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Preliminary design of the RPV and RVIs of the Trino and Caorso NPPs – Effective Dose Optimization

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ISOE Symposium Uppsala, Sweden 26-29 June

Rome, 26/06/2018

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Introduction and motivation

This study is covering all aspects of practical implementation of radiation protection for Occupational Exposure Management, through the application of the ALARA principle, in terms of:

Preliminary dose evaluation to workers for their performance during every scenario for different critical NPPs dismantling activities in normal conditions

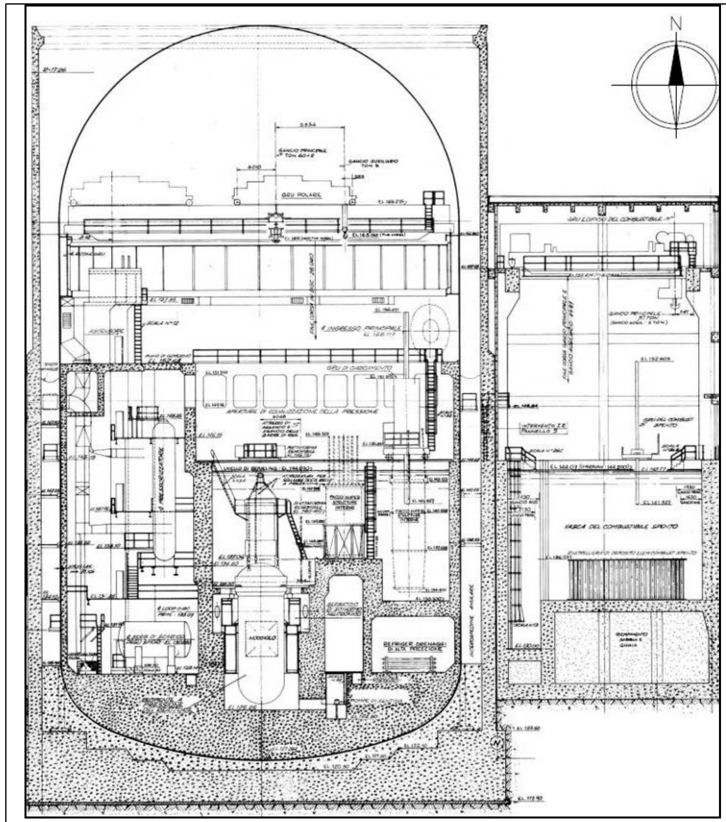
ALARA "as low as reasonably achievable“ objectives:

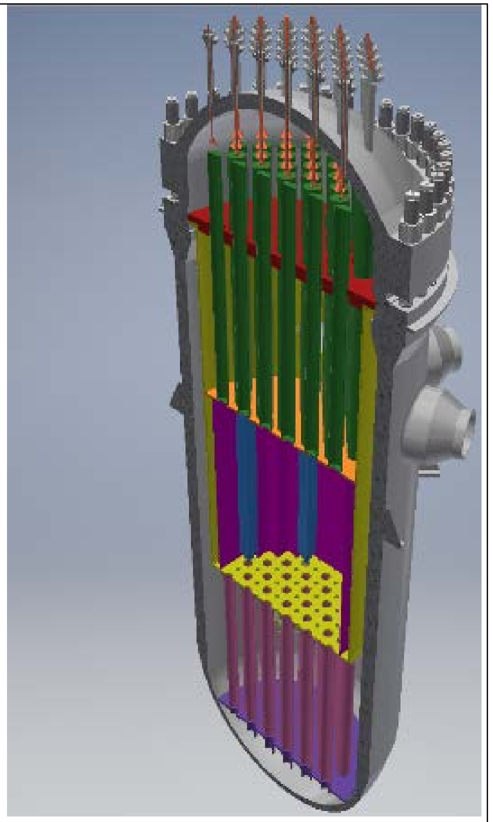
- No work incidents
- No nuclear incidents (no release of radioactive substances into the environment, no on-site cross contamination, no internal human contamination, etc.)
- Minimal collective and individual doses according to the ALARA principle

Introduction and motivation

This activities are:

1-Dismantling of the RVIs and Radiological Characterization of the RVIs and RPV of Trino NPP.





Introduction and motivation

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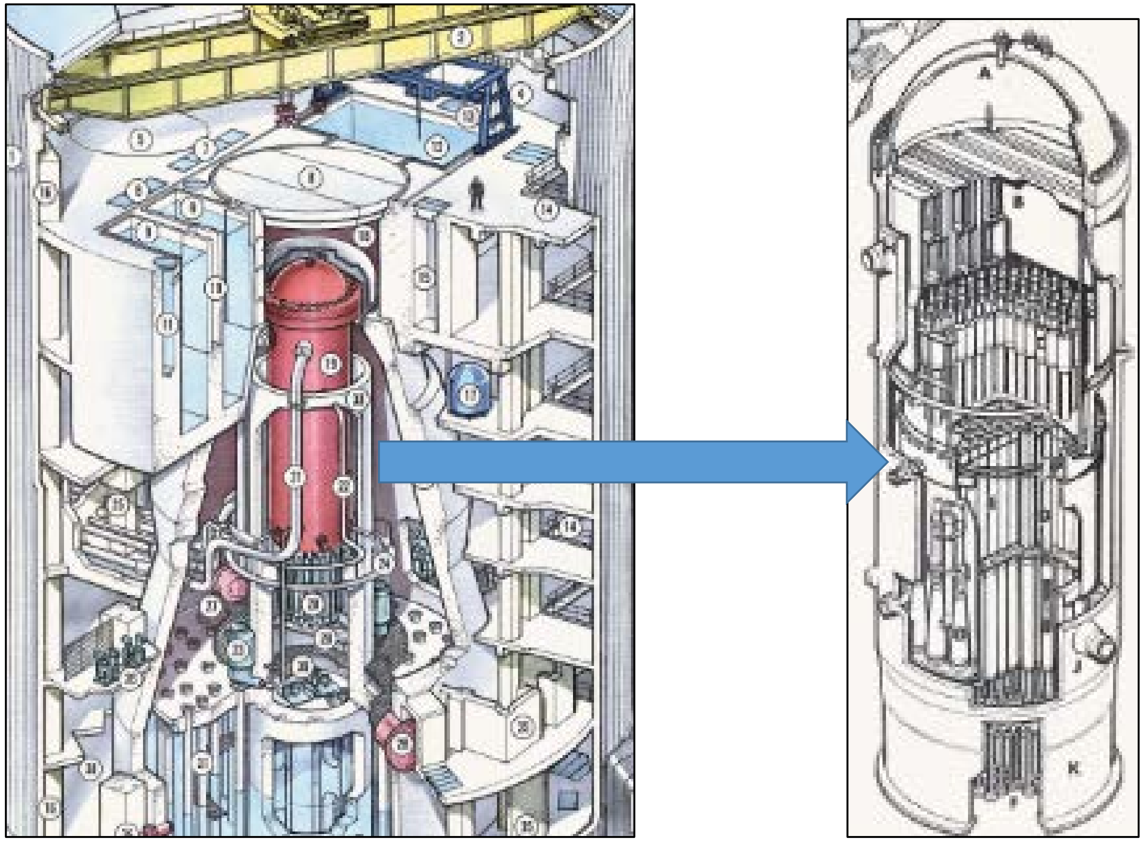
2-Dismantling of the RPV of Caorso NPP, after the removal of the Internals. Two operating conditions were considered: RPV without shielding (water); RPV partially filled with water and in the process of being dismantled with a "mixed" technique, i.e. keeping the water level just below the cutting plane of the shell rings.



Implementation model: Visiplan 3D ALARA code

Occupational doses are determined by a number of parameters, including:

- Activation
- Contamination
- Geometry of shielding
- Self-shielding of components
- Deposits of radionuclides; hot-spots
- Planning of tasks
- Behaviour of workers

The blue coloured items are addressed by our model

VISIPLAN provides an acceptable method to assess dose from radiation transported through intervening shielding materials with a correction for the build up.

Implementation model: Visiplan 3D ALARA code

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A first step in the VISIPLAN approach is the gathering of information about the **working area**. This information includes the **geometry**, the **materials** and the **radioactive sources** of the work area. The aim is to establish an adequate model of the work area with adequate meaning, a level of detail suited for both calculation speed and required accuracy for the dose assessment.

Geometrical information → The geometrical model can be build from technical drawings

Material information → Material information is gathered from knowledge of the site history and from experts on-site.

Radiological information → Radiological information is gathered from detailed information about the sources used on the site.

International Reference

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- **Council Directive 2013/59/EURATOM, 5 December 2013:** «laying down basic safety standards for protection against the dangers arising from exposure to ionising radiation;

*“The Radiation protection of individuals subject to occupational exposure **must be optimised** with the aim of keeping the magnitude of individual doses, the likelihood of exposure and the number of individuals exposed as low as reasonably achievable taking into account the current state of technical knowledge and economic and societal factors”.*

- **Annals of ICRP (International Commission on Radiological Protection), Pubblication n° 103**

Optimization is always aimed at achieving the best level of protection in the existing conditions through a continuous and iterative process that includes:

- assessment of the exposure situation, including any potential exposure (framework of the process);
- choice of a suitable value for the constraint or reference level;
- identification of any protection options;
- choice of the best option under existing conditions;
- execution of the chosen option.

Case:1 - Dismantling of the RVIs and Radiological Characterization of the RVIs and RPV of Trino NPP

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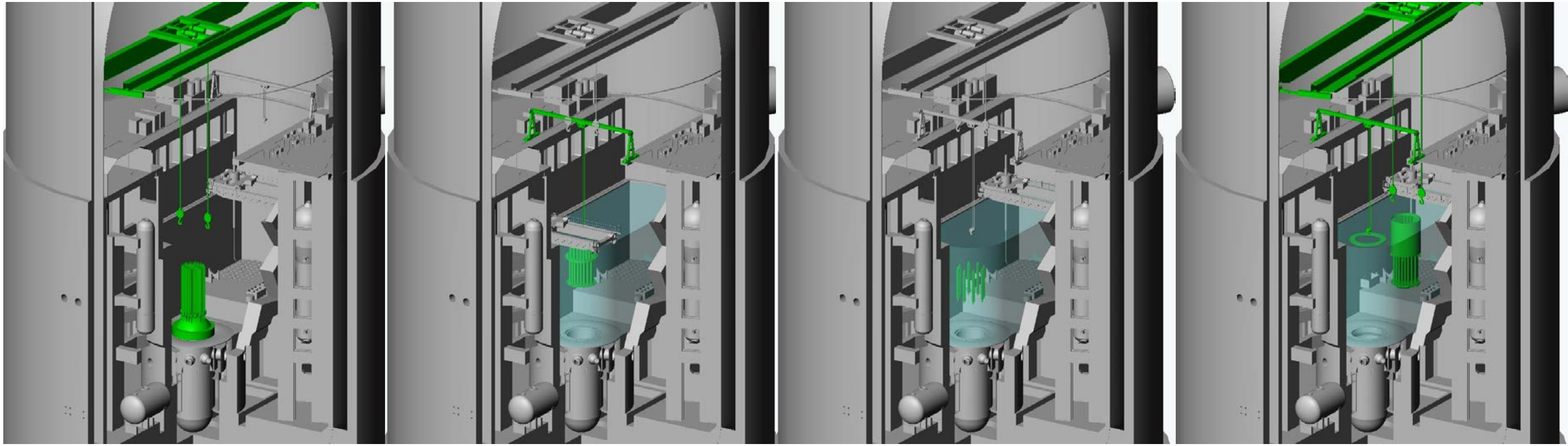
Operating Phases

- Vessel Head removal
- Upper Package Removal
- Moving DFA
- Barrel Removal



Results Analysis Trino NPP: Exposure Scenario

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N°	Operational Phases	Exposure Scenarios
1	1. **Manual removal of nuts and studs** from the Vessel head; 2. Attach the Vessel head to the lifting beam. 3. Vessel filling up to the flange (height 134m).	Initial configuration with Vessel closed and flooded up to the nozzles and the reactor channel is dry.
2	**Shift of the Vessel head** from the reactor well to the control floor (height 152.68m) and subsequent removal, manually, of the Vessel head slat.	Configuration corresponding to the activity of removing the Vessel head and laying on the Control floor with flooded reactor cavity, conservatively, up to 137 m from the ground-level.
3	1. Reactor channel flooding up to 144.07m height through the filling circuit; 2. **Upper Package removal** and positioning on the tooth of the reactor cavity (height 137.06 m). 3. **Removal of dummies** stainless steel elements and transfer to the Spent Fuel Pool. 4. Sample collection from the Barrel, the Upper Package and the Vessel head	Configuration with open Vessel and flooded cavity up to 144.68 m, which corresponds to the height for the operations of refilling the fuel, extraction of the Upper Package, including sampling activities, and removal of the dummies stainless steel elements.
4	**Extraction and handling of the Lower Package** and positioning in the reactor cavity well.	Configuration with open Vessel, flooded cavity up to 144.68 m and sampling with subsequent removal of the Lower Package.
5	**Sample collection from the walls of the Vessel** (inner cladding plus mantle).	

Phisycal and radiological history data Trino NPP

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COMPONENTS	N°	Weight [kg]	High [m]	CO 60 (Bq/g)	CO 60 [Bq]	% CO 60
INTERNALS						
Barrel-Baffle	1	9.45E+03	2.93	1.454E+06	1.374E+13	30.30%
Upper Core Plate	1	9.73E+02	0.04	2.806E+06	2.729E+12	6.02%
Upper Barrel	1	6.47E+03	2.3	2.948E+02	1.907E+09	0.00%
Top Support Plate	1	6.80E+03	0.21	0.000E+00	0.000E+00	0.00%
Upper guide tubes	52	8.02E+03	2.35	1.403E+05	8.967E+10	0.1978%
Upper guide tubes				1.465E+03	2.150E+09	0.0047%
Upper guide tubes				3.671E-01	7.995E+05	0.00%
Upper guide tubes				0.000E+00	0.000E+00	0.00%
Upper guide tubes				0.000E+00	0.000E+00	0.00%
Lower Core Plate	1	1.19E+03	0.04	6.138E+06	7.321E+12	16.15%
Cruciform core radial support	1	3.75E+02	0.21	6.138E+06	2.302E+12	5.08%
Lower guide tubes	52	8.26E+03	3.2	1.697E+01	7.007E+07	0.00%
Lower guide tubes				9.674E-02	3.994E+05	0.00%
Stainless steel elements (Dummies)	8	1.18E+03	3.23	1.630E+07	1.916E+13	42.25%
Total Co-60 [Bq]				**4.534E+13**		
VESSEL						
Vessel wall above the core	1	4.06E+04	2.3	2.654E+00	1.077E+08	0.01448%
Vessel wall at core height	1	5.41E+04	2.7	5.657E+03	3.060E+11	41.11839%
Vessel wall below the core	1	1.35E+04	2.5	3.717E-02	5.019E+05	0.00007%
Vessel flange	1	1.78E+04	0.45	1.138E-02	2.028E+05	0.00003%
Inner cladding (above the core)	1	5.90E+02	2.3	1.450E+02	8.562E+07	0.0115%
Inner cladding (core height)	1	1.04E+03	2.7	4.199E+05	4.359E+11	58.8441%
Inner cladding (below the core)	1	6.11E+02	2.5	1.550E+00	9.470E+05	0.00013%
Inner cladding (Vessel flange)	1	1.89E+02	0.45	2.665E-01	5.026E+04	0.00001%
Total Co-60 [Bq]				**7.442E+11**		
NEUTRON SHIELDING						
Central interior neutron shielding	1	3.20E+03	1.55	6.393E+02	2.036E+09	26.62%
Upper interior neutron shielding	1	4.50E+03	2.2	6.393E+02	2.854E+09	37.32%
Central external neutron shielding	1	4.31E+03	1.55	4.433E-02	1.913E+05	0.0025%
Lower external neutron shielding	1	6.04E+03	2.1	4.433E-02	2.676E+05	0.0035%
Upper external neutron shielding	1	6.05E+03	2.2	4.433E-02	2.680E+05	0.0035%
Lower external neutron shielding	1	4.31E+03	2.1	6.393E+02	2.757E+09	36.05%
Total Co-60 [Bq]				**7.648E+09**		

Characteristics of RPV and RVIs

(radiological activation data updated to 31/12/2018)

The radiological inventory of neutron activation of the Vessel and Internals is reported in the Final Report CISE 5515, which contains the results of the neutron flux simulations during the period of operation and activation, evaluated by applying specific calculation codes.

Results Analysis Trino NPP: Dose Rate calculation

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Scenario 1: maximum value of 500 mSv/h in contact with the flange of the head (137m) and **average value of about 10 mSv/h**;

Scenario 2: **1 nSv/h** in correspondence with the control floor (152.68m height);

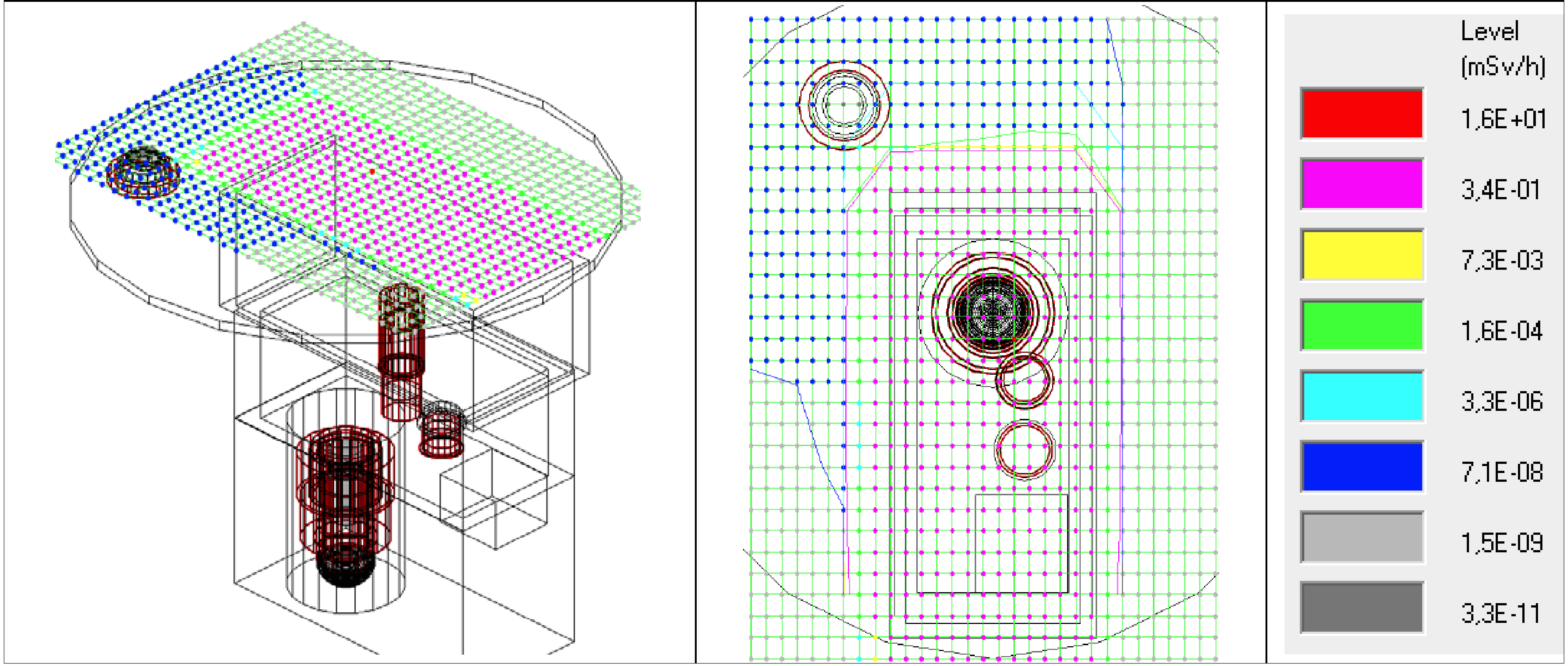
Scenario 3: due to the rising of the water level up to 144.07m, which carries out a considerable shielding, we have obtained dose rates of the thousandth's order of nSv/h and therefore for the evaluations it was considered the **data of the environmental background** of the work areas;

Scenario 4: the **maximum dose of 16 mSv/h** is on the control floor at the reactor cavity when the component is moving at maximum height. The maximum value obtained is high due to the partial escape of the Lower package from the water. The dose rate at the edge of the cavity decreases conservatively to about 500 μSv/h;

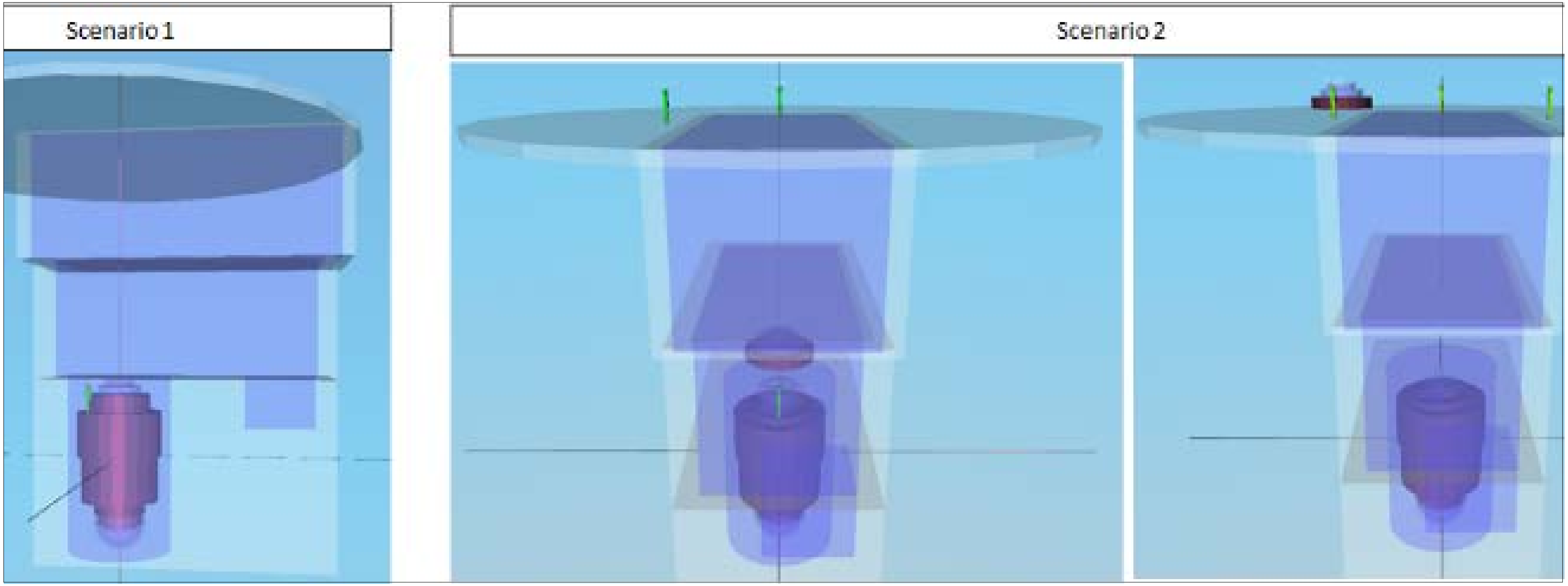
Scenario 5: during the Vessel characterization activities, that will be carried out with the work stations on the footbridge, the **maximum dose rates obtained are 0.92 μSv/h.**

Results Analysis Trino NPP: Dose Rate calculation

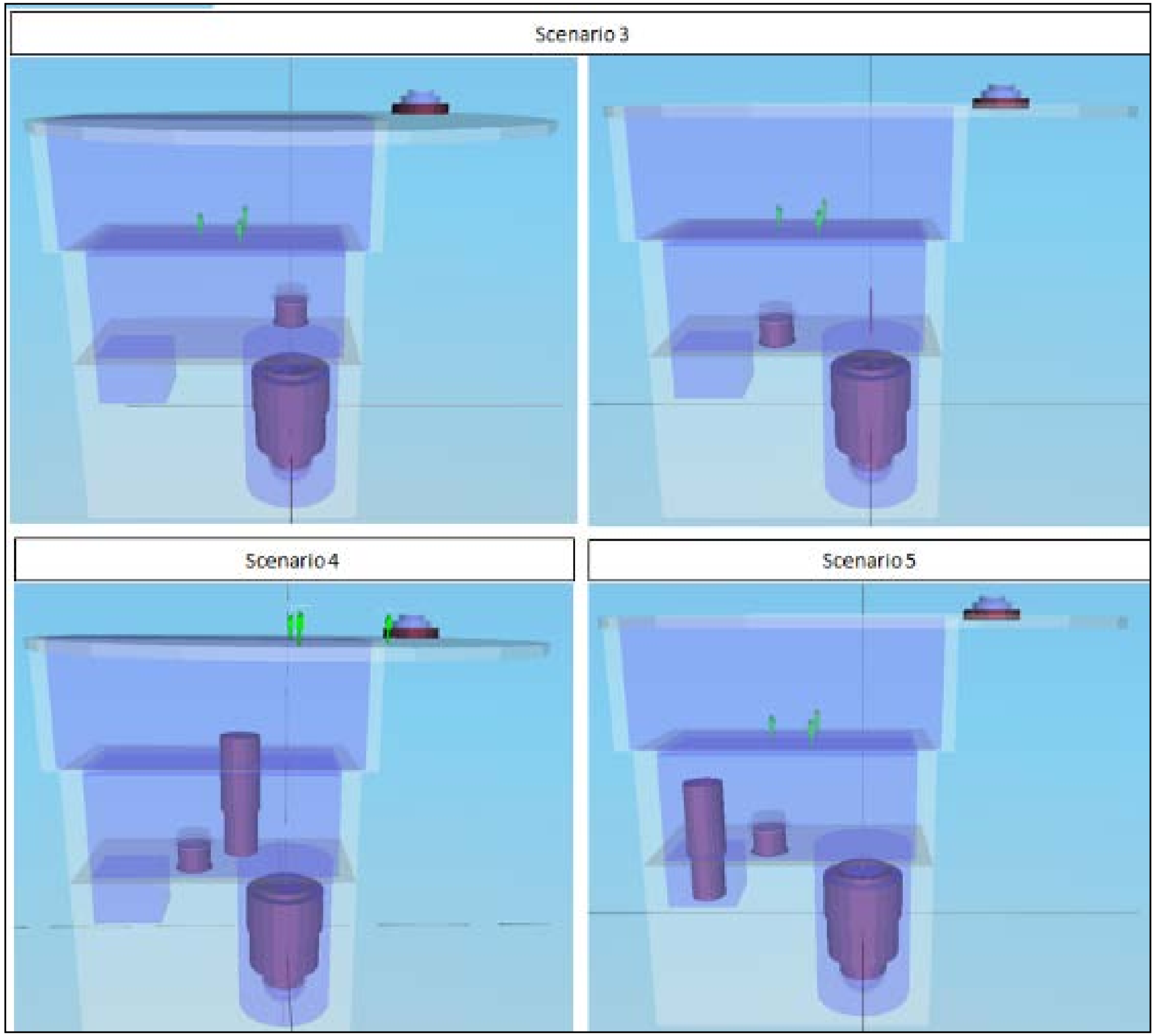
Scenario 4 – Lower Package handling



Results Analysis Trino NPP: Estimation of the Collective Doses



Results Analysis Trino NPP: Estimation of the Collective Doses



Results Analysis Trino NPP: Estimation of the Collective Doses

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Scenario 1 → The dose rates obtained for this activity (§2.3) conservatively expect that the operators in contact with the flange take 10% of the time the maximum dose of 500 mSv/h, 40% of the time 100 mSv/h and the remaining 50% of the time the average value of 10 mSv/h; and that the supervisor conserves the maximum value found on the footbridge. For the sanitary physician we assume 1/10 of the time at the flange quota and the remaining on the footbridge.

Scenario 2 → The evaluations were carried out considering that, during the first quarter of an hour, the operator remains at an height of 137 m while the other operator, the supervisor and the health physician are on the control floor, the remaining time of the operation workers will be on the control floor. For the first quarter of an hour, during which the operator is in correspondence of the tooth, 5 mSv/h were considered, a value obtained by calculation code near of the head and also confirmed by the measurements in the field.

Scenario 3 → To carry out these activities, the reactor cavity will be flooded up to 144.07 m. This water head reduces considerably the estimated dose rates by means of the calculation code and therefore the values of the environmental fund are taken as reference for the evaluation of the dose, near the planned work stations.

Scenario 4 → For dose evaluations, the dose rate values of the environmental fund were conservatively assumed for the same reason previously reported.
Subsequently, due to the lifting operations of the Barrel and therefore of the progressive reduction of the water level until the partial release of the component, the following values were considered: for the two operators, positioned on the control floor, have been obtained the maximum values on the edge of the cavity, while for the supervisor and for the health physician the average value.

Scenario 5 → During this scenario, workstations are planned on the footbridge and the maximum dose rates found were considered.

Results Analysis Trino NPP: Estimation of the Collective Doses

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Scenarios	Task Description	Collective dose [man*mSv]
1	Removal 42 fixings and studs Vessel head with flooded Vessel up to the nozzles and dry reactor cavities.	1.0E+01
2	Head lifting and laying on the control floor / contemporary flooding area Cavity Reactor up to 137 level	1.3E-03
3	Flood chamber cavity up to 144.07, Upper Package removal and radiological characterization	3.2E-01
	Extraction of 8 fake elements and transfer to the Spent Fuel Pool	4.8E-01
4	Lower package Characterization	2.2E-01
	Preparation and handling of the Lower Package	3.2E-01
	Lower Package handling in the reactor cavity under a minimum water head	6.1E-01
	Lower Package handling in the reactor cavity partially out of the water	2.7E+00
5	Vessel Characterization	8.8E-01
Total	**Collective Effective Dose [man*mSv]**	**1.7E+01**

Removal of the Internals
Vessel and Internals characterization activities

→

man hours: 581
collective effective dose: 17 man*mSv
maximum individual effective dose: 6.25 mSv

Case 2 - Dismantling of the RPV of Caorso NPP without Internals

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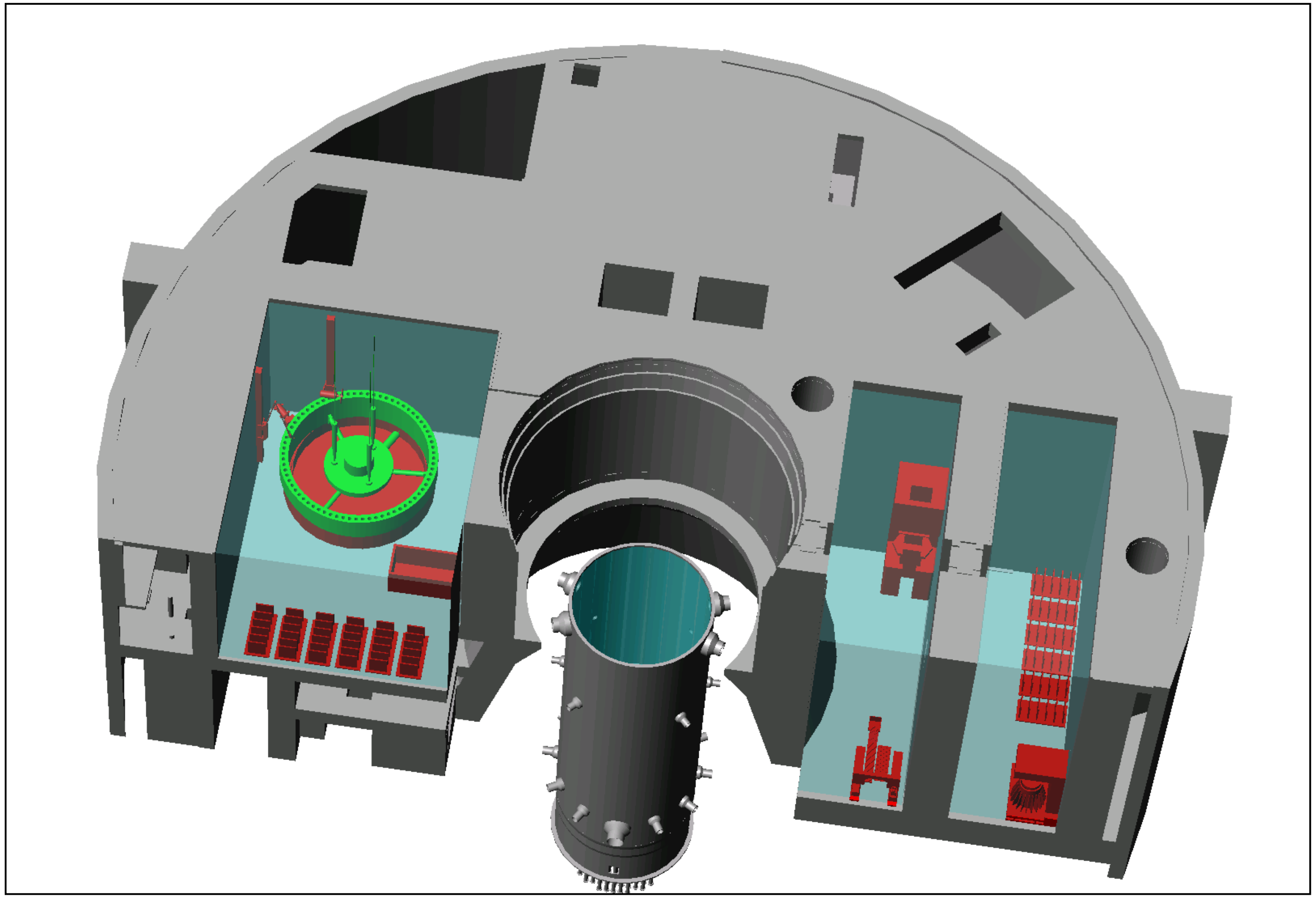

Operating conditions:

- **RPV without shielding (water);**
- **RPV with water shielding**

Phisycal and radiological history data available for Caorso NPP

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Characteristics of RPV
(radiological activation data updated to 31/12/2019)

The radiological inventory of contamination and activation of the Vessel has been deduced from the Caorso CISE database updated to 31/12/2019. Specifically, for the purpose of dose rate evaluations, the most significant radionuclide γ emitter has been considered: Co-60

Components	Internal radius [cm]	External radius [cm]	Activation Co-60		Contamination Co-60	
			[Bq/g]	[Bq]	[Bq/cm^2]	[Bq]
Inner cladding (Vessel Lower cup)	277	277.28	-	-	3,57E+03	1,56E+09
Inner cladding (below the core)			5,04E+00	2,88E+06	3,57E+03	1,09E+09
Inner cladding (core height)			7,11E+04	1,16E+11	3,57E+03	3,11E+09
Inner cladding (above the core)			6,64E+02	1,82E+09	3,57E+03	5,25E+09
Inner cladding (Vessel Flange)			2,10E+00	2,73E+05	3,57E+03	2,48E+08
Vessel wall (lower cup)	277.28	289.28	-	-	-	-
Vessel wall (below the core)			3,37E-02	9,23E+05	-	-
Vessel wall (core height)			6,16E+02	4,61E+10	-	-
Vessel wall (above the core)			4,43E+00	5,31E+08	-	-
Vessel Flange			1,40E-02	1,83E+05	-	-

Phisycal and radiological history data available for Caorso NPP

The evaluation of the radiation fields was carried out using the Visiplan 4.0 calculation code and 2 operating conditions were considered:

- RPV empty;
- RPV partially filled with water and in the process of being dismantled with a "mixed" technique, i.e keeping the water level just below the cutting plane of the shall rings.

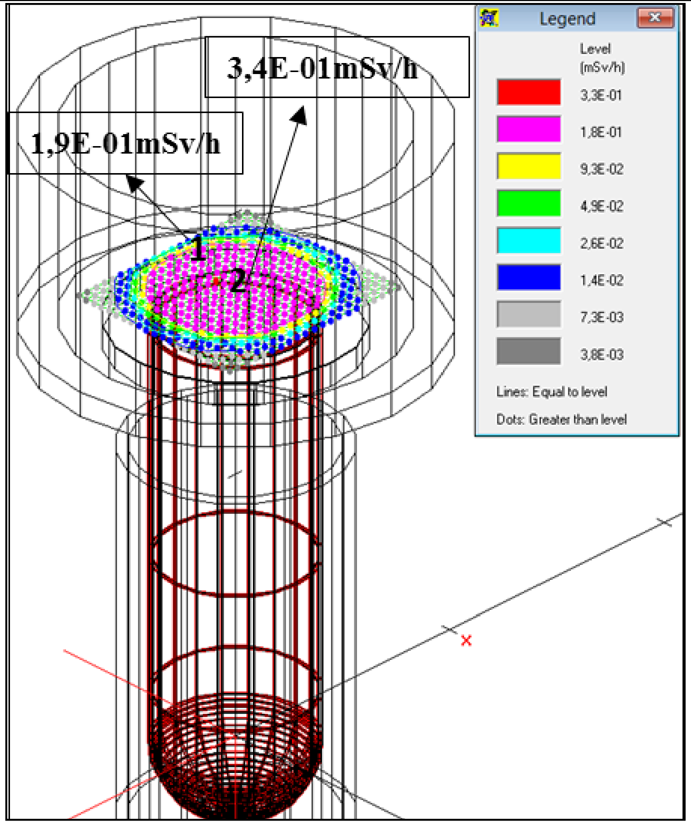
The shell rings, in which the RPV is supposed to be axially subdivided, have a height of 1 meter, taking into account the likely dimensions of the "tiles" (vertical sections of shell rings) that can be housed in CP-5.2 containers suitable for disposal.

Vessel Components	N° Shell rings	Interior lining Stainless Steel A [Bq]	Coating Carbon Steel A [Bq]	A [Bq]
Shell ring 1	1	7.27E+08	2.86E+08	1.01E+09
Shell rings 2-9	8	6.50E+09	4.88E+08	6.98E+09
Shell ring 10	1	2.04E+10	7.86E+09	2.83E+10
Shell rings 11-14	4	9.24E+10	3.58E+10	1.28E+11
Shell ring 15	1	6.95E+09	2.53E+09	9.48E+09
Shell ring 16	1	6.04E+08	5.11E+05	6.05E+08
Inferior cup	1	1.61E+09	4.50E+04	1.61E+09
Total	16	1.29E+11	4.7E+10	1.76E+11

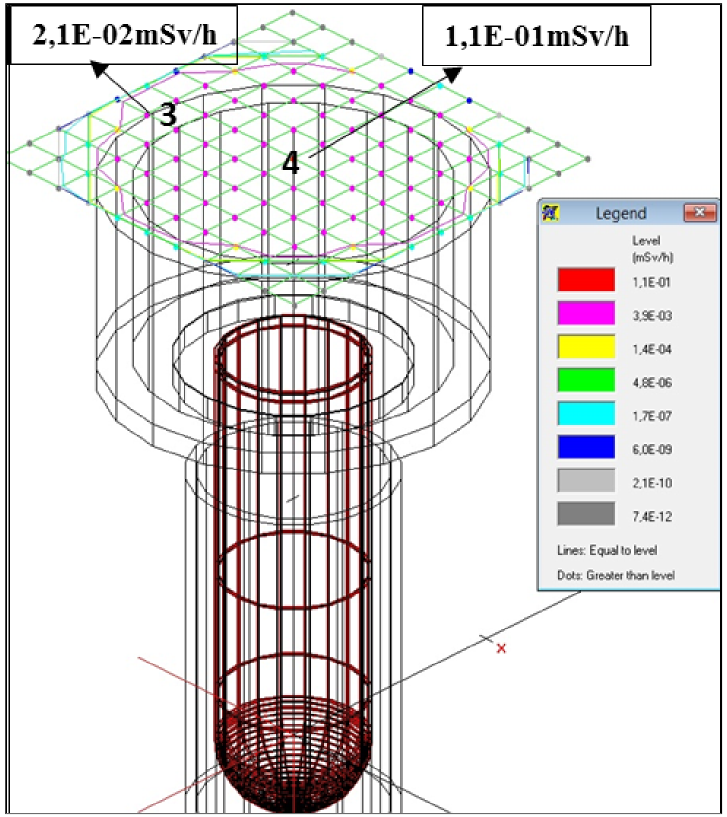
Results Analysis Caorso NPP: Dose rate calculation – Empty RPV

The calculation was performed at the points potentially accessible by the operator by defining the following grids:

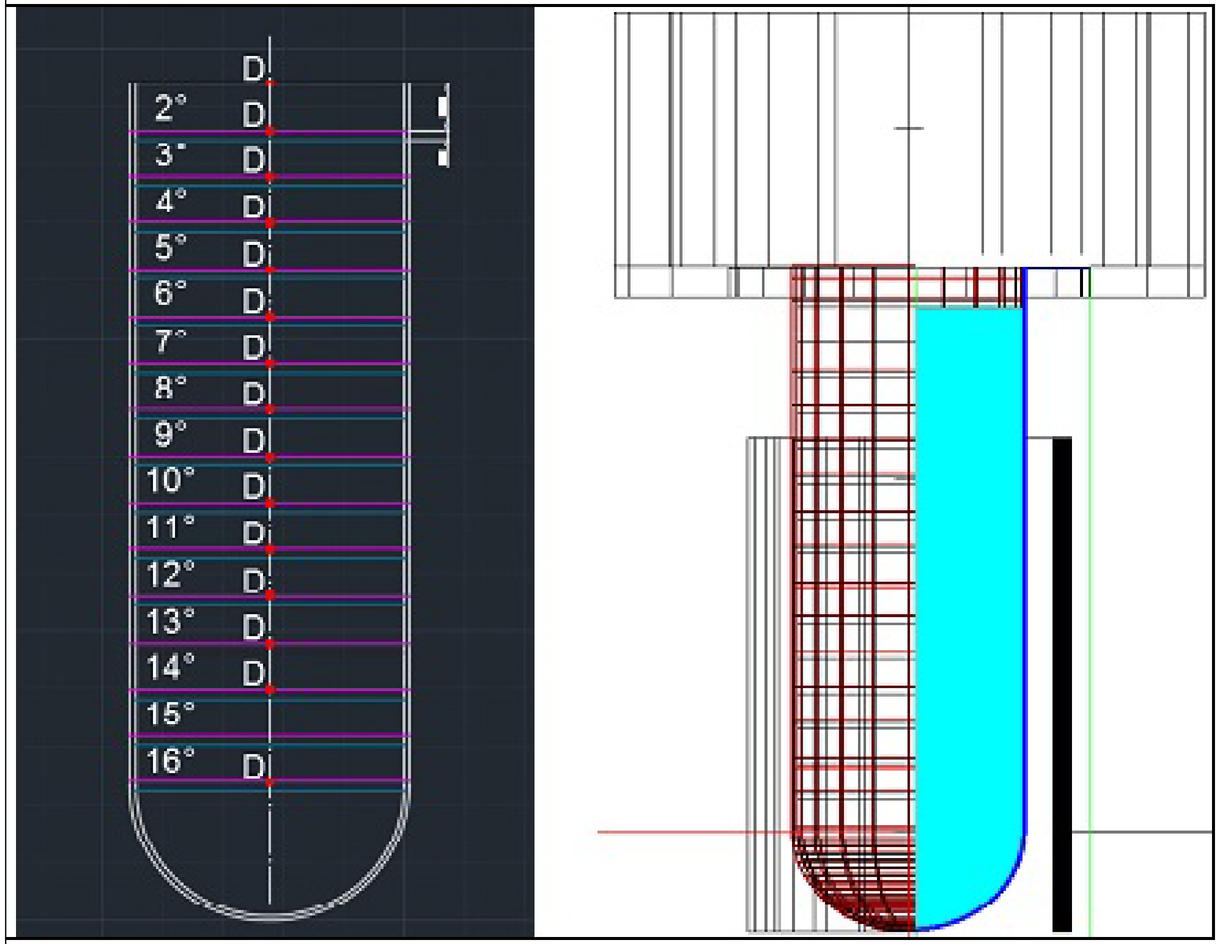
Irradiation fields at a distance of 1 m height from the Vessel flange (position 1 and 2)

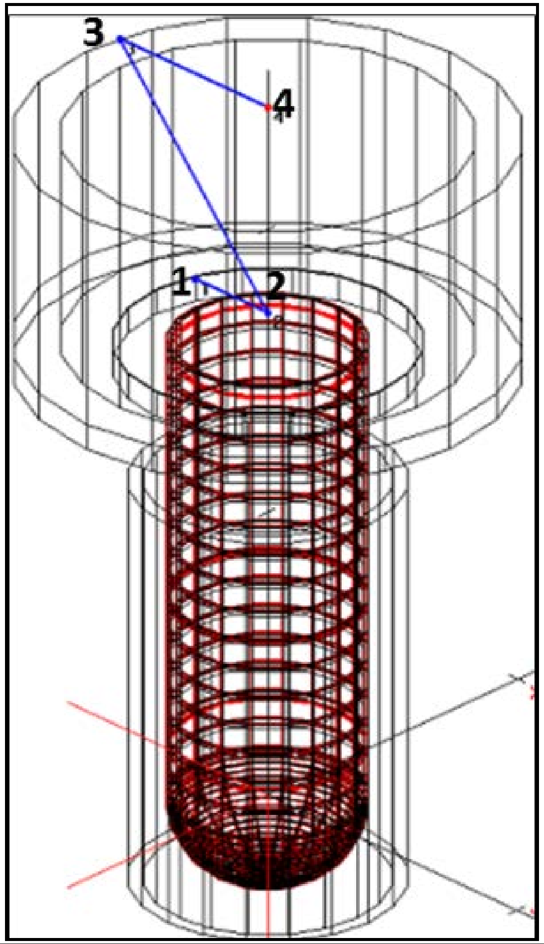


Irradiation fields at a distance of 1 m height from the Reactor Cavity (position 3 and 4)



Results Analysis Caorso NPP: Dose rate calculation – RPV partially filled with water during cutting operations





Results Analysis Caorso NPP: Dose rate calculation – RPV partially filled with water during cutting operations

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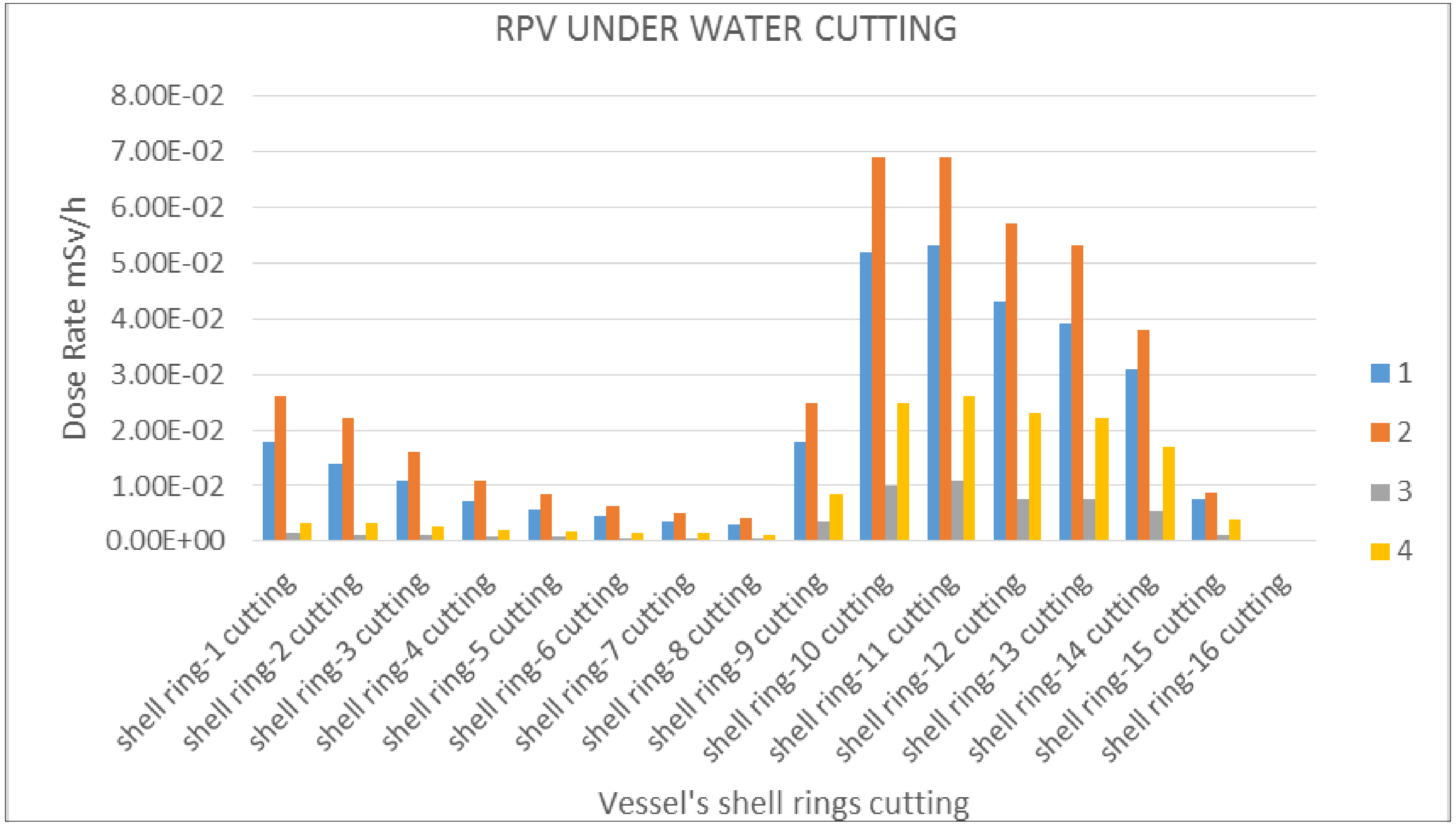
Dose Rate at the 4 workstations at each cut with water head inside the Vessel



Vessel	Dose Rate [mSv/h]			
Position	1	2	3	4
Shell ring-1 cutting	1.80E-02	2.60E-02	1.40E-03	3.40E-03

Results Analysis Caorso NPP: Comparison of operation in different configurations

The dose rate assessments determined by Caorso's Reactor Pressure Vessel (RPV) following its complete emptying by the related Reactor Vessel Internals (RVI) were conducted in 2 operating conditions:

1. RPV empty (“dry”);
2. RPV partially filled with water and in the process of being dismantled with a "mixed" technique, ie keeping the water level just below the cutting plane of each shell ring.

Operating conditions	Decommissioning operations	Dose Rate [mSv/h]			
		1	2	3	4
Case 1	Vessel “dry”	1,90E-01	3,40E-01	2,10E-02	1,10E-01
Case 2	Vessel with water head inside	1.80E-02	2.60E-02	1.40E-03	3.40E-03

Results Analysis Caorso NPP: Comparison of operation in different configurations

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Observing the dose rates obtained, it is clear that:

- **The irradiation fields in the operating conditions of case 1 in which the vessel is "dry" are higher**, as expected; in particular, dose rates in case 1 are higher in all points of at least one order of magnitude compared to those found in case 2.
- **The point at which the maximum dose rate is obtained in both cases is point 2**, positioned at 1 m from the flange at the vessel axis (see Figure 3 3); in particular in the operating conditions of "dry" RPV results to be in the hundreds of μSv/h, while in the operating conditions of the RPV under the order of tens of μSv/h.
- The **dose rates to the refueling floor**, that is above the reactor cavity (point 4), in the probable point of stationing of the personnel to the work plan are in Case 1 (RPV "dry") equal to 110 μSv/h while in Case 2 (RPV under the water head) equal to 3.4 μSv/h.
- Moreover, placing us in the scenario of cutting and dismantling the RPV less conservative in terms of irradiation, or under the water head, in the point 2 of maximum exposure the following **trend of the dose rate shows**:
  - during the cutting of the upper shell ring, decreasing from about 26 μSv/h to about 4.1 μSv/h;
  - then proceeding to cut the shell rings, near the central portion of the RPV, again increasing from about 25 μSv/h to about 70 μSv/h;
  - and finally, with the cutting of the lower portion, again decreasing to about 0.2 μSv/h with the cutting of the last shell ring.

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Conclusions

- This work will describe the radiological protection plan implemented through dose evaluations and exposure scenarios using Visiplan 3D ALARA Nuclear Codes for the activity of the preliminary design phase about **dismantling of RPV and Internals** for this two Nuclear Power Plant Trino's NPP and Caorso's NPP.
- The use of Visiplan 3D ALARA Codes is a suitable tool for optimizing dose assessments according to the **ALARA principle**, defined in the ICRP guidelines and in the Directive 2013/59/Euratom on protection against dangers arising from exposure to ionizing radiation as follows:

> *"The Radiation protection of individuals subject to occupational exposure must be optimised with the aim of keeping the magnitude of individual doses, the likelihood of exposure and the number of individuals exposed as low as reasonably achievable taking into account the current state of technical knowledge and economic and societal factors".*

- Furthermore, the code made it possible to choose the best **exposure scenario**, by creating evolutionary scenarios, in order to optimize future dismantling activities of the Caorso NPP Vessel and the detailed definition of the **collective and individual dose** corresponding to the different operational phases that will allow limiting exposure to workers for the characterization and dismantling of Vessel and Internals of Trino NPP.

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Thank you for your attention!