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RESEARCH ARTICLE

NANOTECHNOLOGY IN SPACE EXPLORATION– A REVIEW.

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Abstract

Nanotechnology is one of the innovative technology in the world. Today, most of the Nanotechnology is one of the innovative technology in the world. Today, most of the researchers and technologists are looking for different ways to utilize nanotechnology to ameliorate the world. There are many applications of nanotechnology in aerospace and space explorer. Nanotechnology keystone in lowering mission cost and mass with increasing efficiency and effectiveness. The paper shows a review of nanotechnology applications, advantages, and risks.

Introduction:-

Nanotechnology operates at the primary level of the structure of atoms and molecules and it promises the ability to build precise machines and components of molecular size[25]. Nanotechnology is usually described at a minimal dimension of 10 nanometers, equivalent to about 30 molecules. A more relevant definition of nanoscience is a dimension that cannot be further lowered without a substantial change of physical properties and non-theoretical or synthesis process. The exemption of nanotechnology is illustrated in Fig.1. The imbricate of electronics, biosciences, and materials designates the scope of nanotechnology[07]. Presently, nanoscience and technology symbolizes the most dynamic discipline all around the world and is marked as the fastest emerging technology conversion in human history had ever detected. Nanomaterials exhibit fundamentally unique properties in all fields it is a multidisciplinary field[05]. According to the National Science Foundation and NNI, Nanotechnology is the capability to acknowledge, control, and operate matter at the level of single atoms and molecules. There isa stupendous amount of researches is going on in the world about nanotechnology. Because of its applications nanotechnology is outlined as a revolutionary discipline. Nanotechnology uses techniques and tools to construct the items from the bottom-up and being evolved to make high-performance products.[25]

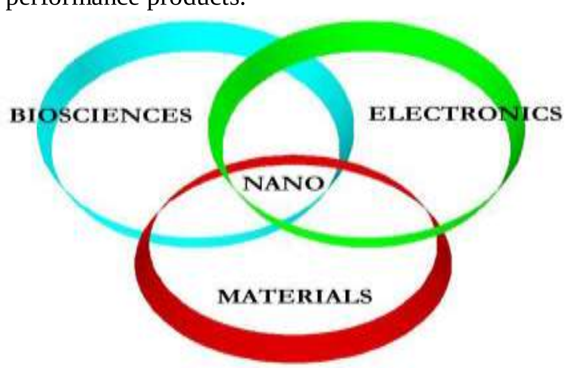

Figure 1:. Illustration of Scope of Nanotechnology[7]

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Nanotechnology is at the front line of scientific development, continuing to astonish and innovate[06]. Nanotechnology will provide the capability to build the small, compact systems that can perform tasks that today only humans can perform, and to do so economically and efficiently[04]. It is estimated that substituting conventional aerospace materials (like composites and metals) with advanced composites derived from lightweight, high strength and durable nanomaterials can lower the weight of air and spacecraft by 30%![08] The advancements in nanotechnology could help to make a chain for the space elevator, fine solar sails and it could remarkably reduce the quantity of rocket fuel required which helps to lessen the cost of traveling in space. Besides, the performance of spaceships, spacesuits, and other types of appliances used to explore planets can be enhanced by the combinations of nanorobots and nanosensors with new materials [25].A microscopic characterization is an invaluable tool across applications including the study of surface materials on planetary bodies, analysis of rocks on earth, hazardous material identification, and defect testing during manufacturing or construction[12].Because of its highly notable impact on almost all industries and entire areas of society nanotechnology sometimes described as General Purpose Technology [25].

Carbon Nanotubes[01,02,06,07,08,15,22,25]:

Carbon Nanotubes have inspired visions of game-changing aerospace applications. Carbon Nanotubes are the allotropes of carbon which are discovered by SumioIijima in 1991. They are cylindrical nanostructure. One-dimensional carbon nanotubes (CNTs) are carbon atoms bound together. They are in a hexagonal pattern and they form long cylinders as shown in Fig.2. The length-to-diameter ratio of nanotubes has up to 28,000,000:1, which is remarkably greater than any other material. The tensile strength of these nanotubes have a one hundred times that of steel, yet are just a sixth of the weight. CNTs can conduct electricity superior to copper, transmit heat preferable than diamond, and has an elasticity five times effective than steel. It has outstanding thermal and electrical conductivity. It is one of the weight-saving and performance-enhancing materials. CNTs are competently studied at microscopic levels, but there is still a needfor understanding their behavior in macroscopic applications. The properties of CNTs at the macrolevel remain far underneath than properties at the individual level of CNT. It is dominant to maintain the noticednanoscale properties at the macroscale if these materials are to find comprehensive utility. This has stayed a challenge.

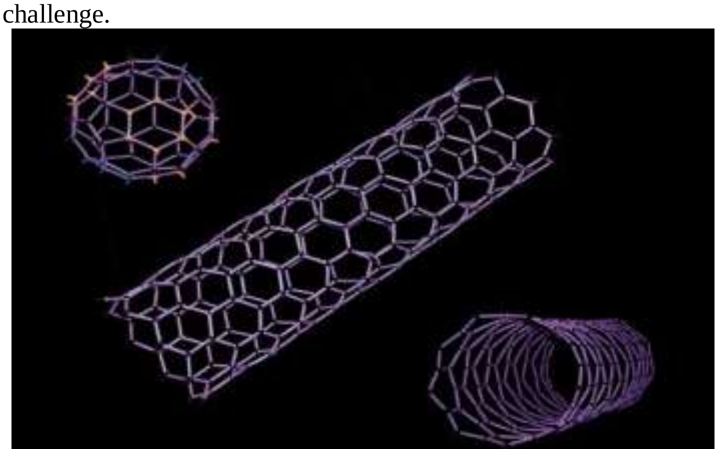

Figure 2:- Carbon Nano Tubes[25]

CNTs are potentially useful in numerous applications in nanotechnology, optics, electronics, and other fields of materials science, also potential advantages in architectural fields because of novel properties of cylindrical carbon molecules. They exhibit astonishing strength and distinctive electrical properties. They are also efficient conductors of heat. Their final use may be limited by their potential toxicity. CNT materials can be utilized in the Thermal Protection System, micrometeorite and orbital debris (MMOD) protection, Surface coating, etc. CNTs are also used to increase rocket efficiency. In NASA’s Juno mission, CNTs were implemented for electrostatic discharge dissipation. There are plenty of other potential space implementations of CNTs such as for optics in a CubeSattelescope a carbon-nanotube resin mirror is used. Other prospective space CNTs applications are: HIADs, space suits, high altitude long endurance vehicles (e.g., Venus and Mars airplanes),parachutes, antennas,in situ resource utilization,adaptive deployable entry and placement technology, planetary rovers, 3D printing, flywheels, sensors, tires, landing mechanisms, filtration,purification, batteries, and habitats. The committee on the planetary science decadal survey endorsed breaking the potential missions into small (<$500 million), medium (<$1.0 billion), and large (>$1.0 billion) categories. Table 2 presents a list of complex missions that have to operate in tremendously severe environments ranging from Moon's poles to Saturn's moon Titan. They also give potential opportunities for CNT applications [01].

Table 1:- Properties of Carbon Nanotubes[24]

	Theory	Measured
Density	1300 kg/m^3	-
Tensile Strength	130 GPA	-
Melting Temperature	7800°C	-
Resistivity	-	$1 * 10^{-4}$ □ cm^{-1}
Young's modulus	630 GPA	1800GPa

A hypothetical technological artifact: Space Elevator[01,02, 06,14, 21,22, 24]:

For many years, rockets have been the only way to explore space and reach space. But between 1960 to 1970 another hypothetical concept was proposed, namely the space elevator. The space elevator is nothing but creating physical contact between space and the earth. The basic concept is to lay the cable from the surface of the earth to a height beyond the geosynchronous orbit. Articles in some major newspapers predicted headlines like "Stairway to Heaven" that helped generate interest among readers.

Table 2:- List of potential robotic missions[01]

Mission categories	**Potential missions**	**Destinations**
Small < $0.5 Billion	➢ Icebreaker Life (Mars) ➢ Mars–Moons Exploration, Reconnaissance And Landed Investigation (MERLIN) ➢ Phobos and Deimos Origin Assessment (PANDORA) ➢ Phobos and Deimos and Mars Environment (PADME) ➢ Advanced Jupiter Asteroid Explorer (AJAX) ➢ Trojan Asteroids (Lucy) ➢ Io Volcano Observer (IVO) ➢ Journey to Enceladus and Titan (JET) ➢ Enceladus Life Finder (ELF) ➢ Venus Atmosphere And Surface Explorer (VASE) ➢ Radar at Venus (RAVEN) ➢ Venus Emissivity, Radio Science, Insar, Topography, and Spectroscopy (VERITAS)	➢ Mars ➢ Mars ➢ Mars ➢ Mars ➢ Jupiter ➢ Jupiter ➢ Jupiter ➢ Saturn ➢ Saturn ➢ Venus ➢ Venus ➢ Venus
Medium < $1.0 Billion	➢ Comet Surface Sample Return ➢ Lunar South Pole–Aitken Basin Sample Return ➢ Saturn Probe ➢ Trojan Tour And Rendezvous ➢ Venus In situ Explorer ➢ Lunar Geophysical Network ➢ Io Observer	➢ Comet ➢ Lunar ➢ Saturn ➢ Asteroid ➢ Venus ➢ Moon ➢ Jupiter Moon Io
Large > $1.0 Billion	➢ Mars Astrobiology Explorer-Cacher (MAX-C) ➢ Jupiter Europa Orbiter ➢ Saturn Enceladus Orbiter ➢ Uranus Orbiter and Probe ➢ Venus Climate Mission	➢ Mars ➢ Jupiter Moon Europa ➢ Saturn Moon Enceladus ➢ Uranus ➢ Venus

The main application of the space elevator is to carry payloads from the Earth's surface into space. There are enormous benefits to such a structure. During take-off, the weight of fuel is approximately 95% the weight of the space shuttle which costing about US$ 20000 per kilogram to dispatch something into space. But by using a space elevator the cost can be lessened to as small as US$ 200. Other space explorations can be started at the tower. The traveling from the moon and to the moon is as effortless as traveling in the morning to work.

The space elevator consists of a cable or tether made of extremely strong and lightweight material to be anchored on a platform with features like the latest airport or rocket launch site somewhere in the equatorial region. The counterweight, used to keep the elevator taught, is proposed to be an asteroid. This would need to be at a distance of 100000 km, a quarter of the distance to the moon. Theoretically, the cable could be manufactured 144000 km long and would be stabilized in equilibrium. The competing forces of gravity at the bottom and external centrifugal acceleration at the other end maintain the cable under tension and stationary across a single position on Earth (Fig. 3). The cable would be tapered such that at the point of maximum tension it is thickest (geosynchronous orbit) and where the tension is minimum it is thinnest (at the ends).The elevator will be about 42000 times taller than the world's tallest building. For traveling such a large distance with incredible speed solar sails can be used. Solar sails use light as a source. The lack of a viable material from which to make a cable presented what engineers sometimes call a "tall tent pole"—a technical problem so critical that solving it can hold up the entire project, with all other problems lost beneath the canvas.

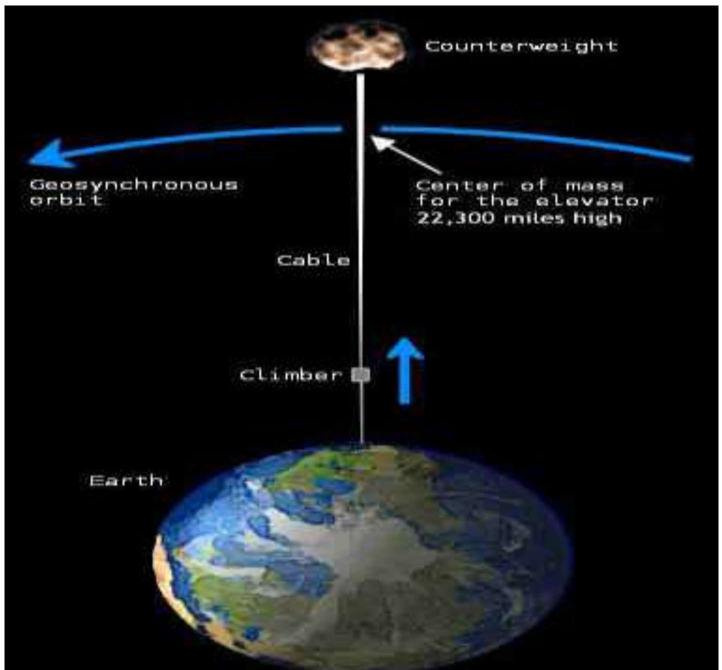

Figure 3:- Space Elevator[21]

Nanotechnology (specifically, the discovery of carbon nanotubes) was central to moving the space elevator to a stage somewhere between speculation, detailed design, and garage tinkering. Carbon nanotubes are the powerful and strongest material ever found. Their properties are as shown in Table 1. This strength merged with the small density of the material makes it captiously dominant when considering the design of a space elevator. The other problems like Radiation damage of cable, Low-Earth-orbit spacecraft impacts on cable, Cable heating by magnetic field-induced electrical currents, Natural frequency, and oscillations in the cable and Deployment locations should also be considered during designing of the space elevator. Carbon Nanotube is the important material on which scientists focus to overcome all challenges of the space elevator (Fig.4)A space elevator is possible by nano-to-mega mechanics.

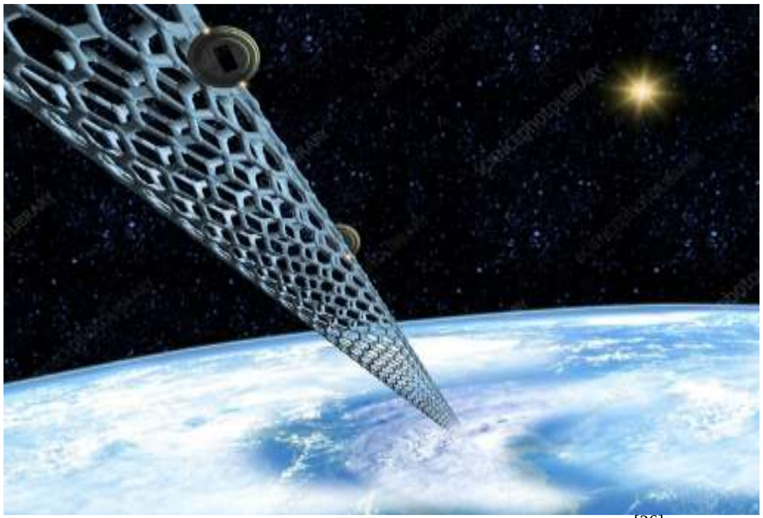

Figure 4:- Space elevator using Carbon Nanotubes[26]

History:

The idea that one could anchor a cable, stretch it out into space, and use it to transport people and payloads in and out of earth's gravity well is more than a century old[02]. Table 3 shows some major discoveries in nanotechnology-related concepts.

Table 3:- Some major discoveries[02]

Year	Name of Scientist/Organization	Theory/ Research
1895	Konstantin Tsiolkovsky	➢ The idea for a Space Elevator
1961	Manfred Clynes Nathan Kline	➢ Concept Cyborg (Altering the human body to allow astronauts to survive the extreme environments of outer space)
1966	Isaacs Vine Bradner Bachus	➢ Described a space elevator like the concept
1970	Hans Moravec	➢ The idea for a skyhook
1970	Gerard O'Neil	➢ The idea of Humanization of Space
1979	Arthur C. Clarke (Science fiction Author And Futurist)	➢ The published novel "Fountains of Paradise" ➢ Introduced Space elevator to thousand of readers
1980-1990	K. Eric Drexler (The most visible popularizer of Nanotechnology)	➢ Book "Engines of Creation" ➢ Encountered O'Neils ideas about Humanization of Space ➢ Wrote technically sound articles about the future possibilities of asteroid mining, space-based closed ecological systems, and solar sails
1985	Nobel laureate Richard E. Smalley Sir Harry Kroto	➢ Discovery of Carbon-60 Buckiminsterfullerene
Mid 1990	NASA	➢ First supported an in-house effort to explore the possibilities of nanotechnology
1990	ARC	➢ Used molecular nanotechnology

		simulations
1991	SumioIijima	➢ Discovery of Helical Microtubules of graphite carbon ➢ Later Carbon nanotube
1993	Kim Stanley Robinson	➢ In Novel Red Mars he described a cable made from robotically processed carbon mined from an asteroid ➢ Later he refers to a cable made from graphite whisker with diamond sponge-mesh gel double-helix into it
1998	NIAC	➢ Created a small operation that had an annual budget around $4.5 million-sought to “inspire, select and fund revolutionary ideas and concepts”
2000	President Clinton (United States federal government program)	➢ NNI established
2007	Bradley C. Edwards	➢ Explained “once you had carbon nanotubes, the rest of it could be done”

Missiles[07]:

There are several applications of nanotechnology in missiles. Many agencies want to know the influence of nanotechnology in the army transformation. Nanosensors and coating materials are used in military appliances. The catalyst to encourage nanotechnology development for military implications is the National Nanotechnology Initiative (NNI). Critical areas for modifying nanostructures or components to missile applications includenanocomposites for light, strong armor and composites in rocket motor casings and missile skin or body structure;nanoshells for thin-film optical coatings on missile domes; nanoparticles for coatings, propellants, and explosives, in missile warheads and propulsion systems; nanotube arrays for batteries, fuel storage, and power sources in power systems; and NEMS (NanoElectroMechanical Structures) and nanocantilevers for ChemBio sensors for environmental monitoring. Tables 4 and 5 indicate listings of research topics for military research and development for nanotechnology in the US by the Defense Advanced Research Projects Agency (DARPA) and the Defense University Research Initiative on nanotechnology of NNI, respectively.

Table 4:- DARPA Initiatives for Military Applications[07]

Technology Areas
Biological and Amorphous Computing
Nanophase Magnetic Materials
Physical Systems Interface
Structural Materials and Devices
Microinstruments
Beyond Silicon
Nanoscale/Biomolecular Materials
Molecular-Level Large-Area Printing
Molecular Electronics
Nanotechnology and Crystalline Arrays
Nanoelectric Research

Table 5:- Defense Initiatives for Military Applications[07]

Technology Areas
Nanoscale Machines and Motors
Nanostructures for Catalysts
Biomolecular Control ofNanomagnetic and Nanoelectronic Structure Formation
PolymerNanocomposites for High-Speed and Space Systems
Nano-Systems Energetics
Organic Nanophotonics and Nanoelectronics
Characterization of Nanoscale Elements

Devices and Systems
Quantum Computing and Quantum Devices
Synthesis, Purification, and Functionalization of Carbon Nanotubes
Molecular Recognition and Signal Transduction in Bio-Molecular Systems
Nanoscale Electronic Devices and Architectures
Synthesis and Modification of Nanostructure Surfaces
Nano-Porous Semiconductors – Matrices, Substrates, and Templates
Magnetic Nanoparticles for Application in Biotechnology
Deformation, Fatigue, and Fracture of Nanostructures and Interfacial Materials

Taxonomy[17]:
NASA uses the technology TAXONOMY to manage and communicate a broad range of technology activities in aeronautics, science, space, and their portfolios. According to this TAXONOMY, NASA engages with applications and developments in the following areas of nanotechnology.

Table 6:- Applications of Nanotechnology[17]

Area of application	**Uses**
Engineered Materials and Structures	1. Lightweight Structures 2. Damage-Tolerant Systems 3. Coatings 4. Adhesives 5. Thermal Protection and Control
Energy Storage, Power Generation, and Power Distribution	1. Advanced Concepts for Energy Storage 2. Dynamic Energy Conversion 3. Power Distribution and Transmission
Propulsion	1. Propellants 2. Propulsion Components 3. In-Space Propulsion
Sensors, Electronics, and Devices	1. Sensors and Actuators 2. Nanoelectronics 3. Miniature instruments and instrument Components

Nanotechnology in Satellites and Robots[03,09,10,11,18,19,20,23]:
Space is a fundamentally unfriendly environment for humans. Space robotic systems likeplanetary rovers, robots in orbit, or even satellites are of splendid importance to space exploration and execute tasks precarious or impossible for humans. The nano-scale device technology is currently a heavily investigated research field. The small satellites with mass 1-to-10 kg called nanosatellites and mass 0.1-to-1 kg called picosatellites. The CubeSats are the ultra-small satellites and small spacecraft, which are poised to invariably transform the global economy and mankind's approach to space exploration (Fig.5). Using nano and microtechnologies in space robotic systems outcomes either in miniaturized systems in terms of mass and volume, while preserving or enlarging their capabilities, or in space robots, with extended capabilities while maintaining their size due to the nature of their tasks. The manufacturing of small satellites by miniaturization of electronics and related systems helps to reduce the cost of the missions. It has a major benefit to universities and small companies. Accordingly, the CubeSat community also has been focusing on the miniaturization of propulsion systems. MRI based micro-robotic system is also used for propulsion and navigation. Near-future ANTS Miniaturized ART (MART) systems using MEMS systems for the Lunar or Mars surface applications would contain a payload-carrying multifunctional lander/rover.

Here are some nanosatellitesprojects[05]

1. NASA has developed small satellites called nano-sats.
2. IIT Kanpur with ISRO developed a nanosatellite called Jugnu.
3. SRM university launched SRMSAT.
4. At present, five institutes IITKanpur, IIT-Mumbai, Indian Institute of Space Technology, Sathyabhama Institute, and Vellore Institute of Technology are building small satellites.

Figure 5: CubeSats[27]

Some other applications of nanotechnology:

1. Nanoscale transistors are used to control the flow of a greater amount of electricity[25].
2. Nanoparticles integrated into liquid and solid fuels, liquid, and solid propellants, and pyrotechnics had the performance advantage[13].
3. Different nanoscale materials can be used in thin films to make them anti-reflective, water repellent, anti-fog, Ultraviolet or infrared-resistant, anti-microbial,self-cleaning, electrically conductive, or Scratch-resistant. Nanofilms are also used now on eyeglasses, cameras, and computer displays, to protect or treat the surfaces. Nanofilm is shown in Figure 6[25].
4. Nanoelectronics increases the capacity of electronic devices by reducing weight and energy consumption[25].
5. Using Nanoscale materials batteries are being manufactured to deliver more power quickly with less heat.
6. Nanotechnology improves the functionality and comfortability of spacesuits[8].
7. Power sources, ultra-small sensors as well as navigation, communication, and propulsion systems with very low volume, mass, and power consumption could be developed using nanotechnology[8].

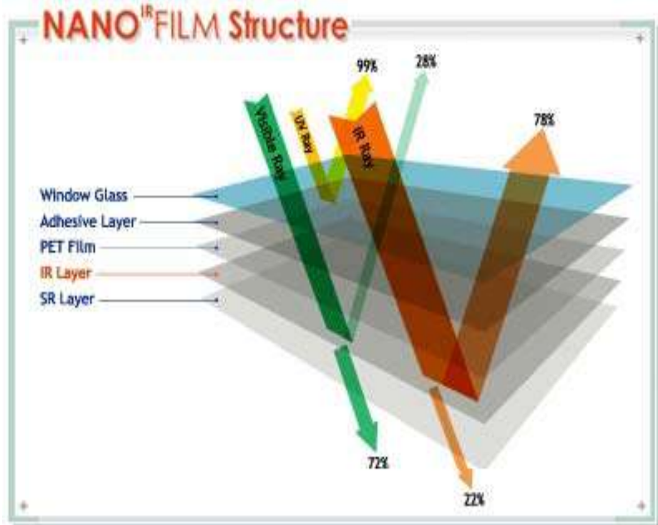

Figure 6:- Nano Films[25]

Applications under Development:

There are numerous potential applications of nanotechnology in space that exist hence it captures and inspired generations to come[06]. Following are some developments under research:

The cable needed for the space elevator using the carbon nanotubes

Reducing the weight of spaceships using carbon nanotubes and maintaining or even increasing the structural strength.

The building of lightweight solar sails using carbon nanotubes
d. Utilizing a network of nanosensors to explore large areas of planets such as Mars for traces of water or other chemicals[25].

Requirements for Future Space Systems[05]:
Here are some requirements of the Space system using Nanotechnology.

Table 7:- Requirements of Future Space System[05]

Cost reduction
On-Board Autonomy
Improvement in communication performance
Making of Innovative components and materials
Lowering of Mission Risks
Innovative System Concepts (Nano-pico-satellites, Gossamer Spacecrafts, Space elevator, Stratospheric platforms)

Risks of Nanotechnology[25]:
There are several risks associated with molecular manufacturing are to be identified. Grey goo is one of the hazard possibilities described by Engines of Creation. Gray Goo is a concept that a small nanomachinethat's capable to copy itself too many times which is in theory. It could be massive damage to unprotected people, objects, and the environment by destructive nanomachines. If the wrong people got the ability to construct any desired product because of the unlimited availability of nanotechnology, they could rule the world, or cause mammoth destruction in the attempt. Certain products such as herculean aerospace weapons, and microscopic antipersonnel devices, equipa special cause of concern. Grey goo is applicable here as well. Several environmental and health issues may be coming out during the production or accidents of nanomaterials or nanoproducts.

Conclusion:-

This paper presents a review of the scope and applications of nanotechnology. In has been observed that nanotechnology encompasses all areas of aerospace, including missiles, satellites, space suits, propulsion, and electrical systems. Nanotechnology has a wide range of applications. New materials designed at the atomic and molecular level provide realistic, cost-effective methods and keep our environment clean. Nanotechnology helps to provide lightweight vehicles with less loss of energy and fuels. Carbon-nanotube is one of the game-changing discovery of nanotechnology. One of the hypothetical concept Space Elevator would be real because of carbon nanotubes. There are many challenges in the field of nanotechnology, but our scientists making efforts to find new materials and technologies for future space exploration.

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