IRPA 13

13 - 18 May 2012 SECC Glasgow Scotland

Living with Radiation - Engaging with Society

Library of Mesh and NURBS Female Phantoms for Pulmonary in Vivo Counting Studies

IRSN
INSTITUT DE RADIOPROTECTION ET DE SÛRETÉ NUCLÉAIRE

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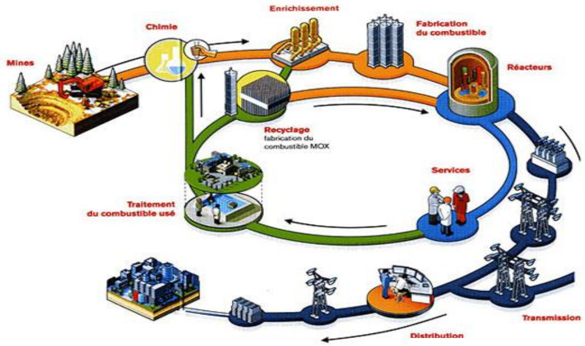
Monitoring the exposure to ionizing radiation



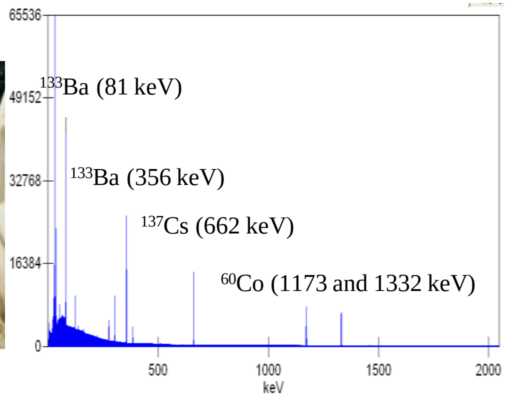
The nuclear industry work chain

Internal contamination

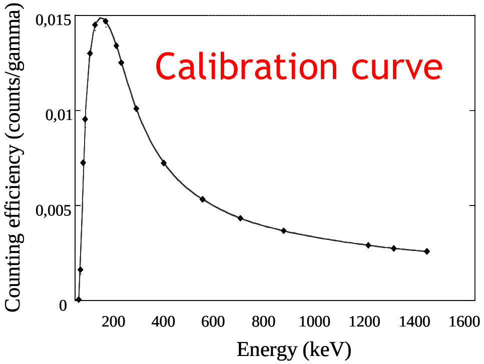
In vitro measurements

In vivo measurements

Principal of in vivo spectrometry measurements



The Livermore phantom

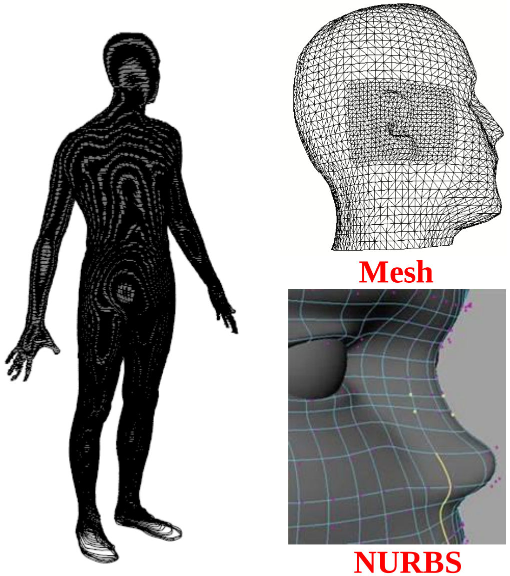


- Identify the radionuclides
- Determine the activity

Limits: Male chest phantom of limited anatomical realism
Calibration curve sensitively affected by breast size

Need for correct female calibration curves

Optimizing the monitoring of female workers



Deformable phantoms

3D modeling tools

MCNPX

Monte Carlo simulations

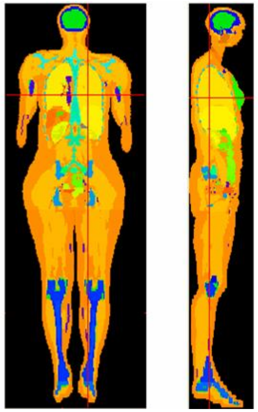
Objectives:

- Develop realistic and representative female models
- Simulate in vivo measurements
- Correct the Livermore calibration curves

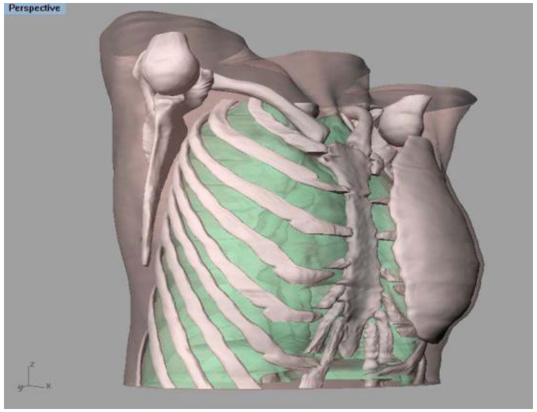
Library of representative female models

Step 1: Deformable torso model representative of the reference female individual

ICRP voxel female



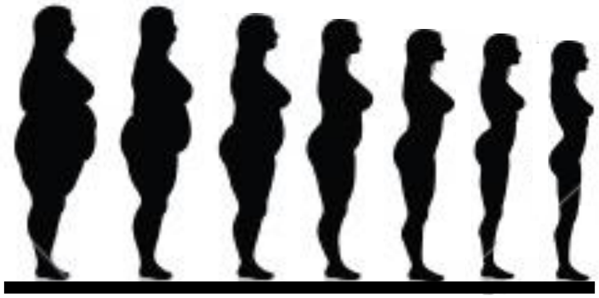
Mesh-NURBS flexible torso



Replacing rigid voxel grids with Mesh and NURBS flexible structures

Step 2: Library of female phantoms with the most common female morphologies

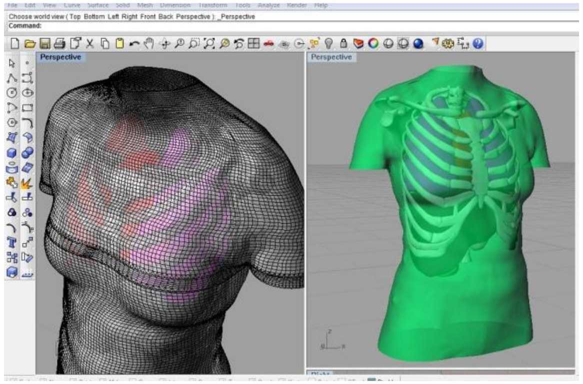
Clothing industry recommendations:
chest girth, cup size and internal organ volume variation



Library of representative female models

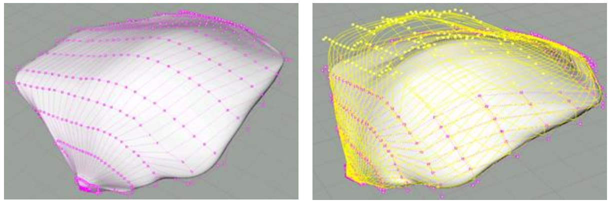
Chest girth variation: 85 – 90 – 100 – 110 – 120

Clothing industry specialists: chest and underbust circumference
(AFNOR CEN 2002, 2004)



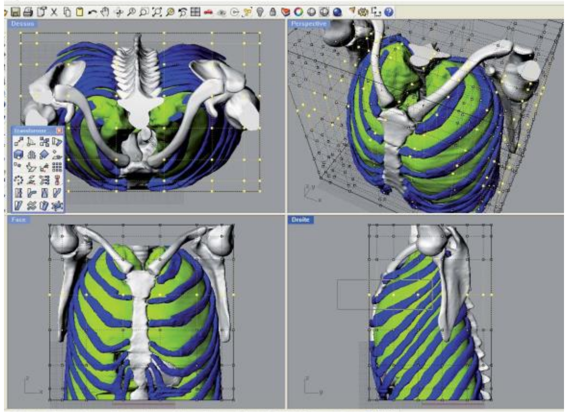
Cup size variation: A – B – C – D – E – F

Plastic surgery recommendations: weight adding per cup size change depending on chest girth
(Turner and Dujon 2005, Wood et al 2008)



Internal organ volume variation

Autopsy data: linear correlation of organ and bone volume with body height
(Clairand et al. 2000, Ferretti et al. 1998)

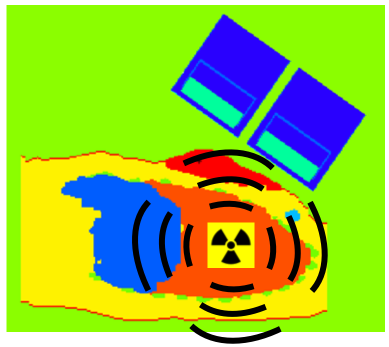


Library of 24 realistic female models

Numerical calibration of in vivo counting systems

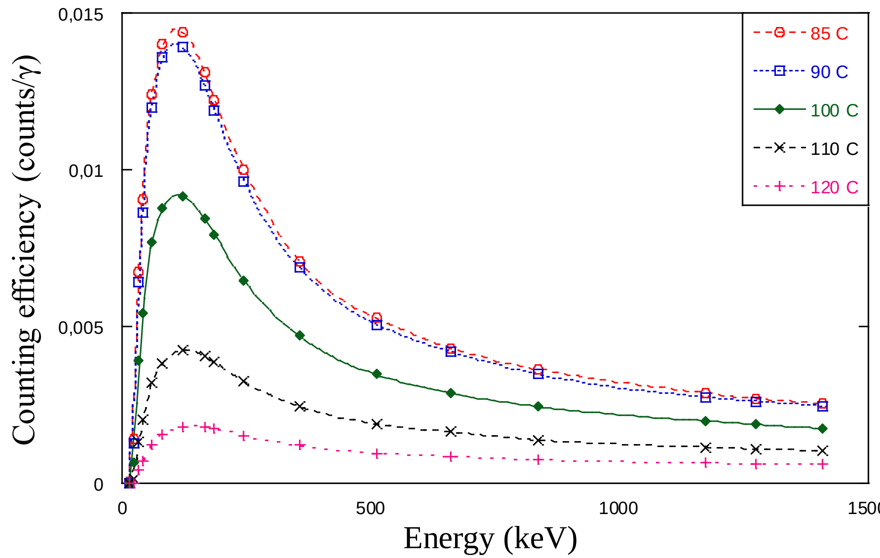
Simulation of *in vivo* counting

OEDIPE
Outil d'Evaluation de la Dose Interne PErsonnalisée



- Artificial gamma source (15 keV – 1.4 MeV)
- Typical 4-Ge counting system (AREVA)
- Automatic creation of the MCNPX input file

Highest efficiency loss at the lowest energies



Farah et al. Health Phys. ***99****(5): 649-661; 2010.*

Quantifying the effect of cup size, chest girth and internal organ volume on counting efficiency

24 numerical calibration curves for 24 female morphologies

Livermore calibration *vs* female individuals

Simulation results with the developed models

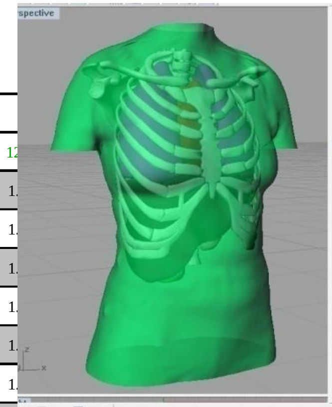
Livermore (male) + ? Plate P1 chest plate

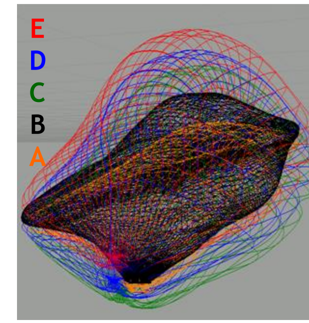
Female + 85A breast size

$Eff = Eff_{Livermore-P1} \cdot correction.factor$

Size		Energy (keV)																
		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	122	165	185	244	356	511	661	834	1173	[illegible]	[illegible]
85	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.01	1.01	1.01	1.00	1.02	1.03	1.03	1.01	1.05	[illegible]	[illegible]
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.09	1.08	1.09	1.12	[illegible]	1.07	1.06	1.08	1.11	[illegible]	[illegible]
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.17	1.15	1.16	1.17	1.18	1.12	1.10	1.11	1.14	[illegible]	[illegible]
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.21	1.19	1.19	1.22	1.21	[illegible]	1.12	1.14	1.16	[illegible]	[illegible]
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.33	1.29	1.29	1.31	1.29	1.23	1.19	1.20	1.22	[illegible]	[illegible]
90	A	2.05	1.75	1.42	1.36	1.21	1.10	1.05	1.04	1.06	1.09	1.09	1.06	1.06	1.08	1.11	[illegible]	[illegible]
	B	4.05	2.35	1.69	1.58	1.37	1.24	1.17	1.15	1.16	1.18	1.18	1.13	1.12	1.14	1.16	1.15	1.11
	C	4.49	2.54	1.80	1.67	1.44	1.30	1.21	1.19	1.19	1.22	1.22	1.16	1.13	1.16	1.19	1.17	1.13
	D	5.68	2.85	1.94	1.79	1.52	1.37	1.27	1.25	1.26	1.28	1.26	1.19	1.16	1.18	1.20	1.19	1.15
	E	8.51	3.49	2.19	1.99	1.67	1.48	1.36	1.32	1.33	1.35	1.33	[illegible]	1.22	1.21	1.23	1.22	1.17
100	B	8.16	3.80	2.56	2.35	2.01	1.81	1.68	1.65	1.66	1.68	1.69	1.60	1.56	1.58	1.60	1.59	1.54
	C	12.11	4.79	2.96	2.67	2.24	2.00	1.84	1.78	1.79	1.81	1.78	1.69	1.65	1.65	1.65	1.64	1.59
	D	20.38	6.17	3.47	3.05	2.51	2.22	2.03	1.96	1.95	1.96	1.90	1.78	1.74	1.73	1.75	1.72	1.65
	E	27.90	7.25	3.81	3.33	2.70	2.37	2.15	2.07	2.07	2.07	2.01	1.85	1.81	1.78	1.78	1.76	1.68
	F	41.56	9.20	4.51	3.87	3.09	2.71	2.44	2.33	2.31	2.28	2.19	2.00	1.95	1.90	1.87	1.87	1.79
110	B	179.4	18.95	7.33	6.09	4.69	4.05	3.56	3.36	3.33	3.29	3.12	2.86	2.73	2.69	2.64	2.59	2.49
	C	325.6	24.68	8.72	7.10	5.34	4.58	3.99	3.74	3.71	3.63	3.39	3.07	2.91	2.85	2.78	2.72	2.60
	D	741	35.43	10.78	8.57	6.27	5.31	4.50	4.22	4.17	4.02	3.71	3.34	3.13	3.02	2.92	2.84	2.72
	E	988	40.34	11.98	9.47	6.87	5.79	4.84	4.51	4.45	4.30	3.94	3.51	3.27	3.15	3.06	2.98	2.82
	F	1359	47.22	13.49	10.56	7.57	6.34	5.35	4.92	4.83	4.63	4.21	3.72	3.46	3.35	3.19	3.10	2.94
120	C	6744	122.2	26.38	19.69	13.59	11.19	9.23	8.34	8.15	7.74	6.94	6.05	5.57	5.33	5.04	4.91	4.65
	D	10277	147.9	30.22	22.30	15.18	12.42	10.17	9.13	8.89	8.40	7.42	6.43	5.90	5.60	5.28	5.13	4.87
	E	15369	176.3	34.90	25.60	17.27	14.06	11.37	10.15	9.85	9.21	8.13	6.99	6.35	6.01	5.59	5.43	5.11
	F	35571	256	45.60	32.66	21.52	17.23	13.76	12.07	11.67	10.82	9.36	7.94	7.17	6.69	6.12	5.88	5.54

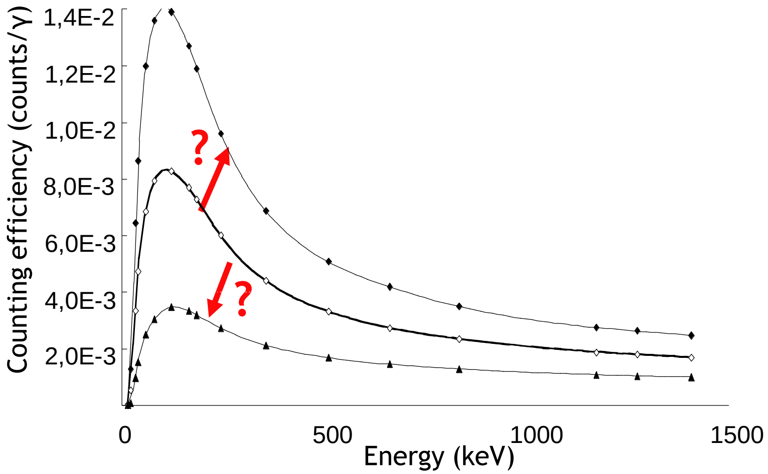
Practical method to correct typical measured calibration curves



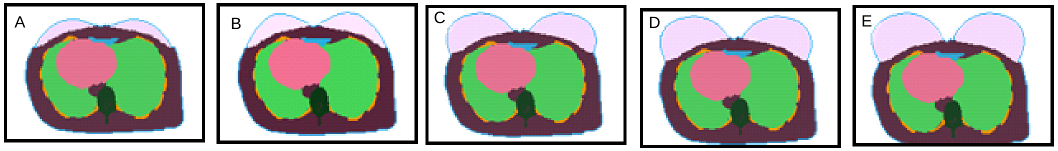


- Specific correction factors for the 24 female models and the AREVA counting system
- Sensitive corrections for the lowest energies and the biggest breast size

Correction factors for other female morphologies



Parameterization of the morphological dependence of lung counting efficiency



Lung volume

$$\varepsilon = \varepsilon_{ref}\, C_1\, e^{(-\,c_2\, \mu(E))}$$

Livermore P1 Breast size

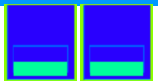
Simple equation with solid physical sense

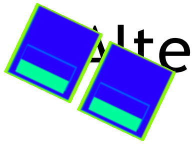
c_1 and c_2 estimated from body height and chest circumference

Equation validated with simulation, experimental and published data

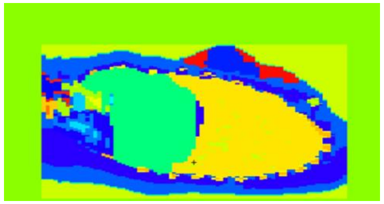
Farah et al. Phys. Med. Biol. ***55****(23): 7377-7395; 2010.*

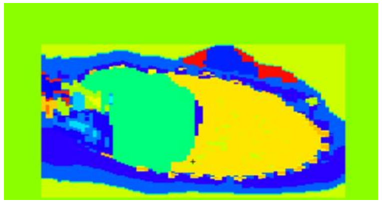
Correction coefficients for any female individual

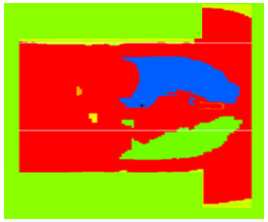




Alternative detector positioning

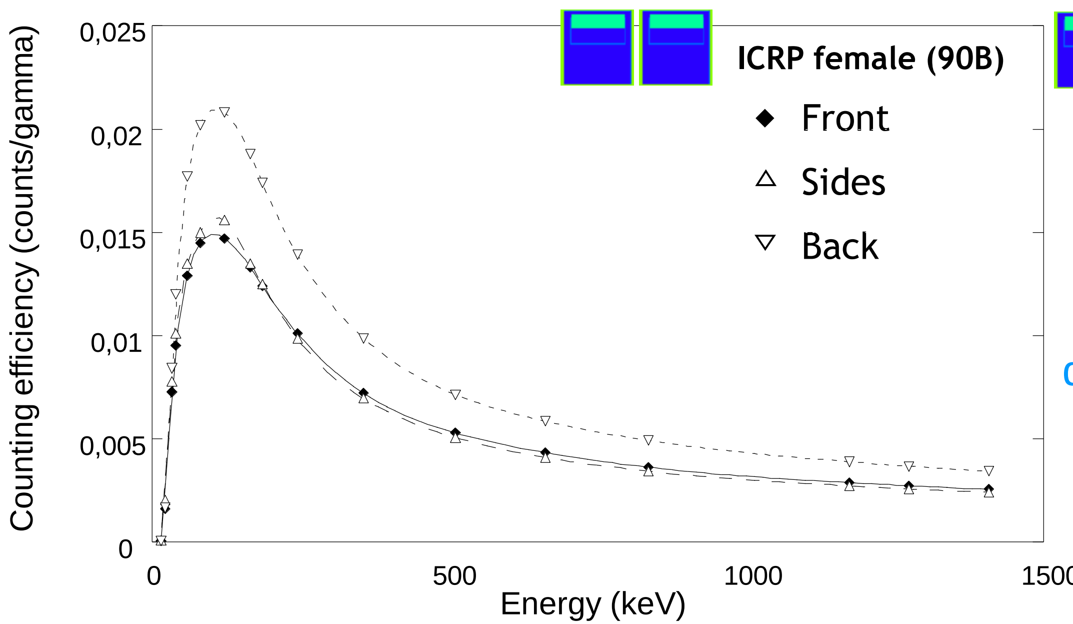


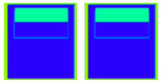




Typical but not optimal considering breast attenuation

Do these “odd” configurations improve the counts?

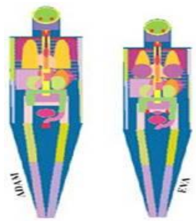




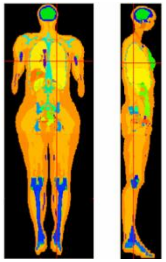
For female workers, it’s better to put the detectors in the back

Evolution of numerical representations for internal/external dosimetry

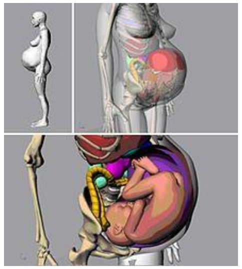
ICRU sphere



MIRD mathematical

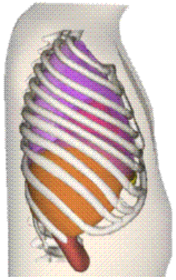


ICRP voxel solid representations



Mesh and NURBS boundary representations

Xu et al. Phys. Med. Biol. 52: 7023-7044(2007)



Deformable and moving models (4D)

Segars W.P. University of North Carolina (2001)

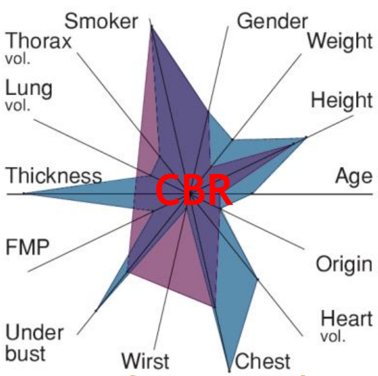
Person specific

1960s - → Tomorrow?

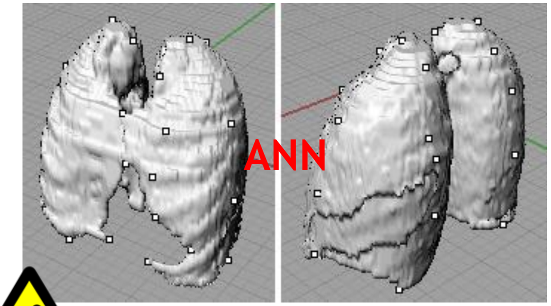
The EquiVox platform for personalized dosimetry

Key points: use the available models to generate a person specific phantom for dosimetry

Selection using Case Base Reasoning + Adaptation using Artificial Neural Networks



Similarity of external parameters



Adaptation in progress

Conclusion

- **Library of female torso models**
  - Female morphology-specific calibration curves
  - Morphological dependence of counting efficiency put into equation
  - For female workers, detectors should be positioned in the back

- **EquiVox platform**
  - Use existing models to carry out personalized dosimetry
  - Case Base Reasoning to select the most similar model
  - Artificial Neural Networks to adapt the model to the subject

Thank you for your attention