Prioritising the use of Nanomaterials in the Space Industry

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Britten Consulting Limited

INSTITUTE OF nanoTECHNOLOGY

Tuesday 14th September, 2010 - 7th ESA Round-table on MNT for Space Applications

The Consortium

- National Physical Laboratory (NPL)
  - The UK's National Measurement Institute, with over 100 years experience in materials metrology, more recently in nanomaterials
- Institute of Nanotechnology (IoN)
  - Established in 1997,one of the world's first independent nanotechnology information providers, and now a world leader.
- Britten Consulting ltd.
  - A small consultancy with extensive experience in the space industry

….. **The Technology Push team**

(the **Application Pull** team are up next)

The Project

Evaluate, Quantify, Prioritise and Roadmap
nanomaterials for use in future space applications

This project explicitly excluded MEMS or NEMS or any other nano-related electronics

Stage One

- Review various nanomaterials groups and their properties (ISO TC 229 WG)
- Identify potential European suppliers for each nanomaterial group
- Produce a searchable supplier database

Nanomaterials Review

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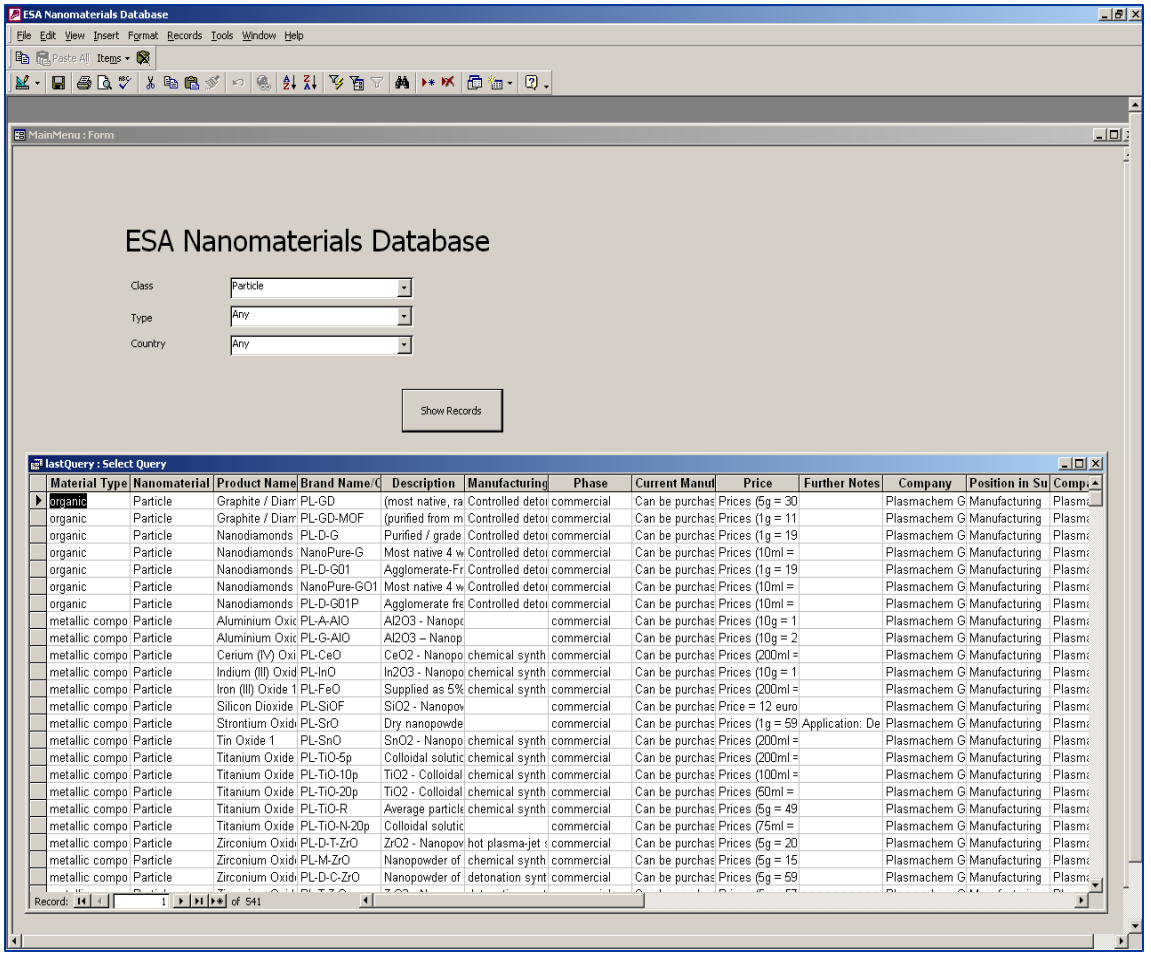
- Nanoceramics
- Nanocomposites
- Nanotubes
- Nanoparticles
- Nanoclays
- Fullerenes
- Nanofibres for reinforcement
- Electronic Nanowires
- Quantum dots
- Dendrimers
- Hard-metal nano-alloys



Nanomaterials for space applications

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This task looked at the **specific requirements** of the space community

- What are the existing space materials problems?
- Can nanotechnology help?
- If so, where and how?
- How quantifiable are these improvements?

A **Round Table** meeting was used

- To discuss and validate proposals with ESA engineers and scientists
- To educate the space industry on what can be expected from nanotechnology

Possible improvements

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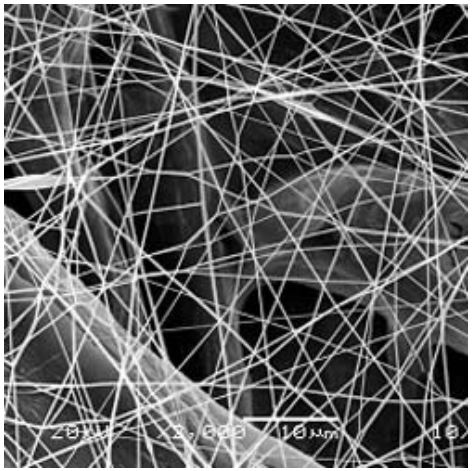
Structural **Thermal** **Electrical** **Active Materials**

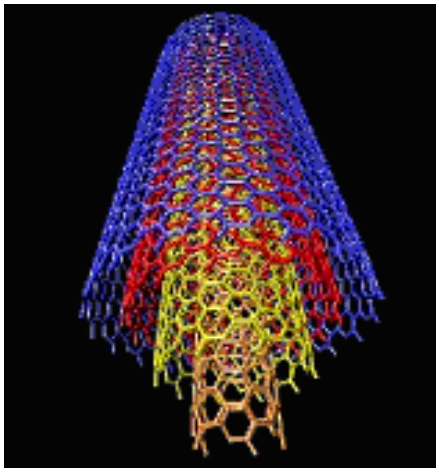
- **Near future**
  - Reduce Mass and improve strength (Structural Materials)
  - Improved thermal protection systems (Thermal conductivity)
  - Electromagnetic compatibility (Charging, Radiofrequency)
  - Radiation Shielding
  - Active Materials (Thermoelectrics)
- **Longer term**
  - Energy storage
  - Coatings (barrier or re-enforcement)

These were used to define the activities in the **Nanomaterials Roadmap**…..

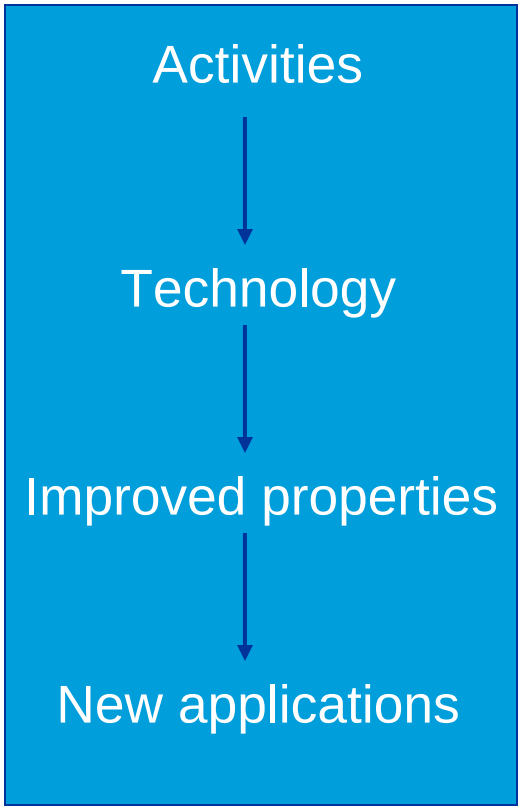
Roadmap development

Time-bound descriptions of specific activities to develop a technology that can improve properties for specific space applications





Each activity has an attached General Activity Description (GAD) which defines the activity, the cost, and the duration involved



TRLs and Nano

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- **TRL 1** **Basic principles observed and reported**

…. most nanomaterials-based technologies are currently at this stage

- **TRL 5** **Component and/or breadboard validation in relevant environment**

…. the predicted position for some nanotechnologies in 5 + years

- **TRL 8** **Actual system "Flight proven" through successful mission operations**

…. with appropriate R&D, **nanomaterials-based technologies could be here in a 10-15 year horizon**

WP 3: Nanotechnology Roadmap

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- 5 year timescale
- 10 Action Areas
- 31 Individual Activities – each detailed in a General Activities Description
- Aims to increase the TRL of nanomaterials-based technologies

Nanomaterials Development Roadmap

Action	Technology Description	Priority	Present	2011		2012		2013		2014		2015		2016	
NANO 1	Polymer based nanocomposite for structural applications		TRL 2	TRL 2	TRL 2	TRL 2	TRL 3	TRL 3	TRL 4	TRL 4	TRL 4	TRL 4	TRL 5	TRL 5	TRL 5
1.1	Industrialise dispersion of carbon nanotubes in polymer matrix	1													
1.2	Improve strength and toughness CNT-CFRP materials	1													
1.3	Validation of a structural model for nanocomposites	2													
NANO 2	Ceramic nanocomposites for harsh environment		TRL 1	TRL 1	TRL 2	TRL 2	TRL 2	TRL 2	TRL 2	TRL 3	TRL 3	TRL 3	TRL 3	TRL 4	TRL 4
2.1	Industrialise sintering techniques suitable for nanoceramic composites	1													
2.2	Improved toughness and wear resistance in nanoceramics composite	2													
2.3	Develop nanoceramics bonding on metal substrate	2													
2.4	Characterize fracture mechanism in nanoceramics and delamination in ceramics coating	2													
NANO 3	Improved thermal insulation using nanomaterials		TRL 1	TRL 1	TRL 1	TRL 2	TRL 2	TRL 3	TRL 3	TRL 3	TRL 4	TRL 4	TRL 4	TRL 5	TRL 5
3.1	Develop thermal insulation nanomaterials	1													
3.2	Design and produce nanocoatings for improved TPS	1													
NANO 4	Improved thermal transport in nanomaterials		TRL 1	TRL 1	TRL 1	TRL 2	TRL 2	TRL 3	TRL 3	TRL 3	TRL 4	TRL 4	TRL 4	TRL 5	TRL 5
4.1	Improved heat transport in carbon nanotubes / epoxy composites	1													
4.2	Develop anisotropic thermal transport materials	2													
NANO 5	Electro-conductive polymeric nanocomposite		TRL 1	TRL 1	TRL 1	TRL 1	TRL 2	TRL 2	TRL 2	TRL 2	TRL 3	TRL 3	TRL 3	TRL 4	TRL 4
5.1	Demonstrate reduced ESD sensitivity in polymer composite using nanofillers	2													
5.2	Extend CFRP processing techniques to produce highly RF conducting CNT/CNF materials	2													
5.3	Conductive nanocoating for ESD mitigation on satellite housing	1													
5.4	Improve bonding properties of coating on polymers	3													
NANO 6	Nano-Thermoelectric materials for energy generation		TRL 1	TRL 1	TRL 2	TRL 2	TRL 3	TRL 3	TRL 3	TRL 4	TRL 4	TRL 4	TRL 4	TRL 5	TRL 5
6.1	TE Materials Development activity	1													
6.2	Characterisation of Efficient nanostructured thermoelectrics	1													
6.3	Prototyping Ultra-high efficiency thermoelectric generator	1													
NANO 7	Improve radiation / EM shielding using nanomaterials		TRL 1	TRL 1	TRL 1	TRL 2	TRL 2	TRL 2	TRL 3	TRL 3	TRL 4	TRL 4	TRL 5	TRL 5	TRL 5
7.1	Characterize space radiation effects on nanocoating	1													
7.2	Improve radiation shielding efficiency of nanocoating	2													
NANO 8	Improve bonding properties of nanocoatings		TRL 1	TRL 1	TRL 1	TRL 2	TRL 2	TRL 2	TRL 3	TRL 3	TRL 4	TRL 4	TRL 5	TRL 5	TRL 5
8.1	Develop low friction surface coatings	2													
NANO 9	Improved energy storage		TRL 1	TRL 1	TRL 1	TRL 1	TRL 2	TRL 2	TRL 2	TRL 3	TRL 3	TRL 4	TRL 4	TRL 4	TRL 4
9.1	Develop reliable nanostructured electrodes for batteries	2													
9.2	Demonstrate high-power and increased lifetime for nano-enhanced batteries	2													
9.3	Characterize degradation mechanisms in nano-based supercapacitor	3													
NANO 10	Characterisation Techniques and fundamentals of nanomaterial		TRL N/A	TRL N/A	TRL N/A	TRL N/A	TRL N/A	TRL N/A	TRL N/A	TRL N/A	TRL N/A	TRL N/A	TRL N/A	TRL N/A	TRL N/A
10.1	Characterization of buried interfaces	2													
10.2	Validated tools to measure transport across interfaces	3													
10.3	Couple theory/modelling and experiment	2													
10.4	System integration - Understand and bridge multiple length scales	1													
10.5	Characterise Thermal transport at the nanoscale	1													
10.6	Test Thermal stress and characterise failure mode on nanomaterials	2													
10.7	Validated quality control methods for nanocoating	3													

WP 3: Nanotechnology Roadmap

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ACTION	TECHNOLOGY DESCRIPTION	DURATION	PRESENT	2016
NANO 1	**Polymer based nanocomposite for structural applications**	66 months	TRL 2	TRL 5
NANO 2	**Ceramic nanocomposites for harsh environment**	54 months	TRL 2	TRL 3
NANO 3	**Improved thermal insulation using nanomaterials**	48 months	TRL 1	TRL 4
NANO 4	**Improved thermal transport in nanomaterials**	42 months	TRL 1	TRL 3
NANO 5	**Electro-conductive polymeric nanocomposite**	54 months	TRL 1	TRL 3
NANO 6	**Nano-Thermoelectric materials for energy generation**	48 months	TRL 1	TRL 4
NANO 7	**Improve radiation / EM shielding using nanomaterials**	48 months	TRL 1	TRL 4
NANO 8	**Improve bonding properties of nanocoatings**	18 months	TRL 3	TRL 4
NANO 9	**Improved energy storage**	48 months	TRL 1	TRL 3
NANO 10	**Characterisation Techniques and fundamentals of nanomaterials**	54 months	TRL N/A	TRL N/A

Examples: Nanocomposites

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NANO 1: Polymer based nanocomposite for structural applications

TRL 2 TRL 5

66 months

- 1.1: Industrialise dispersion of carbon nanotubes in polymer matrix
- 1.2: Improve strength and toughness of CNT-CFRP materials
- 1.3: Validation of a structural model for nanocomposites

…. Very active research area with support from industry (e.g. aviation and automotive)

NANO 4 Improved thermal transport in nanomaterials

42 months

TRL 1 TRL 3

- 4.1: Improved heat transport in carbon nanotubes / epoxy composites
- 4.2: Develop anisotropic thermal transport materials

…. Although improved thermal properties have been demonstrated, this has a much smaller research base

Thermal Nanomaterials

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NANO 3 Improved thermal insulation using nanomaterials

48 months **TRL 1** **TRL 4**

- 3.1: Develop thermal insulation nanomaterials
- 3.2: Design and produce nanocoatings for improved TPS

NANO 4 Improved thermal transport in nanomaterials

42 months **TRL 1** **TRL 3**

- 4.1: Improved heat transport in carbon nanotubes / epoxy composites
- 4.2: Develop anisotropic thermal transport materials

Examples: Nanostructured materials

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- Nanotechnology can improve existing properties – mechanical, thermal and electrical
- It can also improve complex transport properties – high efficiency thermoelectrics, photovoltaics, batteries…
- On the long-term, it may bring new functionalities, such as sensing or self-repairing properties

NANO 6 Nano-Thermoelectric materials for energy generation

TRL 1 **TRL 4**

48 months

- 6.1: Thermoelectric Materials Development
- 6.2: Characterisation of efficient nanostructured thermoelectrics
- 6.3: Prototyping Efficient Thermoelectric Generator (TEG)

Qualification of Nanomaterials

NANO 10 Characterisation Techniques and fundamentals of nanomaterials

54 months - TRL N/A

- There are seven separate activities which come under the heading of "fundamentals of nanomaterials"
- Each of these activities will provide tools to design, develop and validate emerging nanomaterials
- These tools are key to good engineering and are currently missing

These will not further the TRL of the nanomaterials technologies, but are **vital to ensure buy-in** from the space community

Conclusions

- Database: Europe is well-placed for nanomaterial production, with over 200 different types of “off the shelf” nanomaterials produced
- Potential improvement: Four key areas identified

Structural **Thermal** **Electrical** **Active Materials**

- We have proposed an action plan to increase the TRL of nanomaterials for specific applications
- Some classes of nanostructured materials can be **flight-qualified (TRL 7 – 8)** on a 10 - 15 yr timescale, including
  - Nanocomposites for structural applications
  - Nano-thermoelectric materials (for energy)
  - Thermal nanomaterials (for insulation)
- Characterisation, metrology (validation) and design tools for must be developed

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