Project Miniature Sun: RSTV – In Depth

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Context:

- The world is currently witnessing a rapid growth in **population, economy and urbanisation**. World population is expected to reach **900 Cr**. By 2040.
- This will lead to an increase in **electricity demand** by **45% by 2040** and will be two times overall energy demand.
- There is also a growing demand for the **transition from fossil fuels to clean energy.**
- In this context, the **International Thermonuclear Experimental Reactor (ITER)** aims to replicate the reactions inside the sun to harness clean energy.

International Thermonuclear Experimental Reactor (ITER):

- Nick named as '**miniature sun'**, ITER is the **largest plasma based fusion reactor ever built**.
- It is the **costliest** technological project of the 21st century with an estimated construction cost of **$25 Billion**.
- The project site is located in **Cadarache, Southern France**.
- The term '**Thermonuclear**' indicates the **nuclear fusion reaction**.
- ITER will be two times the size of the largest fusion reactor present and the **chamber volume** will be 10 times the present one.

Timeline of ITER Project:

- 1988: The Project was
- 2005: **India joined** the project as one of the 7 major partners.
- 2013: Construction of the **ITER Tokamak Complex** was started.
- 2019: **66%** of the construction has been completed.
- 2025: **Commissioning and initiation of plasma experiments** is expected.

International Collaboration in the Project:

- ITER is a collaborative project of thousands of scientists and engineers from **35 countries**.
- There are seven major partners; **India, U.S.A, E.U, Russia, China, Japan, and South**

Korea.

- These 7 partners constitute about **50% of world population and about 85% of world GDP**.
- **U** alone will bear **45% of the estimated construction cost of $25 Billion** while the other 6 countries will contribute **9%** each.
- Further, **specific tasks and components** are assigned to each country.

India's Contributions to ITER:

- **17500 Cr**. has already been committed by India, amounting to almost **10%** of the overall cost of **construction, operation and decommissioning.**
- India has also provided a **Cryostat, the world's largest refrigerator**, weighing around **3800 tons** and made with **stainless steel**.
- It will **cover the entire structure** and keep the **magnetic components at a very low temperature (less than -200^{O}C)** for maintaining the **superconductivity** of magnets.
- It was built by **L&T Ltd.** in **Gujarat**.
- India is also assigned with the development of critical components such as:
- **Cooling water**
- **Vessel in-wall shielding blocks**.
- **Radio frequency heating source**.
- **Diagnostic neutral beam system**, etc.
- The **Institute of Plasma Research (IPR) at Ahmedabad** will oversee the technological commitments of India.
- Around 100 **Indian scientists** are also involved in the project.
- Prime Minister **Narendra Modi** recently visited the project site and also held discussions with French President **Emmanuel Macron.**

Sun as a Source of Energy:

- The Sun is the **primary source of energy** for the earth and also **sustains life** on the planet, since it is located at a **habitable distance** from the sun.
- **Human civilizations** have considered the sun as a **deity** and attempted to **harness the heat and light energy** released by the sun.

- **ITER** attempts to generate **solar energy 'without using sun'** by replicating the nuclear fusion reaction taking place in the sun.

Mechanism of Nuclear Fusion in the Sun:

- The sun is composed of **Hydrogen (75%), Helium (25%)** and smaller amounts of **Oxygen, Iron, Neon, Nitrogen, Silicon**, etc.
- The sun is **a massive nuclear fusion reactor** like all the other stars.
- The reaction began when a **nebula** (a cloud of gas and particles) collapsed under its own **gravitational force** forming a **big ball of hot plasma**, the sun.
- The **core** of the sun is the **hottest and has high pressure** which makes the **Hydrogen** atoms collected at the centre to **fuse together to form Helium** atoms and release solar energy.
- **Two Hydrogen** atoms fuse to form **one Helium**

Technical Details of ITER:

- **Tokamak reactor** is a term used for the location where the nuclear fusion takes place.
- The terminology is similar to the term '**boiler**' used in **steam power plants**, wherein the core reaction takes place.
- It is a magnetic fusion device to harness fusion energy by mimicking the sun and other stars.
- In the **sun**, the massive **gravitational force** creates the conditions for fusion.
- On earth, it is much harder to achieve:
- Fuel must be heated to around **15 million ^{o}C**.
- Fuel need to be **dense** enough and maintained at **higher temperature and pressure** for fusion to take place.
- Initially, the Tokamak cylinder is made completely **vacuum**.

Nuclear Fusion inside ITER:

- Inside the Tokamak reactor, **2 atoms of Deuterium** fuses, at **150 million ^{o}C** and

intense **pressure**, to form **one atom of Helium** and release **huge amount of energy**.

- Deuterium is a **heavier isotope of Hydrogen** with **one each of proton and neutron**.
- **Pulses of LASER** is used to heat the Hydrogen atoms to a plasma state.
- **The plasma** content is **suspended in space** by using a **huge magnetic field**.
- **Ignition or self-sustaining reaction** is achieved when enough heat is produced from fusion.
- The energy released will be absorbed by the walls as **heat which** will be used **to boil** water as in a conventional power plant.
- **Electricity** will be generated with the use of a **steam turbine and a generator**.
- **Tritium** (another isotope of Hydrogen) breeding, which is crucial for next stage fusion reactors, will also be tested in the ITER.

Energy Output from ITER:

- The energy output will be **directly proportional to the number of fusion reactions** taking place.
- Net **energy yield** will be around **4 times that of a nuclear fission reactor**.
- It will generate **500MW energy** which could supply power to **5 Lakh homes**.
- It requires **50MW of input energy** in the form of heating, **8minutes** at a time. Hence output energy is **10 times** the input energy.

Theory behind Energy Generation in ITER:

- A **thermonuclear reactor** or a **nuclear fusion power plant** converts the fusion energy into electricity.
- In a nuclear fusion reaction, **multiple smaller atoms** react to form a **single and more massive atom**.
- However, the **mass of the resultant atom will be slightly lesser than the sum of the individual masses of the reactant smaller atoms**.
- The **differential mass** will be converted into energy according to the equation given by Albert Einstein: **$E = mc^2$**
- **E** represents **energy**.
- **m** represents **mass** and

- **c** represents the **speed of light**.

Other Fusion Reactors across the World:

- In the **1960s**, erstwhile **USSR** developed the **first Tokamak** reactor which was eventually accepted globally as the most promising configuration for **magnetic fusion reactors**.
- **JET Tokamak** developed by the **U, in 1997**, holds the world record for power generation (**16 MW**).
- In **2018, China** built a fusion reactor which was able to achieve a temperature of **100 million ^{O}C** for the **first time**. It was seven times hotter than the sun's core.
- Earlier, the **MAS (Mega Amp Spherical) Tokamak** built by **K** had achieved **15 million ^{O}C**. They are also planning to design smaller fusion reactors.
- The **Massachusetts Institute of Technology (MIT) in the USA** is developing **SPARC**, a doughnut shaped magnetic fusion reactor, in collaboration with **Commonwealth Fusion Systems**.
- It is funded by the **Breakthrough Energy Venture** started by Bill Gates, Jeff Bezos, Michael Bloomberg, etc.
- By **2025**, they plan to develop **smaller reactors** which can be produced in factories, transported and assembled on site.
- In **2018**, the Government of **Canada** has invested **$ 37.5 million** for developing **Magnetized Target Fusion** by **General Fusion**, a **start-up** founded in 2002. Their plan is to **commercialize** it within five years.

Environmental Significance of the Project:

- **Fossil fuel** sources are limited and will not satisfy the growing energy demands.
- **Solar energy** is an unlimited source of **clean energy**.
- However, **renewable energy sources** like wind, hydroelectricity and solar has **some limitations** as well.
- **Sustainable development** requires energy sources which are **clean, pollution free, emission free, safe, globally available and economically viable**.
- **Nuclear energy** is a clean source of energy since it has **very little carbon emissions** and ultimately it will reduce the effects of pollution.
- Nuclear fusion can be harnessed as a **sustainable long term** energy solution.

- Further, the **ITER** project is designed with **negligible impact on the environment**.

Benefits from the Project:

- **Results of the experiments and Intellectual Property Rights** generated during it will be shared with all the partner countries.
- In the future, individual countries **may use the technology** for carrying out a transition from fossil fuels into clean energy sources.
- The designing and construction of components will provide **technological experience** to scientists, engineers, research institutes and construction firms.
- Such experience will prove useful for **expanding nuclear fusion power projects** in future, harnessing **energy from Hydrogen.**

Challenges:

- **Containing the plasma** inside a vessel is impractical since it will melt down the vessel itself.
- Hence, **magnetic field** is used to keep the **plasma suspended in space**.
- Although technological breakthroughs are making huge strides, **perfecting a magnetic field** is a difficult task.
- Managing a **massive temperature gradient** within the reactor also is a challenging task.
- There are **safety concerns** related to likelihood of **reactor melted down, health related risks, radioactive waste disposal, heat tolerance of exhaust system**s, etc.
- Systems for the **storage and breeding of fuel**, recovery of energy, robotic maintenance, etc. need to be fool proof.
- Huge **capital investment** and **economic competitiveness** of the output energy are also crucial bottlenecks.
- An **'experimental'** reactor may not be sufficient to identify the risks associated with a **'commercial'**

Conclusion:

- Recreating the reactions inside a sun on earth was once unthinkable. However, ITER attempts to realise it, as a way forward for providing an unlimited supply of green and safe energy.