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Introduction & 3-level strategy

Nanotechnology has found many environmental applications, both current and potential, in areas such as site remediation with zero-valent nanoscale iron, protective coatings with nanoscale TiO_2 and nanoscale CeO_2 fuel additives for reduction of CO_2 emissions, as well as many possible secondary environmental routes through its manufacture and application in other products and processes and their subsequent disposal.

The potential of nanomaterials lie in their unique properties at the nanoscale, their potential reactivity and strength. However, these novel characteristics may also result in potential human health and ecological risks, and although research into nanomaterial fate and transport in human systems and to a lesser extent ecological systems is currently underway there are still many data gaps, assumptions and uncertainty inherent in attempts to perform comprehensive nanomaterial life cycle assessments.

These issues also affect attempts to regulate nanomaterials which may not fit easily into any current regulatory frameworks due to their differing characteristics to their bulk counterparts. Exposure metrics traditionally used to regulate exposure, such as mass or number may not be appropriate to the true toxic potential of the material. This uncertainty over regulatory issues may in turn affect nanomaterial R&D and commercialization.

The objective of this risk assessment strategy is to provide qualitative estimates of human risk upon exposure to nanomaterials, resultant from environmental applications, with potential application in a semi-quantitative model for use in pre-empting hazards in R&D and regulatory issues. The basis of this strategy may be seen in the figure opposite.

Environmental behavior

Some particle and process characteristics that may affect typical material behavior in the environment and of relevance in assessing the human exposure risk, according to available literature, are highlighted in the figure opposite. As the characteristics indicated will have different effects on the final behavior of the material, such as transport or adsorption, in the final exposure assessment these different characteristics must be weighted in accordance to their perceived relevance to specific nanomaterial behavior. The listed characteristics and behaviors will have many inter-relationships and layers of complexity, although this strategy only considers those behaviors and characteristics which are reasonably easy to define and have a potentially significant effect on the nanomaterials final exposure risk.

Model application

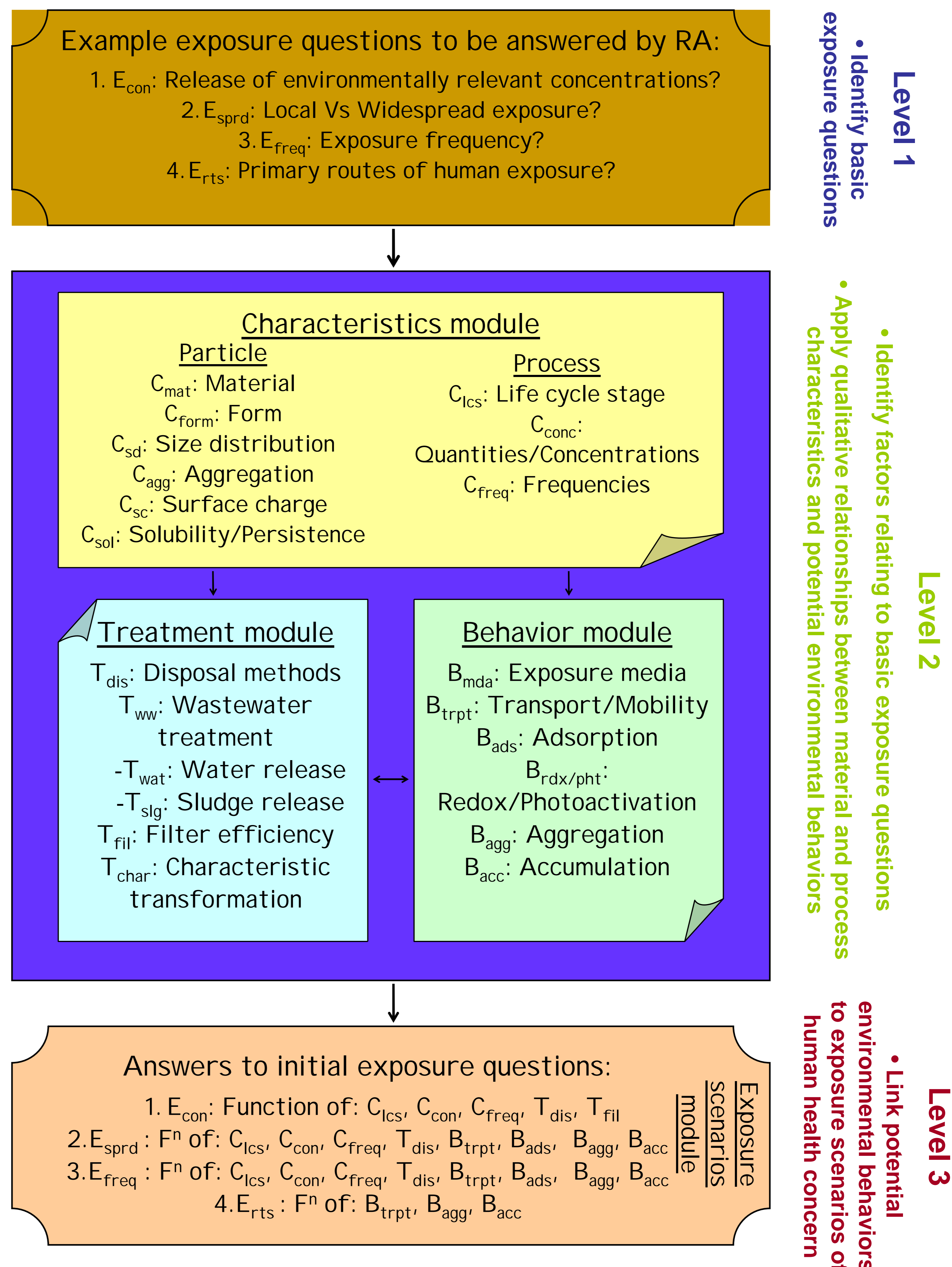
In the case of nanomaterials, and free nanoparticles in particular, there is great uncertainty as to their fate in the environment; the quantities these particles may be present in at each exposure point and the potential ecotoxicological hazards and transformations that may take place such as disaggregation and adsorption of potentially harmful materials. Because of a lack of exposure and toxicological data concerning nanoparticles, any quantitative or semi-quantitative model derived from this strategy would require probability distributions, substitutions and even simulation, in tandem with expert opinion and critical literature reviews, to fill these data gaps

Conclusions

The strategy presented here does not cover every material, process and environmental characteristic that may be relevant to human exposure to nanomaterials, though it does provide an overview of the principle factors, their inter-relationships and effects on nanomaterial environmental behavior that need to be taken into account before developing a nanomaterial or process for wide scale release, or before developing regulatory frameworks for these materials. Due to its largely qualitative basis, any model derived from this strategy would be of more use in comparing two nanomaterials, or comparing the effects of changing one or more material or process characteristics.

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As more information is generated on critical exposure points such as fate during treatment processes and transport in different environmental media, models with a quantitative basis may be constructed on this basis, where nanomaterials may be compared on a common risk ranking structure, while also removing the subjectivity associated with qualitative risk analyses. This model strategy could find application in regulatory forecasting, where future exposure scenarios may be explored and controls set where appropriate.