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MATREX/SPIS

Material data basis, space environment software exchange protocole(s)

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Criticality of material characterization in SEATs

- **Charging analysis**
  - Materials properties may deeply impact simulation results (e.g. secondary emissions, conductivity…)
  - Limits of the existing list of materials provided with the SPIS releases
    - Old and poorly materials, partially issued from NASCAP
    - Not corresponding to the most recent real materials used in the industry
  - Material characterisation following the numerical models evolutions
    - Finer characterization of secondary emissions (e.g. angular and energy dependency, see experiments done at ONERA)
    - 19 legacy NASCAP parameters not enough anymore
- **Multi-physics / multi-model approaches**
  - The characterization of materials differ from one physic to another one:
    - Not the same key properties (e.g. atomic number in radiations)
    - The geometrical mapping may differ in function of the physic
    - Fabrication process may impact in function of the physic (e.g surface treatment)
  - Difficulty for non-experts to identify / select the relevant material

Criticality of material characterization in SEATs

- **Need of a finer material characterisation due to new and finer numerical models**
- **Need of a central and validated reference point for materials**
  - Need to « speak about the same material » along the whole conception, building and maintenance phases of real devices.
  - Re-inforced aspect if:
    - Several physics must be considered
    - The material characteristics
- **Most of stored materials are incomplete (not all physics defined)**
  - How to complete missing properties ?
  - How to identify the most relevant material ?
- **New uses:**
  - Platform and payload optimisation
    - Identify the most adapted / relevant material to optimise the device
  - Confidentiality and strategical issues

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Objectives of the project

Preliminary results only presented today

•CNES activities

- Project ref. DCT/TV/EL-2015-10521, « Etude de la défin… …ole de modélisation des interactions plasma-satellite avec les outils S… adapté aux missions scientifiques du CNES »
- Project ref. DCT/TV/EL- 2015.0011248, « Mise à jour des protocoles de tra… et de stockages de propriétés matériaux relatifs aux bases de données CNES/MATREX et ESA/ESMAT afin de supporter le stockage des données issues du caisson CEDRE »

•A sustained CNES effort

- Extends and push further the work done in the frame of the previous study ref. 4700041143 / DCT094 « Interopérabilité SPIS/MATREX »

•Technical objectives

- Identify a « manual protocol » or procedure to help SPIS's users to use material defined in central data basis like MATREX or ESMAT
- Identify and review the underlying concepts needed to define materials
- Identify the needed functional scope of generic, robust and versatile software exchange protocol
  - Multi-physics (including charging)
  - Between material data-bases and consuming software

Scenarios of use

- **SPIS expert**
  - Know the constraints of the plasma-surface physics and is able to focus on the most relevant physics and/or complete
  - Generally start from one of the default materials provided with SPIS
  - How to find in MATREX or his reference data base the real material being the closest to the used one for the simulation ?
- **Payload or platform designer**
  - Starting from real design constraints and available materials, e.g. « fiche materiaux »
  - Need real and validated materials
  - Not an « expert in SPIS » and is completely lost facing to the richness of the SPIS documentation
  - Most of the used materials are incompletely defined w.r.t the plasma-surface physics (and SPIS needs)
  - How to complete missing informations in order to perform a SPIS simulation ?
  - How to find the closest equivalent « SPIS material » ?
- **How to define a univocal and clear material identification ?**

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Access to MATREX

- **Development of an experimental script based (Python + curl) based client**
  - Test the possibility of a direct integration of a tailored MATREX client into SPIS
  - Allow a full text search and/or richer/finer material analysis
    - Full text search
    - Computation of distance of interest
  - Test the CSV based export capabilities of MATREX
- **Experimental MATREX CSV to Frida importer (not finalised yet)**

CSV MATREX export

###
General Information
###
User Type Usual name Others designations AFNOR DIN AISI ECSS Material class Materials family Chemical family Other chemical information Presentation
Application Means of implementation Comments
CNES Kapton H 17 : Résines thermoplastiques Polymères thermoplastiques Polyimide (PI) (thermoplastique) Polyimide Polyimid film with different thicknesses: 12, 25, 30, 50, 125, 250 µm (available for thicknesses from 7,6µm à 127µm). Max width: 1320 mm (ECSS-Q-70-71A/C.17.11) It is a special version of the standard Kapton HN. It exists in aluminized version (1 or 2 faces, see dedicated material sheets).Protection, mechanical wear of wires, repair Insulating film plate/shunt MLI / SLI It is possible to cover Kapton with protective layers, such as Al2O3, PTFE+SiO2... or with protective layers in Mapatox K and Mapatox 41B (see Mapatox sheet for more information)
(…)
###################################
Documents joined to this material
###################################
Document type Document location Document name
(…)
Public DocId=623472&content_name=K-15345-1-04-11_--.PDF Technical Data Sheet Kapton H/HN

Public DocId=622976&content_name=MAT_1076_--.PDF General informations Kapton
Public DocId=623474
Public DocId=623468

####################
Properties joined to this
####################
[Electrical]
Propertie Value (unit)
Dielectric strength 276
(25µm film @25°C)" 09/0
Relative dielectric constant
(25µm film @25°C)" 09/0
Dissipation or loss factor (
(25µm film @25°C)" 09/0
Electrical resistivity 1e1
(25µm film @25°C)" 09/0

Public DocId=622976&content_name=MAT_1076_--.PDF General informations Kapton
Public DocId=623474&content_name=H-38479-4_0900.PDF General Specifications Kapton (1)
Public DocId=623468&content_name=H-38479-9_0312.PDF General Specifications Kapton (2)

###################################
Properties joined to this material
###################################
[Electrical]
Propertie Value (unit) Visibilité Comments Last modification date Type utilisateur Obsolete
Dielectric strength 276 (kV/mm) Public "ECSS-Q-70-71A / ASTM D149-64
(25µm film @25°C)" 09/07/14 03:32 CNES Valide
Relative dielectric constant (Epsilon_r), relative permittivity 3.5 (-) Public "ECSS-Q-70-71A / ASTM D150-64T @1 KHz
(25µm film @25°C)" 09/07/14 03:32 CNES Valide
Dissipation or loss factor (tan delta) 0.003 (-) Public "ECSS-Q-70-71A / ASTM D150-64
(25µm film @25°C)" 09/07/14 03:32 CNES Valide
Electrical resistivity 1e16 (ohms.m) Public "ECSS-Q-70-71A / ASTM D257-61
(25µm film @25°C)" 09/07/14 03:32 CNES Valide

[Mechanical]
Propertie Value (unit)
Ultimate tensile strength
(…)

[Physical]
Propertie Value (unit)
Density 1420 (kg/m3)
(25µm film @25°C)" 09/0

[Space]
Propertie Value (unit) Visibilité Comments Last modification date Type utilisateur Obsolete
Flammability 0 (-) Public "ECCS-Q-71-71A
(…)

[Thermal]
Propertie Value (unit) Visibilité Comments Last modification date Type utilisateur Obsolete
Infra-Red normal emittance (epsilon) 0.61 (-) Public "Hemispherical Emittance
ECSS-Q-70-71A / ECSS-Q-70-09
(25µm film @25°C)" 09/07/14 03:32 CNES Valide
(…)

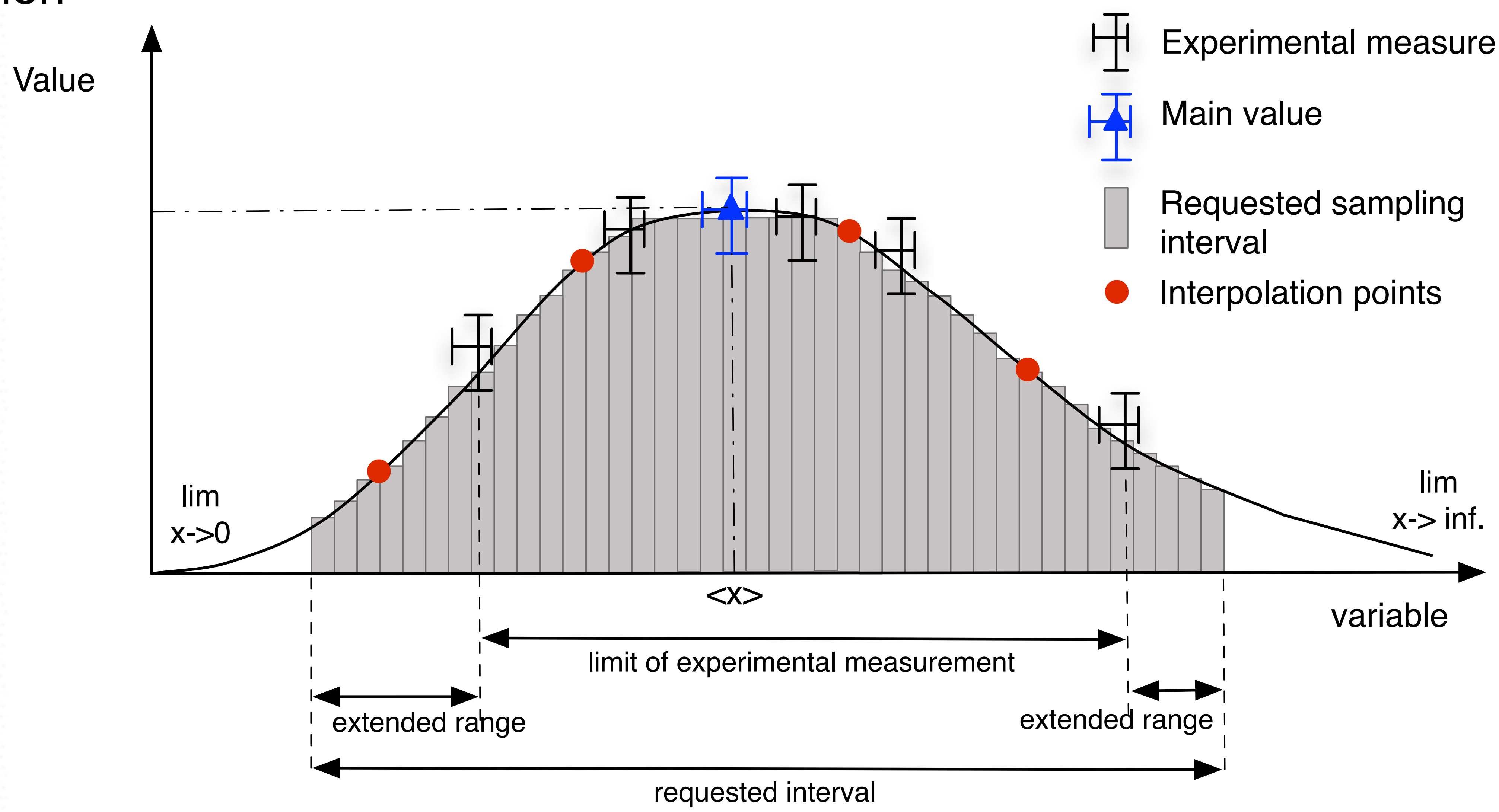
SPIS/MATREX materials

- **Current material characterization**

MATREX property					Conversion	SPIS characteristic				
Identifiant	Intitulé propriété	Traduction / description	Unit	Material class		Identifiant	SPIS Parameter	Unit	Description	NASCAP parameter
1	Facteur de perte (tan delta)	Dissipation or loss factor (tan delta)	-	Electrique						
2	Rigidité diélectrique	Dielectric strength	kV/mm	Electrique						
3	Résistivité électrique	Electrical resistivity	ohms.m	Electrique	direct	24	ELRE	[ohm.m]	Electric resistivity of metal	Used in SPIS-ESD
4	ELE04_Potentiel différentiel critique (seuil de décharge)	ELE04_Potentiel différentiel critique (seuil de décharg	V	Electrique						
5	ELE05_Exposant de conductivité induite par rayonnement	ELE05_Exposant de conductivité induite par rayonnen	-	Electrique						
6	Perméabilité magnétique	Permeability (electromagnetism)	-	Electrique						
7	-	-	-	Electrique						
8	-	-	-	Electrique						
9	Autre propriété électrique	Other electrical property	-	Electrique						
37	Constante diélectrique relative (Epsilon_r)	Dielectric constant (Epsilon_r)	-	Electrique	direct	0	RDC	[-]	Relative dielectric constant	Used in SPIS 4 - Nascap parameter 0
38	-	-	-	Electrique						
39	PIP03_Conductivité de volume (obscurité) BOL	PIP03_Volume conductivity (darkness) BOL	ohm-1.m-1	Electrique		2	BUC	[ohm-1.m-1]	Bulk conductivity, must be set negative if a conductor (in place of infinite for a perfect conductor)	Used in SPIS 4 - Nascap parameter 2
40	PIP04_Conductivité de volume (obscurité) MOL	PIP04_Volume conductivity (darkness) MOL	ohm-1.m-1	Electrique						
42	PIP06_Maximum d émission électronique secondaire sous impact d électron BOL		-	Electrique	direct	4	MSEY	[-]	Maximum secondary electron emission (SEE) yield for electron impact	Used in SPIS 4 - Nascap parameter 4
43	PIP07_Energie d électron primaire qui produit le maximum BOL		keV	Electrique	direct	5	PEE	[keV]	Primary electron energy that produces maximum SEE yield	Used in SPIS 4 - Nascap parameter 5
44	PIP08_Rendement d émission électronique secondaire sous impact d électrons d énergie 1-2-3-4-5 keV BOL		-	Electrique						
45	PIP09_Maximum d émission électronique secondaire sous impact d électron pour le contaminant référence MOL		-	Electrique						
46	PIP10_Energie d électron primaire qui produit le maximum pour le contaminant référence MOL		keV	Electrique						
47	PIP11_Rendement d émission électronique secondaire sous impact d électrons d énergie 1-2-3-4-5 keV pour le contaminant référence MOL		-	Electrique						
48	-	-	-	Electrique						
49	-	-	-	Electrique						
50	-	-	-	Electrique						
51	-	-	-	Electrique						
52	PIP16_Rendement d émission secondaire électronique sous impact d 1 protons keV BOL		-	Electrique	direct	10	SEY	[-]	Secondary electron yield due to impact of 1 keV protons	Used in SPIS 4 - Nascap parameter 10
53	PIP17_Energie de proton primaire qui produit le rendement maximum d émission électronique secondaire BOL		keV	Electrique	direct	11	IPE	[keV]	Incident proton energy t hat produces maximum secondary electron yield	Used in SPIS 4 - Nascap parameter 11
54	PIP18_Rendement d émission photo électronique sous incidence solaire normale		A/m²	Electrique	direct	12	PEY	[A/m2] at 1 AU	Photoelectron current for normally incident sunlight	Used in SPIS 4 - Nascap parameter 12
55	PIP19_Résistance de surface	PIP19_Surface Resistance	Ohm/m2	Electrique	needed	13	SRE	[ohms]	Surface resistivity	Used in SPIS 4 - Nascap parameter 13
56	PIP20_Potentiel absolu maximum (déclenchant une décharge)		-	Electrique	direct	14	MAP	[V]	Maximum (absolute) potential attainable before a discharge occurs	Used in SPIS 4 - Nascap parameter 14
57	PIP21_Champ électrique de rupture (déclenchant une décharge)		-	Electrique	direct	15	MPD	[V]	Maximum potential difference between surface and underlying conductor before a discharge occurs	Used in SPIS 4 - Nascap parameter 15
58	PIP22_Coefficient K de conductivité induite par rayonnement BOL ((?.m) ?1.(Gr/s)) ?1		-	Electrique	needed	16	RCC	[ohm-1.m-1]	Radiation induced conductivity coefficient K in the law K*(rate/rate0)^D, with rate0 = 1 Rad/s (TBC), (or equivalently with no rate0 coefficient and rate expressed in Rad/s)	Used in SPIS 4 - Nascap parameter 16
59	PIP23_Coefficient (?) de puissance BOL		-	Electrique		17	RCP	[-]	Radiation induced conductivity power (D)	Used in SPIS 4 - Nascap parameter 17
60	PIP24_Coefficient K de conductivité induite par rayonnement MOL ((?.m) ?1.(Gr/s)) ?1		-	Electrique						
41	Numéro atomique	Atomic number	-	Physique	direct	3	ATN	[-]	Atomic number	Used in SPIS 4 - Nascap parameter 3
62	Masse volumique	Density	kg/m3	Physique	needed	18/29	MAD/VMAS	[kg/m3]	Material density/Volumic mass	
77	Conductivité thermique	Thermal conductivity	W/m/K	Thermique	direct	21	THCO	[W/K/m]	Thermal conductivity	Used in SPIS-ESD
78	Capacité thermique massique, chaleur massique	Specific heat capacity	J/kg/K	Thermique	direct	22	HEAT		Specific heat	Used in SPIS-ESD
84	Température de fusion	Melting point	°C	Thermique	needed	30	MELT	[K]	Melting temperature	

Modelling of material properties

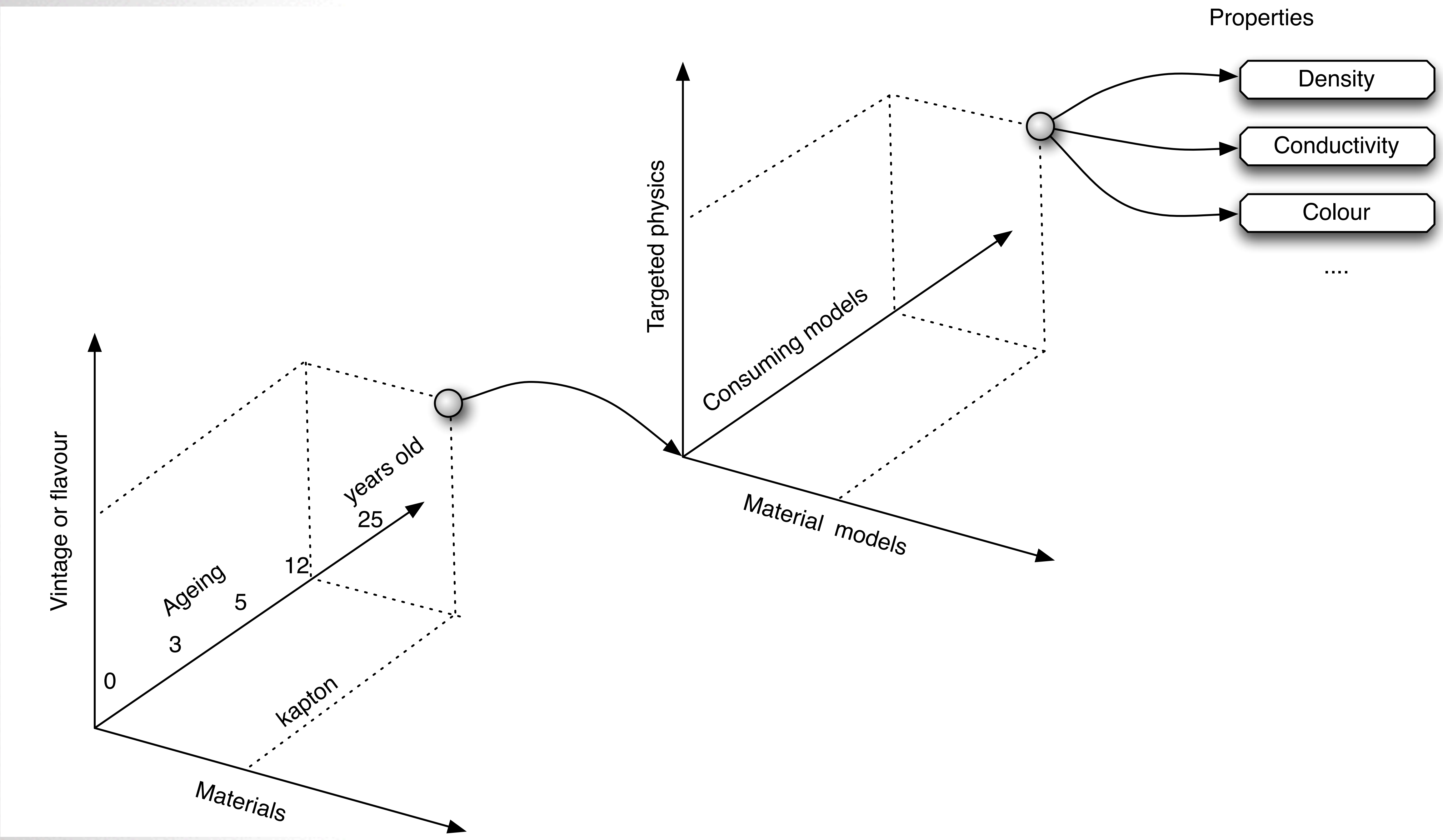
- **Exchange protocol is constraint by the data to exchanges**
- **Definition and storage of properties data induces a choice of model**
  - Raw experimental data
  - Single mean value
  - Interpolation function
- **Depend on**
  - Measurements
  - Theoretical constraints
  - End software



Material definition

- **Define a material is a complex task, because is may depend on numerous aspects**
  - Categories or global material types (e.g. Kapton in the general sense)
    - Need of a hierachised taxonomy: materials are not a flat structure
  - Source (i.e. provider) or testing procedure may impacts properties or modeling of properties
    - Need of the concept of vintage or flavor to
  - Age and storage
  - Model used to define each property
  - The targeted physics and consuming models
  - The stored properties

Material definition



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Distance of interest

For a given reference material Mat_i, defined by the vector of dimension n

$$\mathrm{Mat}_i = (\alpha_{i0}, \alpha_{i1}, \ldots, \alpha_{\mathrm{ik}}, \ldots, \alpha_{\mathrm{in}})$$

a second vector, Mat_j, defined by the vector of dimension m,

$$\mathrm{Mat}_j = (\alpha_{j0}, \alpha_{1j}, \ldots, \alpha_{\mathrm{jk}}, \ldots, \alpha_{\mathrm{jm}})$$

phase space of the global system is defined as $p = \max(m, n)$

considering a normalised vector of priority P defined as:

$$P = (p_0, p_1, \ldots, p_k, \ldots, p_p) \qquad \sqrt{\sum p_i^2} = 1$$

an “existance vector” defined as follow:

$$M = (\mu_0, \mu_1, \ldots, \mu_k, \ldots, \mu_p)$$

$$\begin{cases} \mu_k = 1 \text{ if the data exists in both materials;} \\ \mu_k = 0 \text{ if the data does not exis at least in one of materials.} \end{cases}$$

$$\mathrm{Doi}_{\mathrm{ij}} = \sum_{k=0}^{k=p} \left(\frac{|\alpha_{\mathrm{jk}} - \alpha_{\mathrm{ik}}|}{\alpha_{\mathrm{ik}}} . p_k . \mu_k + (1 - \mu_k) \right)$$

Distance of interest

- Smaller is the distance of interest closer are both materials regarding the targeted domain of application.
- If both materials have the same data (and values), the distance of interest $\mathrm{Doi_{ii}}$ is null. If both material share none of data the distance of interest, the distance of interest is equal to the dimension of the phase space, $\mathrm{Doi_{ik}} = p$.
- For each missing property, the distance of insterest make a jump of one unit.
- One must outline that the metric is defined on the basis of non-null coefficients of the priority vector. This means that, whatever both materials have a different name or reference or other properties differing, if the distance of interest is null, both materials can be considered as the same.
- The distance of interest must be dimensionless.
- The $\frac{|\alpha_{\mathrm{jk}} - \alpha_{\mathrm{ik}}|}{\alpha_{\mathrm{ik}}}$ ratio must be dimensionless to be valid, otherwise both properties have different dimension and do not aim the same physics. This de facto checks the cross-consistancy of both materials.

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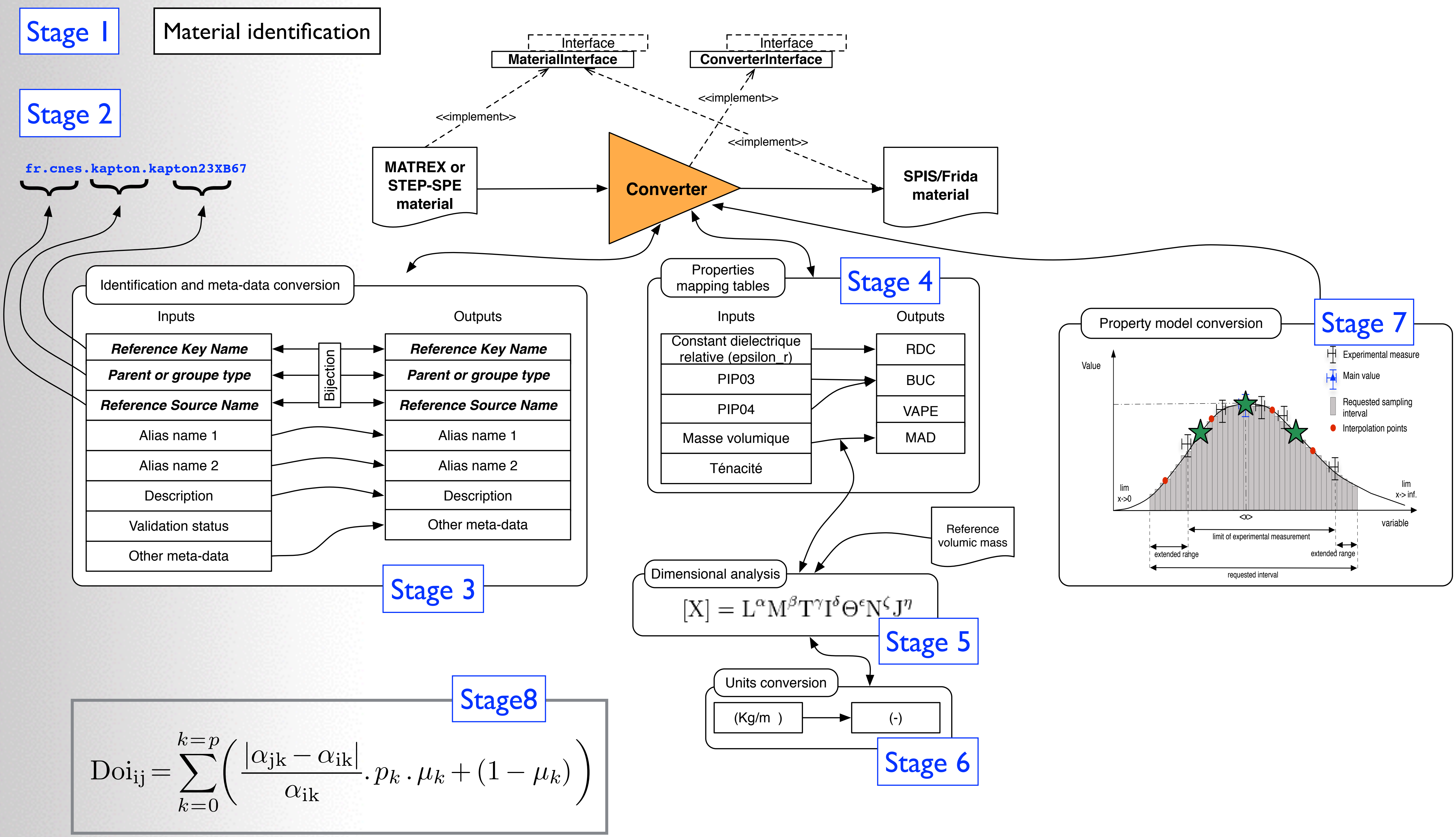
Conversion process



$$\mathrm{Doi_{ij}} = \sum_{k=0}^{k=p}\left(\frac{|\alpha_{\mathrm{jk}} - \alpha_{\mathrm{ik}}|}{\alpha_{\mathrm{ik}}}.p_k.\mu_k + (1-\mu_k)\right)$$

What's about an exchange protocol?

- **We need not only a « pivot format » but an « exchange protocol »**
  - Materials characterisation constitutes an « ontology »
- **Ontology**
  - **In philosophy :** « *Ontology is the philosophical study of the nature of being, becoming, existence, or reality, as well as the basic categories of being and their relations. Traditionally listed as a part of the major branch of philosophy known as metaphysics, ontology often deals with questions concerning what entities exist or may be said to exist, and how such entities may be grouped, related within a hierarchy, and subdivided according to similarities and differences.* »
  - **In computer science and information science:** « *An ontology is a formal naming and definition of the types, properties, and interrelationships of the entities that really or fundamentally exist for a particular domain of discourse.* »

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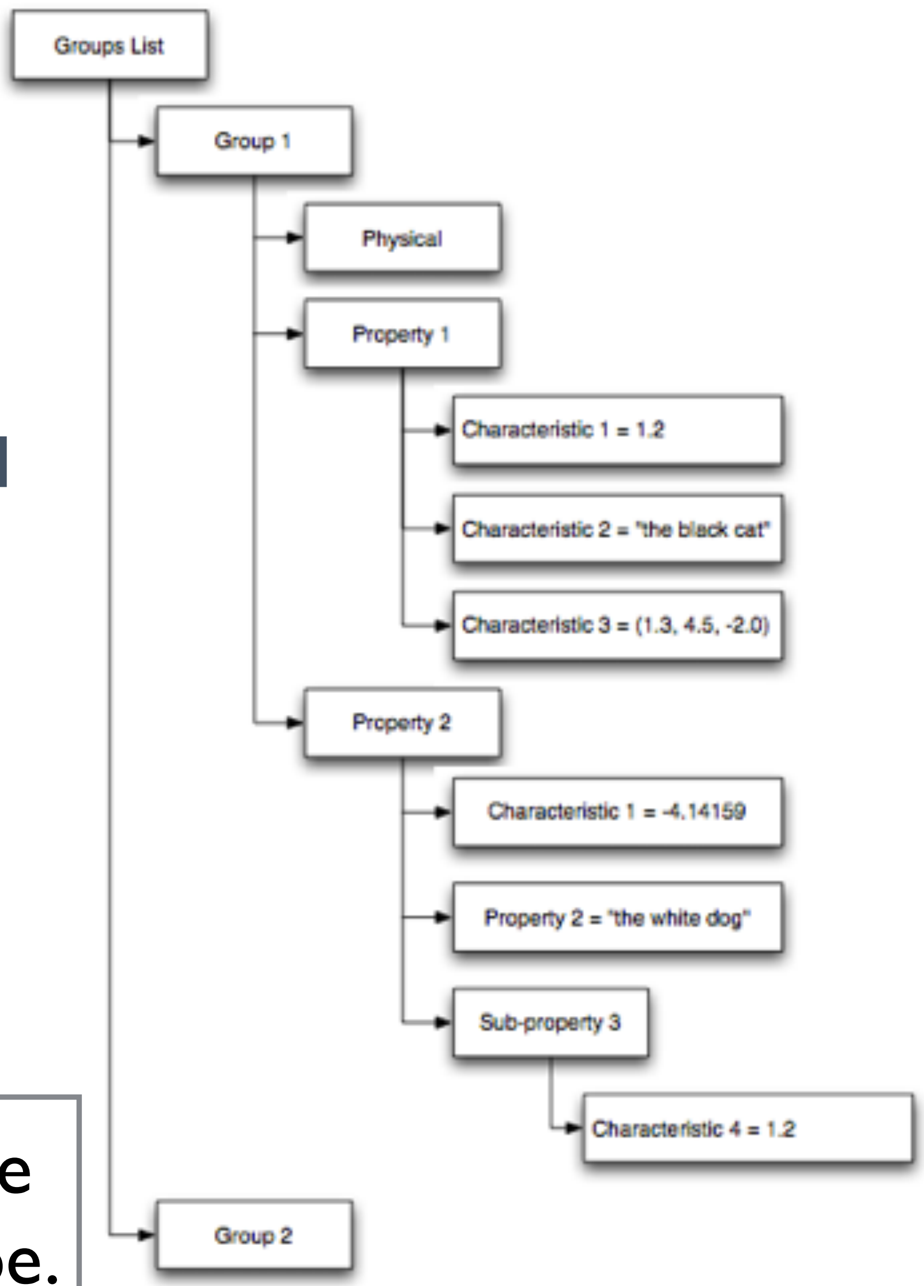
What's about an exchange protocol?

- **A protocol should allow**
  - Provide the abstract layer corresponding to the ontology definition
  - The conversion of data (i.e. expression of « semantics »)
  - Keep the consistency of converted data, considering
    - The input material modelling
    - The output consuming model
  - Handle the data flux in whole
- **Some candidates**
  - EXPRESS (for definition language)
  - STEP-NRF (for the implementation)
  - Other XML protocols, like issuer from the semantic Web

STEP-SPE to SPIS (Frida) material properties conversion

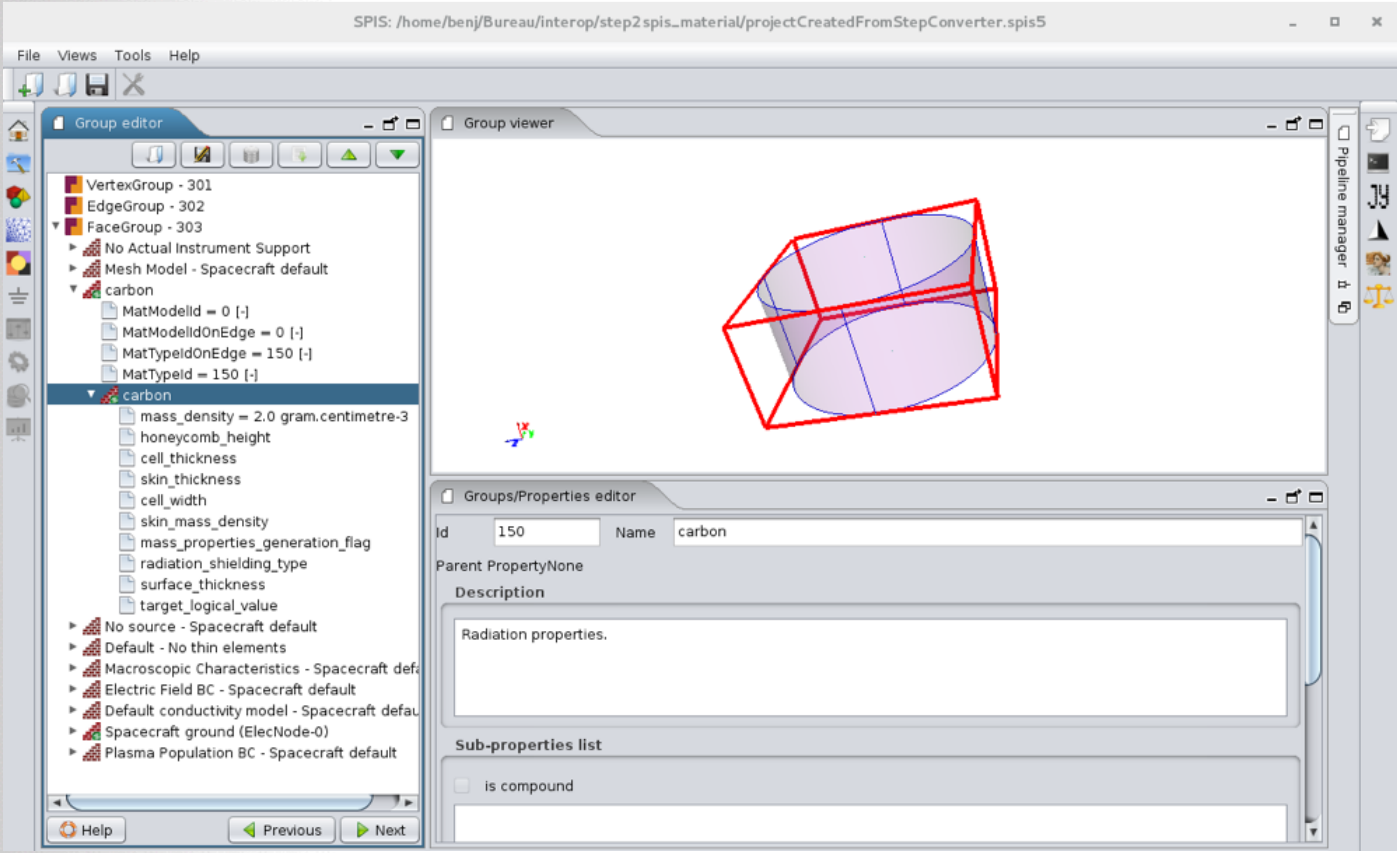
- **Materials are defined / supported by STEP-NRF**
- **Highly modular and structured**
- **Support various types of properties**
  - Scalars
  - Vectors and matrices
  - Strings
  - Material models
- **Rich typing of material models and targeted physics**
- **Provide a clear identification mechanisms**
  - Name
  - Author/sources
- **Compound materials through STEP-SPE**
- **Support both catalogues of materials and deployment on modelled systems**



STEP-NRF material data structure and Frida data are very close and cover an almost same functional scope.

Compliance possible.

STEP-SPE to SPIS (Frida) material properties conversion



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Conclusion

- Material definition constitute a key issue for space environment analysis especially in a multi-model/multi-physics approach
- Definition, storage and exchange of material properties are much more complex issue that a simple « text form »
- We need a clear identification of materials (and sources), what ever the conversion of data
- Material definition cannot be separated from the materials models and consuming models.
- We need to identify / use a real « exchange protocol »
- The conversion process can be decomposed into several stages and offer various degres of interfacing.
- STEP-NRF and SPIS material model (Frida) present a good level of interoperability.

To be continued…

Home work for Denis and Alain