

B.3 Sampling of reactor pressure vessel and core internals

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AREVA: Sampling of Reactor Pressure Vessel and Core Internals

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Decommissioning and dismantling of nuclear power plants is a growing business as a huge number of plants built in the 1970s have now reached their lifetime. It is well known that dismantling a nuclear power plant means an extraordinary expense for the owner respectively operator. Beside the dismantling works for itself, the disposal of activated components and other nuclear waste is very expensive. What comes next is the fact that final disposal facilities are not available yet in most countries meaning a need for interim storage on-site in specially built facilities. It can be concluded that a special attention is paid on producing a minimal radioactive waste volume. For this, optimized dismantling and packaging concepts have to be developed. AREVA is proud of versatile experience in successfully dismantling nuclear components like core internals and reactor pressure vessel (RPV).

The basis of a well-founded and optimized dismantling and packaging concept must always be the detailed knowledge of the radiological condition of the component to be and in the best case a 3D-activation-model. For keeping the necessary sampling effort as small as possible, but simultaneously as efficient as possible, representative sampling positions are defined in advance by theoretical radiological examinations. For this, a detailed 3D-CAD-model of the components to be dismantled has proven very helpful and effective.

Under these aspects a sampling of RPV and its components is necessary to verify the theoretically calculated radiological data. The obtained results of activation and contamination are taken into account for the optimized dismantling and packaging strategy. The precise 3D-activation-model will reduce the necessary number and type of final disposal containers as security factors are minimized leading to a lower shielding effort, too. Besides, components or even parts of components may be subject of release measurement. In the end, costs can be reduced.

In this context, AREVA has developed various dedicated studies and already carried out sampling activities during the last years in different countries.

First step of work is the identification of representative sampling positions and proving the accessibility taking into account the most suitable techniques. In general, scratch, drilling and so-called shuttle as well as lens samples are available with their different advantages and disadvantages. An intensive sampling above and below the core center axis reduces the modeling uncertainties in these areas which arise from the relative distance from the neutron flux, from rescattering effects and from different materials.

After this a detailed planning of the work execution on-site provides a trouble-free and time optimized project process taking into account the relevant protection goals.

The samples are then transported to our accredited radiological laboratory for detailed analysis resulting in a respective analysis report.

In the end the customer has a precise overview over the radiological condition of its RPV and the internals to optimize the radioactive waste management.

Sampling of Reactor Pressure Vessel and Core Internals

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1 Introduction

Decommissioning and dismantling of nuclear power plants is a growing business, as a huge number of plants built in the 1970s have now reached their lifetime. It is well known that dismantling a nuclear power plant means an extraordinary expense for the owner respectively operator. Besides the dismantling works, the disposal of activated components and other nuclear waste is very expensive. Moreover, the fact that, in most countries, final disposal facilities are not available yet implies the need for interim storage on-site in specially built facilities. It can be concluded that a special attention is paid on producing a minimal radioactive waste volume. For this, optimized dismantling and packaging concepts have to be developed. The challenge is a fair balance between the obtainment of optimized packing and on the other side the fulfillment of stringent regulations set by the authorities and the storage requirements.

The basis of a well-founded, optimized dismantling and packaging concept must always be the detailed knowledge of the radiological condition of the component to be dismantled. In the best case a 3-dimensional activity model contributes to this basis.

AREVA has developed various dedicated studies and already carried out sampling activities in different countries for many years. This paper describes the approach and the main aspects of sampling activities.

2 Objective of Sampling

Under the above mentioned aspects of dismantling and minimization of radioactive waste a sampling of the reactor pressure vessel (RPV) and its internals is necessary to verify the theoretically calculated radiological data. For keeping the necessary sampling effort as small and efficient as possible, representative sampling positions are defined in advance by theoretical radiological examinations. For this, a detailed 3D-CAD-model of the components to be dismantled has proven very helpful and effective.

The obtained results of activation and contamination are taken into account for the optimized dismantling and packaging strategy. The precise 3-dimensional activity model will reduce the necessary number and types of final disposal containers significantly. The shielding effort is also optimized. Besides, components or even parts of components may be subject of release measurement. All these facts can cause a significant reduction of costs.

3 Main Aspects

The following main aspects have to be taken into consideration for sampling activities:

- Site-specific conditions in general
- History of the plant
- Representativeness of sampling positions
- Accessibility
- Handling effort
- Radiological conditions
- Occupational safety
- ALARA principles (As Low As Reasonably Achievable)
- Approval conditions
- Intermediate and/or final storage requirements
- Legal and commercial aspects

Taking into account the relevant protection goals, a detailed planning of the work execution on-site enables a trouble-free and time optimized project process. In the end, the customer gains a precise overview over the radiological condition of the RPV and its internals necessary to optimize the radioactive waste management.

4 Sampling Techniques

There are different sampling techniques available. Each has specific advantages and disadvantages, as shown in table 1.

Technique	Advantage	Disadvantage / Comment
Scratch sample	Low device-related effort	Mixture of CRUD ¹⁾ , cladding and bulk material Subjective factor with regard to removal depth

Drill sample	Low device-related effort Wall activation profile possible (samples from different depths)	Mixture of CRUD ¹⁾ , cladding and bulk material
Shuttle sample	Sample is suitable for materials testing	Relatively high device-related effort (EDM) Flush water influences CRUD ¹⁾ results Relatively high space requirement
Lens sample	Undamaged surface for CRUD ¹⁾ -sampling in laboratory Sample of cladding and bulk material from same position Enough material for reserve sample	Cooling needed when used on atmosphere

Table 1: Comparison of sampling techniques

¹⁾ CRUD = Chalk River Unidentified Deposits

To decide on which technique is the most suitable the respective boundary conditions have to be specifically taken into consideration.

4.1 Lens Sampling

To sample spherical samples, i.e. lens samples, with a diameter from 20 mm to 70 mm, the sampling device designed by AREVA cuts these samples out of the surface of the component (picture 1). Thickness can be chosen from 3 mm to 12 mm. The well-proven, robust and adaptable sampling device is applicable for both under-water and on-atmosphere sampling.

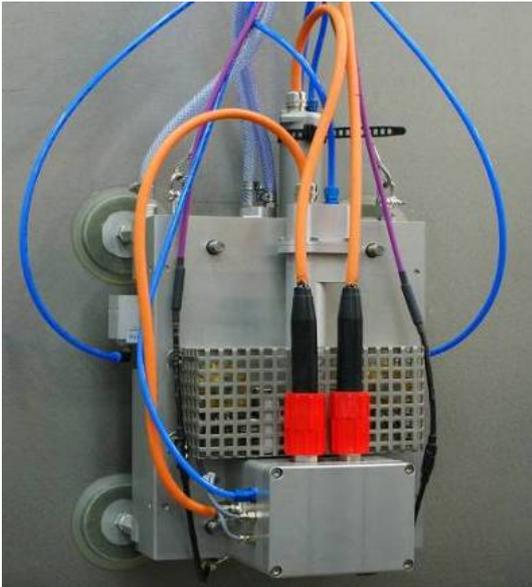
The sampling device consists of the following components:

- Control unit with integrated surveillance system
- Pneumatic unit
- Cutting device

For sampling the device with its hollow-ball-shaped cutter is placed at the defined position on the component and is fixed by vacuum or via tensioning or clamping. The drive of the cutting device is operated pneumatically.

The device offers the following advantages:

- Works in dose rate intensive areas
- Cuts out complete samples which are perfectly suitable for analyses (CRUD, cladding, wall)
- Dimension respectively mass of the sample can be influenced by cut-in depth (important for handling in the laboratory)



Picture 1: Sampling device positioned on a wall



Picture 2: Lens sample

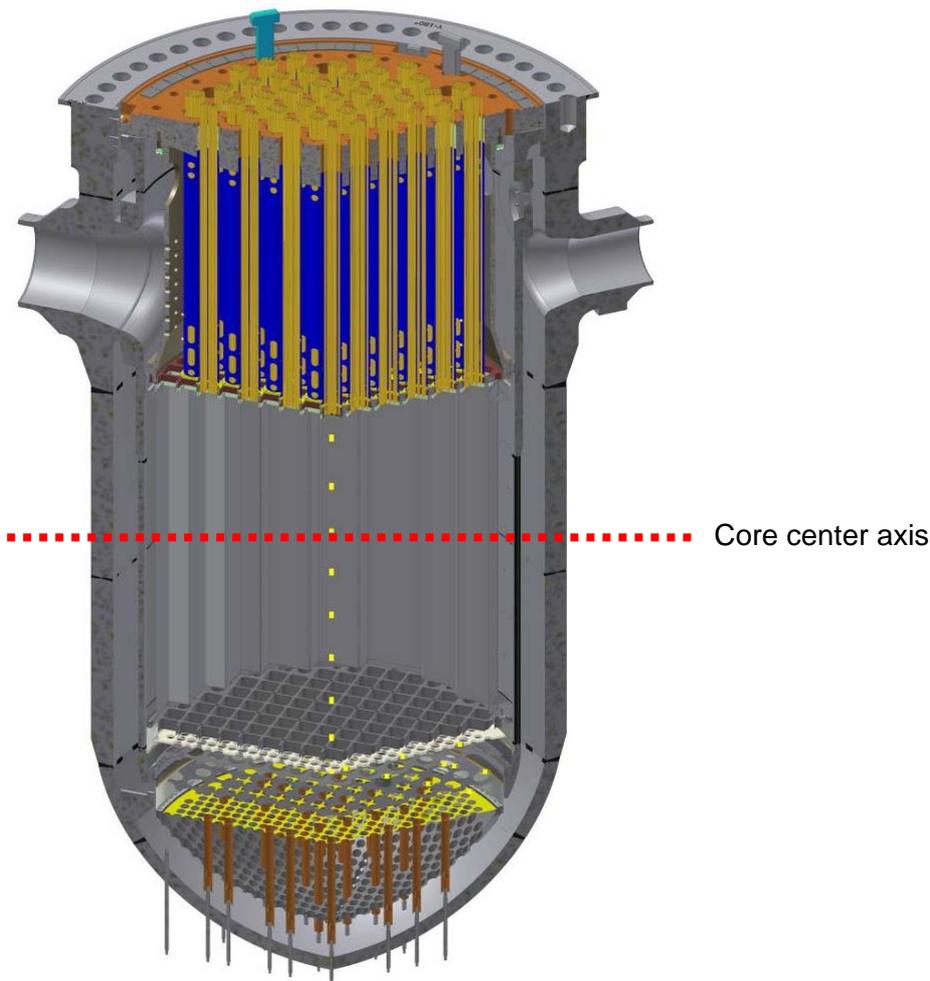
5 Sampling Positions

The challenge is to keep the number of samples and the handling effort as low as possible and, at the same time, as effective as possible.

An intensive sampling far away from the core center axis, above and below (picture 3), reduces the modeling uncertainties in areas that arise from the relative distance from the neutron flux, from rescattering effects and from different materials.

Characterization samples taken from low activated core internal components are then used to verify the calculated activity data. This prevents an overestimation of activities leading to higher effort regarding packing, shielding and container amount can be avoided.

If sampling at a specific position is not possible due to e.g. interfering edges, a new and equivalent position will be defined. Overall, it is very important to determine and consider the exact sampling positions in order to create a most realistic activity model.



Picture 3: RPV (without head) and its internals

6 Accessibility Studies

For shielding and dose rate minimization reasons sampling of the components will mostly be done under water and remote-controlled. In the initial state, as assumed, the RPV is in installed position and the internals are located inside the RPV. Therefore, accessibility studies need to take into account the following main aspects:

- Accessibility of the specific position with the chosen sampling technique
- Minimization of preparation and execution time (dose rate)
- Current licensing conditions
- Other boundary and site-specific conditions (e.g. influence from or on ancillary activities)
- Early consideration of future activities (dismantling of the components)

The easiest variant resulting in the lowest expense is the sampling of the RPV and its internals without dismounting the components. This means that samples are taken only from positions accessible in an installed position. Hence, this variant avoids time consuming disassembly activities. On the other hand it is clear that some sampling positions can only be reached with higher effort (which might lead to

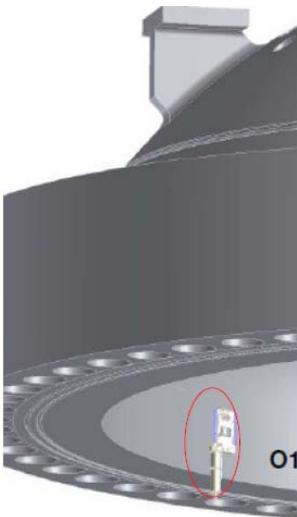
increased personal dose rate). Some positions are not accessible at all. To conclude, this variant does not provide comprehensive sampling, as important positions inside the RPV can not be reached.

The other extreme is the temporary dismantling of the entire core internals, causing a logistic and time consuming effort. Transporting the internals might cause additional personal dose rate. Space and tooling is needed in the ancient area, e.g. spent fuel pool, for parking the internals and for the sampling activities. Additionally a lot of water may be needed for radiation protection reasons. On the other hand, both the upper and lower core internals as well as the RPV inside is easily accessible allowing a comprehensive sampling and by this a detailed overview over the activation conditions can be gained.

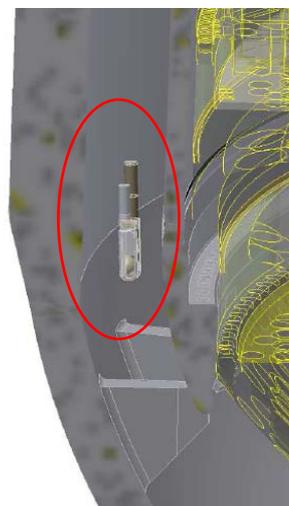
As shown, there is no ideal solution which satisfies all technical, radiological and commercial aspects. Therefore, a compromise between different variants has to be entered. It has proven effective to develop a matrix of different intelligent variants comparing their characteristics. For this a detailed expert knowledge and specific experience as well as foresighted planning is indispensable. Finally, the most suitable variant can be chosen.

Attention must also be paid on samples to be taken from the RPV wall (outside). Accessibility has to be checked here, too, as space between RPV wall and biological shield, respectively RPV insulation, is often limited and hindered by interfering edges.

Pictures 4 and 5 show examples of the sampling device positioned at the RPV head and the RPV wall.



Picture 4: Sampling device at RPV head



Picture 5: Sampling device at RPV wall close to the calotte

7 Handling and Transportation

Dose rate measurements of the samples taken are necessary for their radioactive transport to the laboratory. Afterwards samples are transferred to an adequate primary packaging, e.g. a plastic box. Samples with estimated higher dose rate are handled with appropriate tooling (long-stemmed gripper etc.). For transporting the samples there are different boxes available that take into account the specific

characteristics of the samples. Beside its shielding effect the box protects the samples from cross contaminating. Underwater samples require special boxes with holes for draining.

8 Radiological Analysis

Radiological analysis of the samples is employed in a suitably equipped and accredited laboratory. There the samples are analyzed with respect to their activation nuclides and other important element contents:

- Co-60 and other gamma-emitters
- Fe-55, Ni63 and C-14
- Other nuclides if necessary (site and country specific)
- Element content of cobalt (source for Co-60)

The goal is to get a correlation with the activity calculations.

The final report may contain 2 different examinations:

- Checking the acceptance conditions for an on-site interim storage facility at time X (current dose rate)
- Checking the ability for final disposal at time Y (decay correction of the relevant nuclides)

It is recommended to hold back spare material for possible necessary future examinations.

9 Summary

It has been shown that, in order to choose representative sampling positions and to verify their accessibility, different technical, radiological and commercial aspects have to be taken into account.

The results from the radiochemical analyses performed with the taken samples can be used for correlation with the activity calculations and to develop a 3-dimensional activity model.

A comprehensive sampling of the RPV and its internals is of decisive importance prior to dismantling. Only this provides for a detailed overview of the radiological condition of the components. Being aware of this condition is a prerequisite of being able to develop a dismantling and packaging concept optimized in work amount and, in the end, cost.





Sampling of Reactor Pressure Vessel and Core Internals

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Sampling of RPV and Core Internals Content



- ▶ **Introduction and Motivation**
- ▶ **Main Aspects**
- ▶ **Sampling Techniques**
- ▶ **Sampling Positions**
- ▶ **Accessibility Studies**
- ▶ **Handling and Analysis**
- ▶ **Summary**

Sampling of RPV and Core Internals Content



▶ Introduction and Motivation

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Sampling of RPV and Core Internals Introduction and Motivation

▶ Dismantling means an extraordinary expense:

- ◆ Dismantling works and equipment
- ◆ Costs for storage and disposal
 - Containers
 - Facilities to be built on site
 - Fees



Examples:

- ▶ RPV Internals Stade NPP: 37 MOSAIK® containers saved
- ▶ RPV Würgassen NPP: Bonus for saved containers



Minimization of the radioactive waste volume as a key factor

▶ Optimization / validation of the dismantling and packaging strategy

- ◆ Sampling at relevant areas to **calculate** expected radiation exposure
- ◆ **Verification** of the theoretically calculated radiological data
- ◆ Most realistic evaluation of required technical & radiological measures (shielding, number & type of disposal containers, decontamination ability etc.)

Sampling of RPV and Core Internals Introduction and Motivation

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➤➤ **Minimization of the radioactive waste volume as a key factor**

➤➤ **All these facts can cause a significant reduction of costs.**

Sampling of RPV and Core Internals

Background: Calculations



► Objective goals of activation calculations

◆ Depending from project phases

- Radiological planning
- Planning on cutting and packing
- Preparation of waste documentation

◆ Basis of calculations

- Neutron flux
- Content of Co-60

Sampling of RPV and Core Internals

Background: Calculations

► Objective goals of activation calculations

◆ Depending from project phases

◆ Radiological planning

- As a first and conservative approach: estimated maximum of activity
- For planning of **dismantling and packing** strategies (remote handled required or manual work possible)
- For planning of **radiation protection** measures (restrictions for retention and working time, shielding effort)
- Nuclides Co-60 (for steel) and Co-60, EU-152, EU-154 (for concrete) represent the major sources of ionizing radiation which have to be considered for adhering to the dose rate limits
- Caution: Be aware of the exact position and amount of stellite as a major source of gamma radiation!

Sampling of RPV and Core Internals

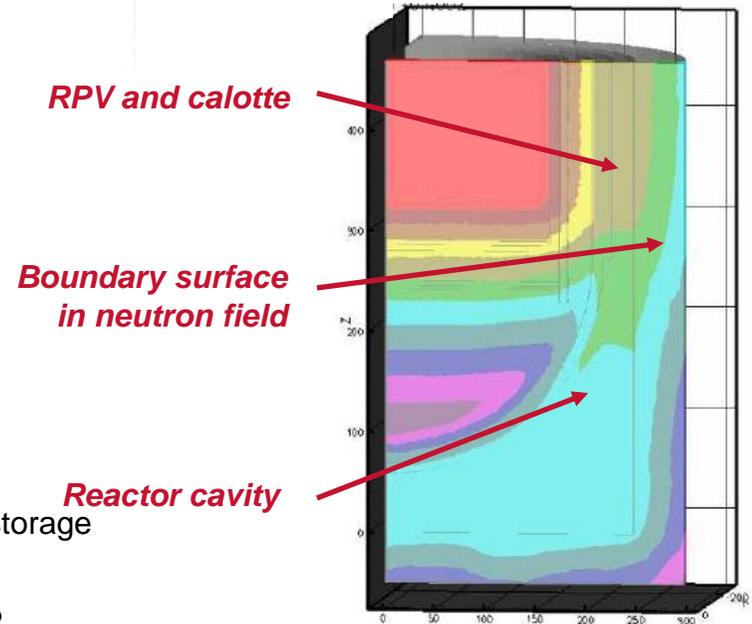
Background: Calculations

► Objective goals of activation calculations

◆ Depending from project phases

◆ Planning on cutting and packing

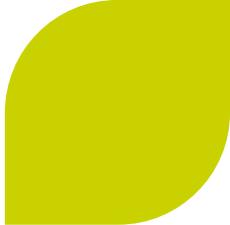
- Mandatory knowledge on
 - **Activity inventory** (nuclide vector)
 - **Spatial distribution** of activity inventory in RPV, internals and biological shield (especially outside the main axes)
- Data help on
 - **Cutting plan** for components
 - Selection of **suitable containers** for intermediate and/or final storage
 - Decision on **storage or free release**
- Co-60, Fe-55, Ni-63 (for steel) and Co-60, Eu-152, Eu-154, Ba-133 (for concrete) plus H-3 and C-14
- Creation of spatial distribution by connection of results from 3D-calculation programs with measuring results (**sampling**)
- Especially in areas where the share of activity is low compared to contamination, a detailed **sampling is mandatory anyway** to gain information on the contamination level
- All calculations must be **verified by measuring results** as a principle



Example: 3D activity model, source: DSR

Sampling of RPV and Core Internals

Background: Calculations



► Objective goals of activation calculations

◆ Depending from project phases

◆ Preparation of waste documentation

- For **declaration of the waste** according to the relevant acceptance and storage specifications, the information on **additional nuclides** is necessary
- Can be derived from either complementary calculations or feasible comparisons or any other procedure aligned with the authorities
- It is **highly recommended** (and often mandatory) to **confirm the „calculated“ activity proportions of nuclides to each other by respective sampling** and radiological and chemical analysis

Sampling of RPV and Core Internals Content



- ▶ Introduction and Motivation

- ▶ Main Aspects

- ▶ Sampling Techniques

- ▶ Sampling Positions

- ▶ Accessibility Studies

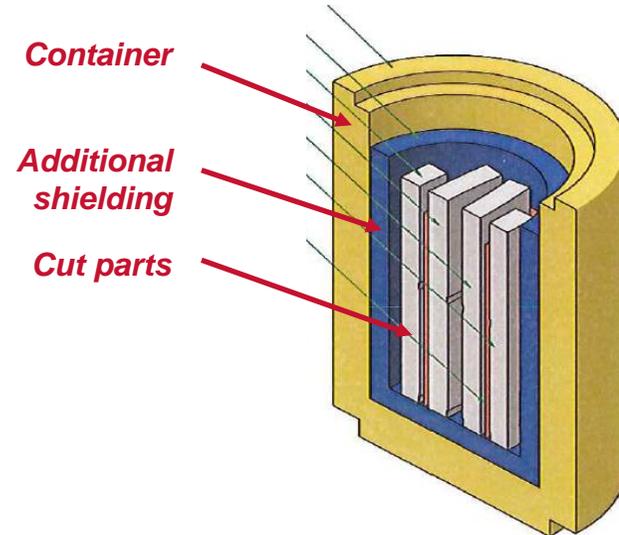
- ▶ Handling and Analysis

- ▶ Summary

Sampling of RPV and Core Internals Main Aspects

► The following main aspects have to be taken into consideration for sampling activities:

- ◆ Site-specific conditions in general
- ◆ History of the plant
- ◆ Representativeness of sampling positions
- ◆ Available time frame
- ◆ Accessibility & handling effort
- ◆ Radiological conditions
- ◆ ALARA principles & occupational safety
- ◆ Intermediate and/or final storage requirements
- ◆ Approval conditions & legal and commercial aspects



Example: Loaded MOSAIK® container

► Detailed planning provides a trouble-free sampling process optimized in time

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Sampling of RPV and Core Internals

Sampling Techniques

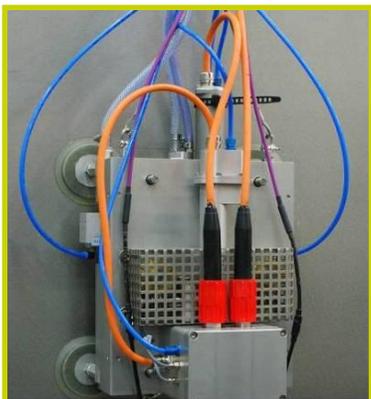
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Sampling of RPV and Core Internals

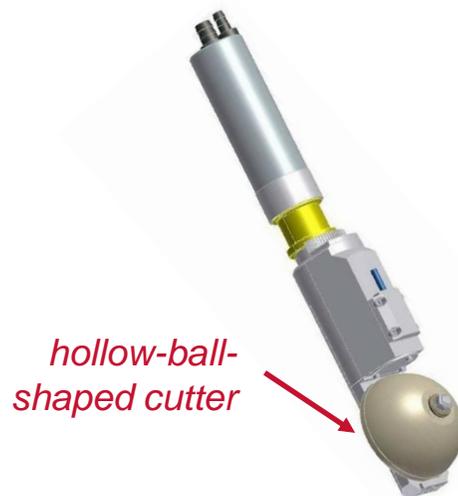
Sampling Techniques

► Lens sampling device, designed by AREVA:

- ◆ Diameter from 20 to 70 mm
- ◆ Thickness from 3 to 12 mm
- ◆ Well-proven, robust and adaptable
- ◆ Applicable for under-water and on-atmosphere sampling
- ◆ Works autarkic, no manual intervention necessary in dose rate intensive areas



Lens sampling device



Lens sample

Sampling of RPV and Core Internals Content

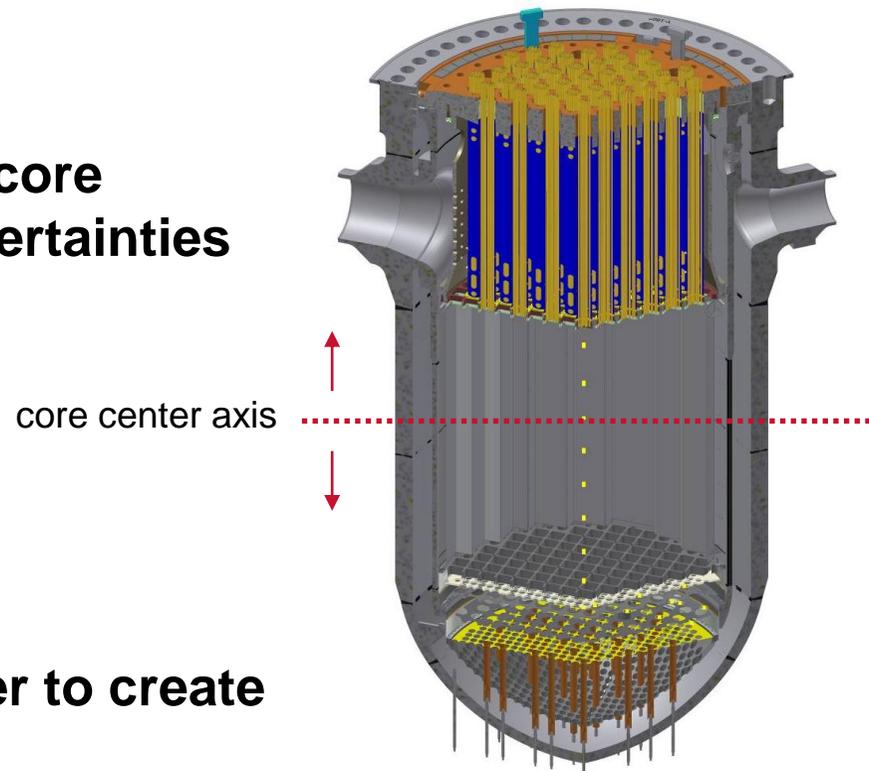


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Sampling of RPV and Core Internals

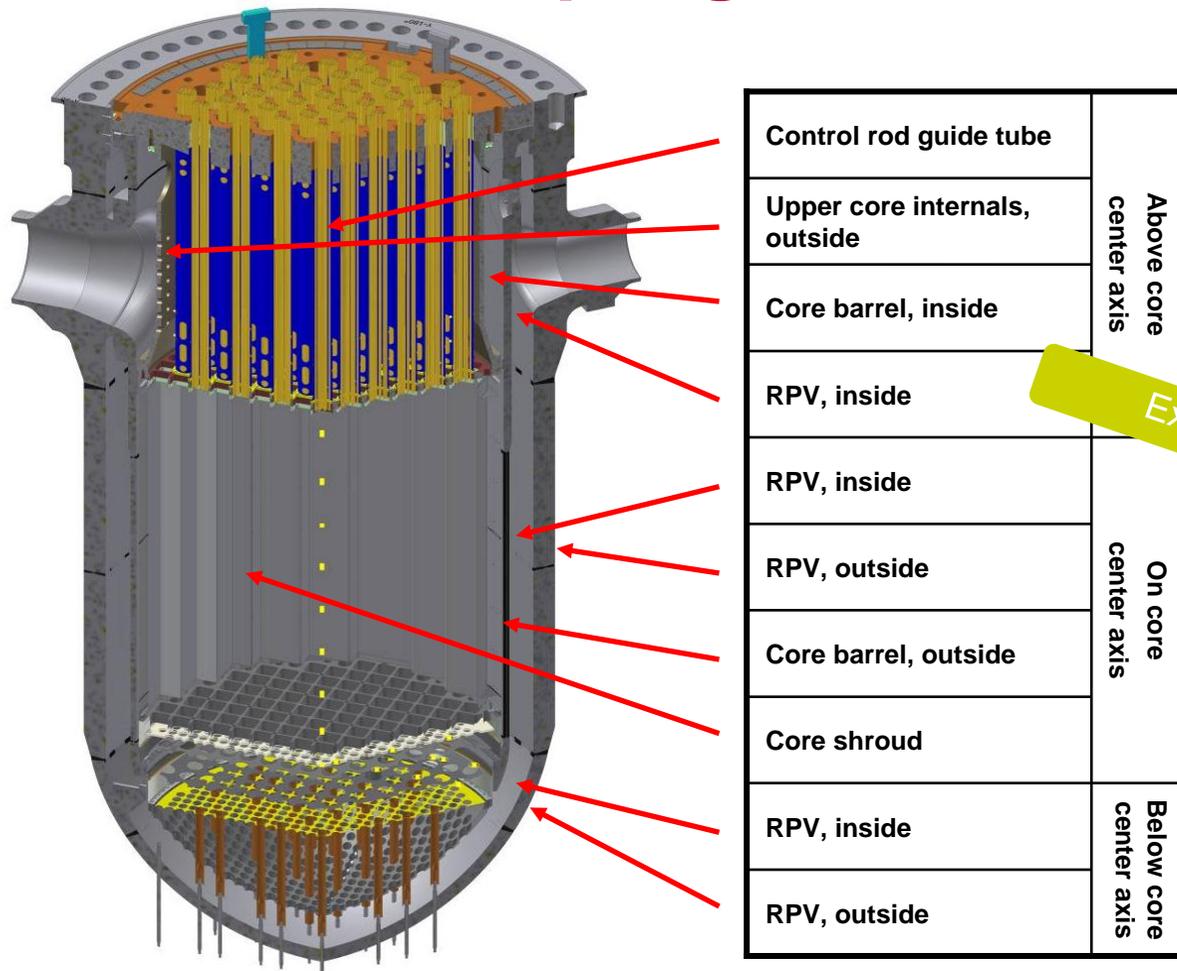
Sampling Positions

- ▶ **Challenge:** Keep the number and effort as **low** as possible but **simultaneously** as **effective** as possible
- ▶ **Intensive sampling far away from core center axis reduces modeling uncertainties arising from**
 - ◆ distance from neutron flux
 - ◆ rescattering effects
 - ◆ different materials
- ▶ **Define intelligent positions in order to create a most realistic activation model**



Sampling of RPV and Core Internals

Sampling Positions – PWR



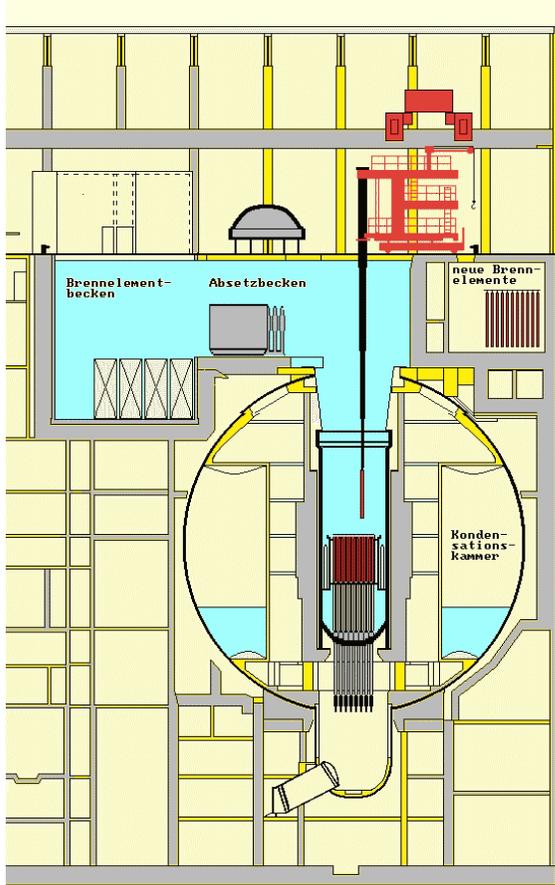
AREVA NP



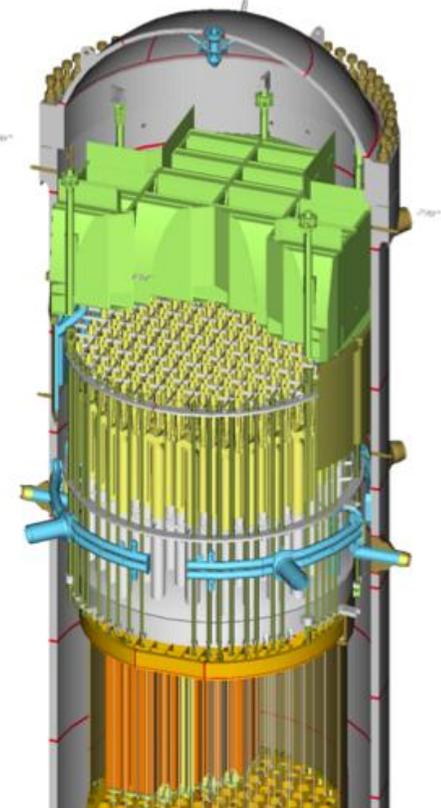
If specific position is not accessible due to e.g. interfering edges, a new and equivalent position will be defined.

Sampling of RPV and Core Internals

Sampling Positions – BWR



Component	Metal Samples	CRUD Samples
RPV Head	4	1
Steam Dryer	1	1
Separator	3	3
Feedwater sparger	1	1
Upper Grid Plate	1	0
Core Shroud	1	0
Jet Pump	1	0
Control Rod Guide Tube, Shut down position	2	1
Control Rod Guide Tube, Control position	2	1
RPV Calotte	3	0
Total	20	8



Source: Würgassen NPP, e.on



AREVA NP

Number, position and type of samples are results of a dedicated study. Experience: the number of 28 samples were sufficient, but according to customer an even higher number would have been helpful.

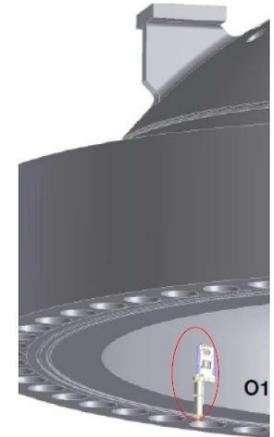
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Sampling of RPV and Core Internals Accessibility Studies

- ▶ Most likely sampling will be done under water (dose rate minimization)
- ▶ Assumed as initial state: RPV and internals in installed position
- ▶ Accessibility studies need to take into account
 - ◆ Chosen sampling technique
 - ◆ Minimization of preparation and execution time (dose rate)
 - ◆ Current licensing conditions
 - ◆ Other boundary and site-specific conditions
 - ◆ Early consideration of future activities



Sampling device located
on RPV head

Sampling of RPV and Core Internals Accessibility Studies

▶ Different variants are possible

◆ 1: Sampling without any dismantling activities

- + time consuming dismantling is avoided
- some positions may not be reachable at all -> no comprehensive sampling

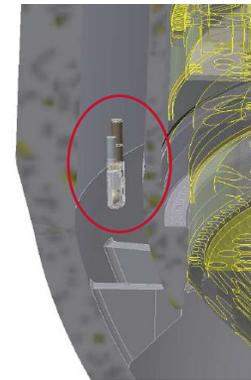
◆ 2: Something between

◆ 3: Temporary dismantling of the entire core internals

- logistic and time consuming
- space and tooling needed
- + easily reachable position on all components
- + detailed overview over activation conditions can be gained

▶ Compromise which satisfies all technical, radiological and commercial aspects

▶ Detailed expert knowledge and specific experience as well as foresighted planning is indispensable



Sampling device located on RPV wall close to the calotte

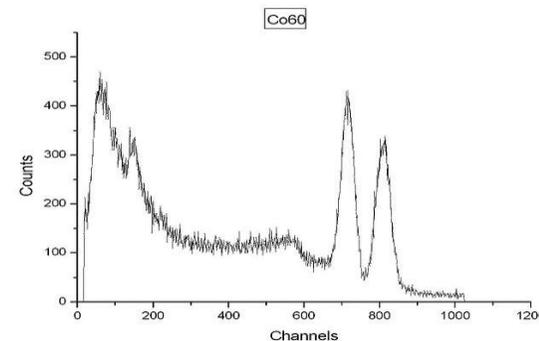
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Sampling of RPV and Core Internals Handling and Analysis

- ▶ Dose rate measurements on the taken samples
- ▶ Transfer to adequate primary packaging
- ▶ Appropriate tooling might be needed
- ▶ Beside the shielding effect the box secures samples from cross contamination
- ▶ Transport to a suitably equipped laboratory
- ▶ Radiological analysis:
 - ◆ Co-60 and other gamma-emitters
 - ◆ Fe-55, Ni-63 and C-14
 - ◆ Other nuclides if necessary
 - ◆ Element content of cobalt (source for Co-60)



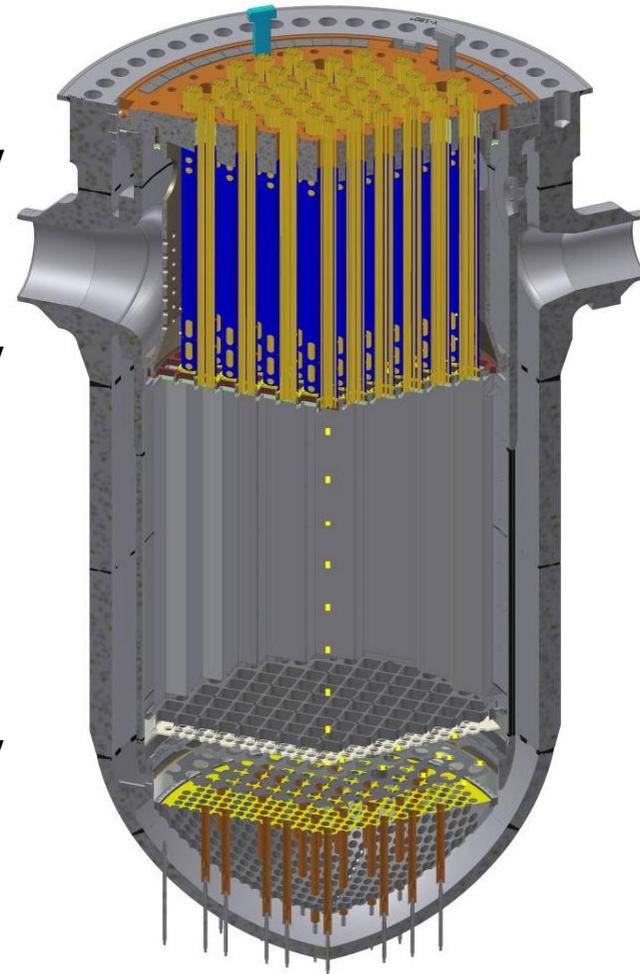
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Sampling of RPV and Core Internals Summary

- ▶ Representative sampling positions have to be determined
- ▶ Accessibility under the respective boundary conditions has to be verified
- ▶ Correlation with the activation calculations and development of a 3-dimensional activity model
- ▶ **Comprehensive sampling** of RPV and its internals is of decisive importance **prior to dismantling**
- ▶ Only a detailed knowledge of the **radiological conditions** offers the possibility to develop a dismantling and packaging concept optimized in **amount and costs**





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