) isotopes by analysing neutron transmission resonance dips. The results of NRCA are used to account for the influence of neutron absorbers on transmission profiles obtained with NRTA.

NRCA: Quantification of matrix materials by analysing gamma-ray spectra resulting from neutron absorption reactions.

Figure 1 NRD; A NDA technique based on combination of NRTA and NRCA



$$T \cong e^{-n\,\sigma_{tot}}$$

n: areal density
amount of material per unit area

n (e.g. areal density of Pu-239) is determined by analysing resonance transmission dips caused by the absorption of neutrons in the sample (Pu-239).

Figure 2 Determination of the areal density (e.g. Pu-239) by NRTA.

Measurement Obiects of NRD

- **Particle like melted fuel debris, removed from damaged nuclear reactors, and stored in a thin (~2 ㎝) disk container**
- Safeguards (solid) sample in a small vial containing U/Pu with high intensity gamma-ray emitting (i.e fission products) and neutron emitting (actinides) radionuclides

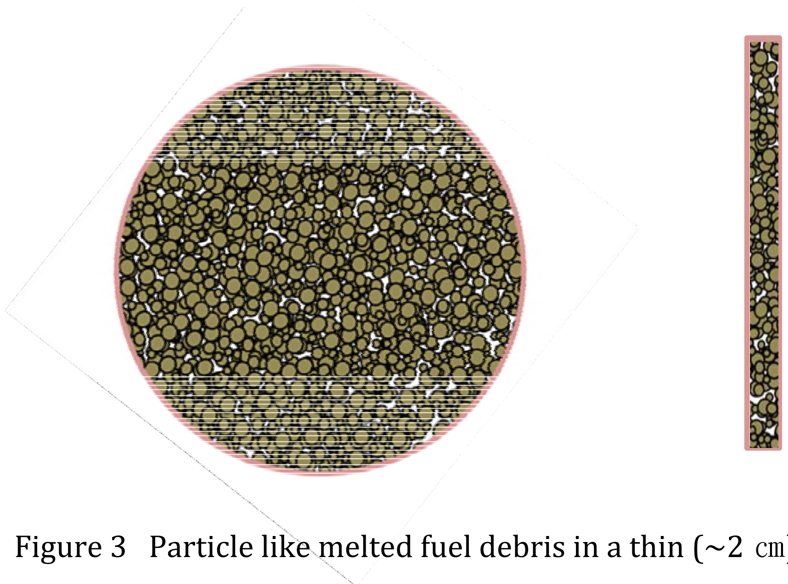


Figure 3 Particle like melted fuel debris in a thin (~2 ㎝) disk container.

Systematic effects affecting the accuracy of NRD for Measurement of U/Pu (Collaboration Studies between JAEA and JRC-IRMM)

- Experimental studies at the TOF-facilty GELINA of EC- JRC-IRMM. The study concentrates on particle like melted fuel debris that is removed from damaged nuclear reactors and stored in a thin (~2 ㎝) disk container. The main effects which have an impact on the accuracy of NRD for the characterisation of such samples are:
  - **Thickness of particle like debris**
  - **Particle sizes of particle like debris**
  - **Presence of neutron absorbing matrix materials**
  - **Temperature of particle like debris (to be studied in future)**
- Development of a conceptual design of a NRD system for the characterization of particle like melted fuel debris

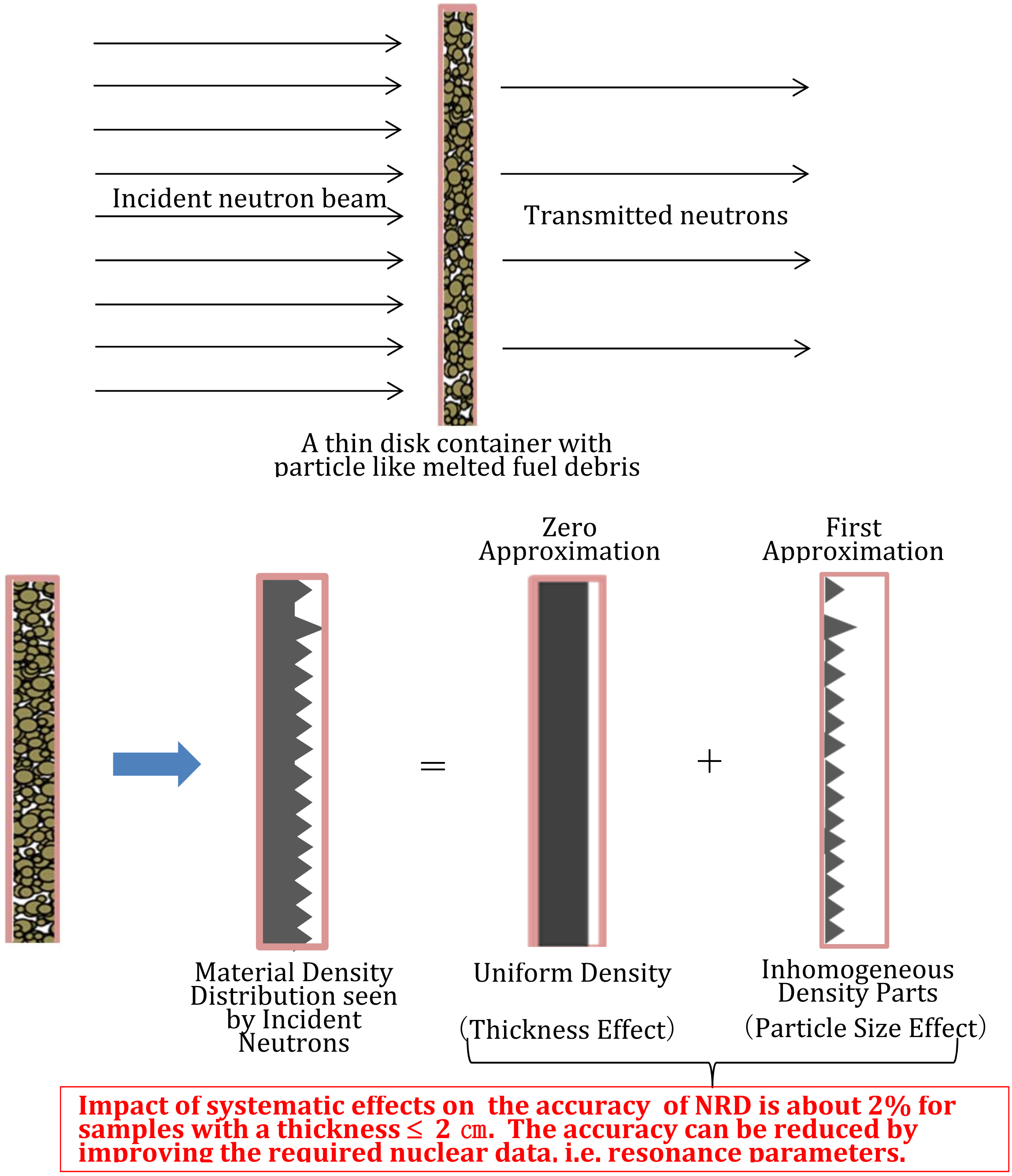


Figure 4 Studies on the accuracy of NRTA for the analysis of particle like melted fuel debris in a thin disk container.

Estimated accuracy of NRD
(as a result of collaboration studies)

- **About 3% for the quantification of the amount of U/Pu in particle like debris, removed from damaged reactors and contained in a thin (~2 ㎝) disk container. Figure 5 shows that a c**ounting statistics uncertainty ≤ 1% can be achieved for the main U and Pu isotopes by measurements of 20 min. Uncertainties due to other systematic effects can be reduced to 2% by dedicated data reduction and analysis procedures.

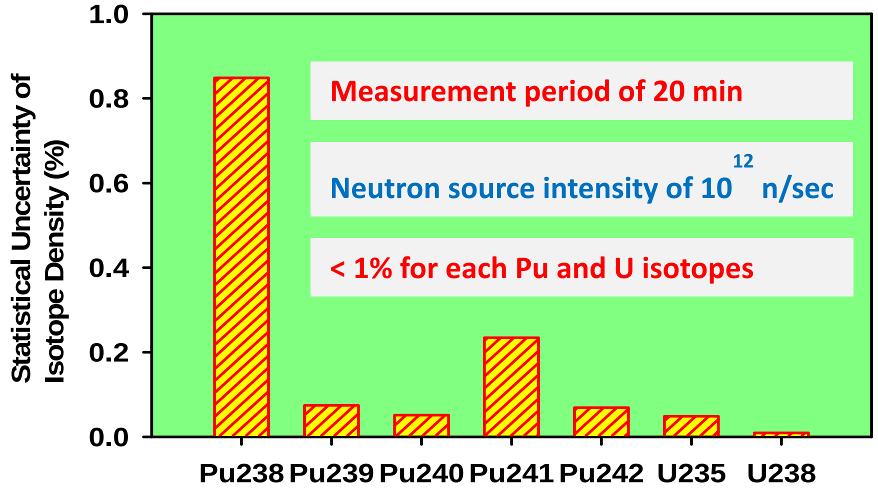


Figure 5 Achievable counting statisticsl uncertainty for NRTA on melted fuel debris containing B-10 as matrix material.

Effect of B-10 to NRTA

The intensity of the transmitted neutron beam will be strongly reduced by when boron is present in the sample, as illustrated in Fig. 6. This figure reveals the strong impact of the , boron content on the observed transmission. The influence of both the ^{10}B content and the sample thickness on the achievable uncertainty due to counting statistics is shown in Fig 7. From the data in Fig. 7 one concludes that :

- the uncertainty increases with the boron concentration.; and
- for a given boron concentration an optimum sample thickness can be defined.

Therefore, it is important to have an estimate of the relative amount of boron present in the sample to optimize the results obtained from a NRTA measurement.

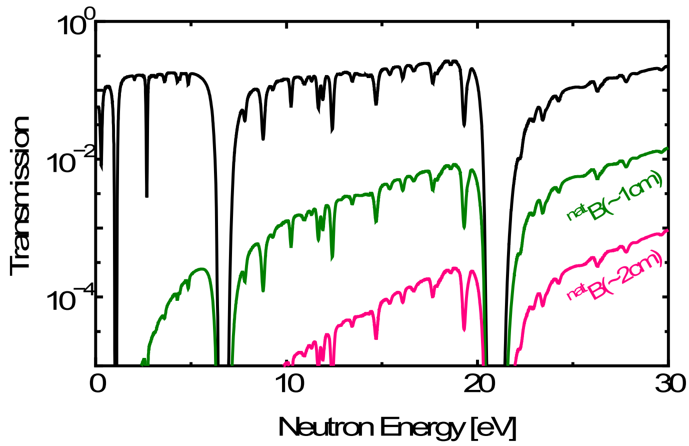


Figure 6. The transmission spectrum shown in Fig. 2 is distorted by ^{10}B in the sample.

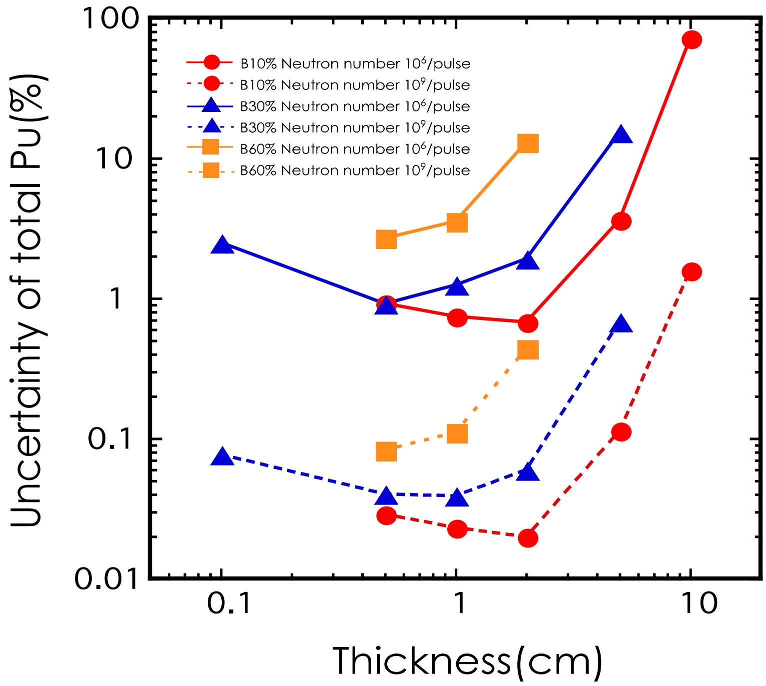
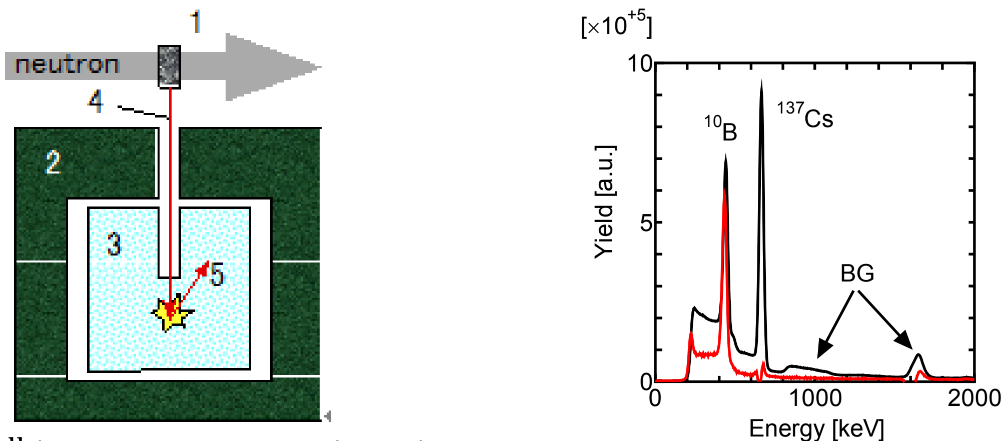


Figure 7. Counting statistics uncertainty on the total Pu amount in the sample as a function of the sample thickness for different boron concentrations.

NRCA for Determining the relative B-10 content in Particle Like Debris

To determine the B-10 concentration in the sample a method based on a combination of NRCA and PGAA is proposed. To apply this method a γ-ray spectrometer consisting of $LaBr_3$ scintillation detectors and a dedicated data acquisition (DAQ) system are under development. A schematic scheme of the detection system consisting of $LaBr_3$ scintillators, with an energy resolution of about 3.6% at 662 keV, is shown in Figure 8. The DAQ system will be able to record 500k events at a rate of 500 kHz for each of the 8-channel inputs, i.e. in total a 4 MHz event rate.



(a) An well-type gamma-ray spectrometer: (1) a sample, (2) a passive shield, (3) a well-type $LaBr_3$ detector, (4) a gamma-ray, and (5) a scattered gamma-ray.

(b) Identification of ^{10}B by the detection of prompt gamma –rays using a (5'' x 5'') LaBr3 detector at GELINA.

Figure 8 A Gamma-ray spectrometer and quantification of ^{10}B by prompt gamma-ray analysis under existence of Cs-137using NRCA system.

Experiments were carried out at GELINA to test the performance of the main $LaBr_3$ scintillation detector. A gamma-ray spectrum obtained by placing a 10B sample in the beam is shown in Figure 6. A comparison of this spectrum with a spectrum resulting from measurements with a 137Cs source illustrates that the resolution of a LaBr3 based gamma-ray spectrometer is good enough to determine the relative amount of 10B from an analysis of the γ-ray peak due to $^{10}B(n, \alpha\gamma)$ reaction. Further development is in progress and NRD demonstration experiments are planned in 2015 at a short neutron flight path of GELINA.

Conceptual design of a NRD System (for quantification of U/Pu in particle like melted fuel debris)

Monte carlo simulations have been carried out to define the characteristics of a NRD facility for the quantification of U/Pu in particle like melted fuel debris. The facility consists of a 30 MeV electron accelerator, a neutron producing target and two measurement stations. A pulsed electron beam is stopped in the target. The resulting Bremesstrahlung gamma-rays produce a pulsed neutron beam (10^{12} n/sec) by photonuclear reactions. One measurement station is equipped with a neutron detector to register the neutron passing through the sample and analyse the sample by NRTA. The other station is equipped with gamma-ray detectors for analysing spectra resulting from gamma-rays emitted after neutron absorption reactions.

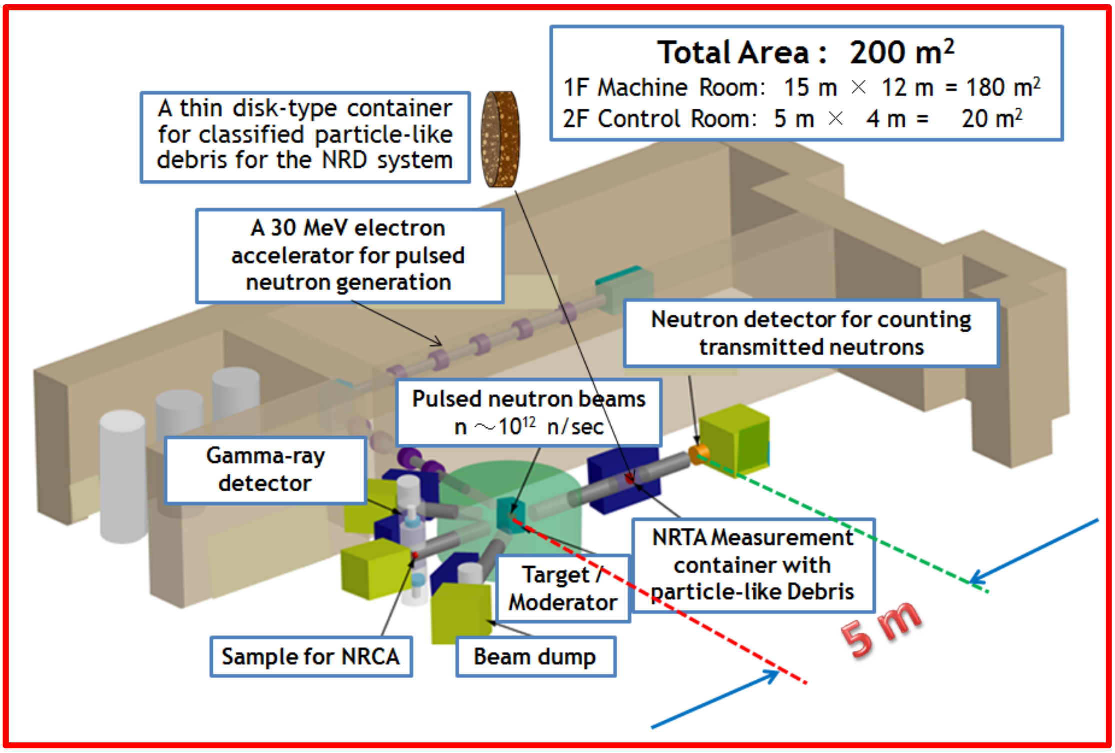


Figure 9 A Picture of a practical NRD system

Cost evaluation of a NRD System (for quantification of U/Pu in particle like melted fuel debris)

(Very rough Estimation)

- 5- 6 M$ for the 30 MeV electron accelerator (accelerator part has length of 3-4 m)
- 1- 2 M$ for the neutron producing target
- 1- 2 M$ for the detectors for counting transmitted neutrons and gamma-rays
- **7-10 M$ in total**

Illustration of the Preparation of Objects for NRD Measurements

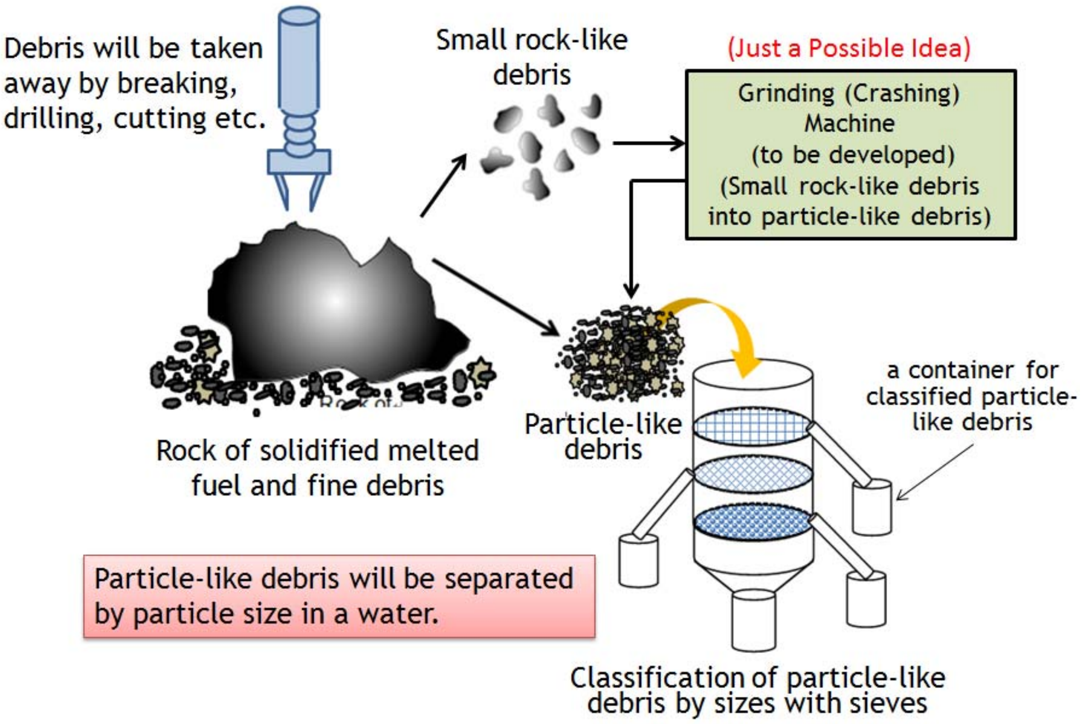


Figure 10 (a) Collection of particle like melted fuel debris

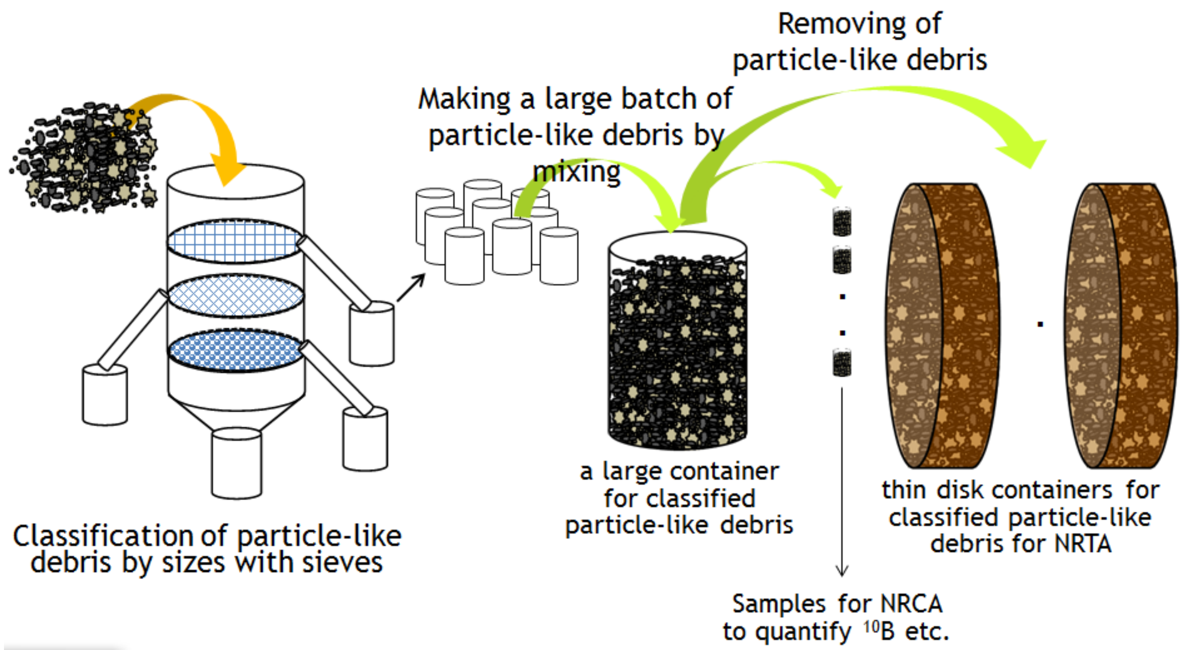


Figure 10 (b) Preparation of measurement objects for NRD