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Attributes – How do we categorize nanotechnology?

Once we determine that something can be classified as nanotechnology, the following attributes can help determine it sits in the design space.

Size: For something to be categorized as nanotechnology, the process/application its dimensions must be on the nanometer scale.
Value Range: < 100 nm

Assembly Method: How the tool / device is assembled. When one considers the conventional notion of nanotechnology as manipulating objects at the nano scale, the ultimate goal is to manipulate individual atoms. Certain assembly methods can be considered more "nanotechy" than others, but the end product is what is important.
Value Range: Bottom up, Top down, Hybrid

Dimensions Controlled: The number of dimensions controlled describe the degree to which the manipulation of nano scale objects has been achieved in any particular process.
Value Range: >0

Assembly Process (Precision): The specific type of assembly process involved. End products can be considered as nanotechnological, whether there is controlled manipulation of nano materials (deterministic) or whether the process is random.
Value Range: Random, Deterministic, Hybrid

Active / Passive Device: A nano device can be either active or passive. There are also two distinct notions of active (i.e. the distinction between transporting electrons, and moving a mechanical arm).
Value Range: Active motion, Active non-motion, Passive

Macro Scale Forces: The forces involved in the interaction between the nano-scale material / system and any macro scale components.
Value Range: Van der waals forces, electrostatic interactions, hydrophobic / hydrophilic interactions, chemical bonds (covalent, ionic).

Nano Scale Forces: The internal forces involved in the nanometer scale device or system.
Value Range: Van der waals forces, electrostatic interactions

Macro – Nano Interface: For a device or system to be useful there must be some interaction with existing devices or systems which are currently at the macro scale (larger than nano). The interface should not be a performance limiting factor. In other words, there should be a gain in performance and/or utility in downsizing to nano scale components.
Value Range: (unclear)

Bio Integration: Whether a nano device / system is integrated with biological processes or systems, and if so, the nature of the integration (integration includes both direct interactions with biological processes, and basing a process on naturally occurring parallel process in nature) Examples: A nano system that is assembled using DNA based assembly is directly integrated with a biological process; a motor that is based on ATP Synthase for example, or a proton gradient, is not directly integrated but draws its origins from a biological process.
Value Range: (i) Yes / No (Is the device/system integrated?)
(ii) If the answer to (i) is "yes", then values include:
DNA assembly, Ion gradient, Active transport, ATP based. etc.

What is nanotechnology?

A subset of the above attributes can be used to determine *whether* a device / tool / material or system can be classified as nanotechnology. There is an important distinction between the manufacture of materials and that of systems. It is usually easier to classify materials as a part of nanotechnology based on the following criteria, but when a system is being analyzed, care must be taken to distinguish between a system incorporating nano components and a system being nanotechnological.

Size: Clearly if the operating size scale is greater than the threshold (say 100nm), it cannot be classified as nanotechnology.

Dimensions controlled: A system that uses nano materials but doesn't control any nano scale dimensions doesn't constitute nanotechnology (eg. Buckeyballs in face cream, nano composites in lubricants). The end product must involve control of nano scale dimensions (drug delivery nano robots – dimensions may include those of delivery arms, propulsion motors etc.)

Assembly Method: Both top-down and bottom-up methods can be used to manipulate nano-scale dimensions, but bottom up methods are "more nanotechy" when compared against the rubric of manipulating individual atoms. (eg. top down – photolithography; bottom up – synthesis of nanocrystals)

Assembly Process /Precision: An assembly process can be random, deterministic, or a mixture but the end product needs to be definite. In other words, the assembly process may be random, but there must be a way of selecting "desired" end products (eg. harvesting nanocrystals and selecting spherical crystals with 10nm radius). A deterministic process can also be inaccurate (eg. Mismatches in DNA pairing), so determinism does not necessarily indicate that nanotechnology is being done. The only criteria that needs to be met is that the *end product* is determined.

Nano Scale Forces: The functionality of the *end product* should rely on nano scale forces to be classified as nanotechnology (eg. Nano-electronic devices uses electrostatic forces to transfer charge; the functionality of lubricants that use nano-particles is enhanced by but does not depend on nano-scale forces)