

Challenge for Better Future, Challenge with FNC



THANK YOU!
감사합니다!

국내외 소형모듈원자로(SMR) 기술개발사업 현황

Small and Micro Modular Reactor Development Status in the World and Related Activities in Turkey

PRESENTER

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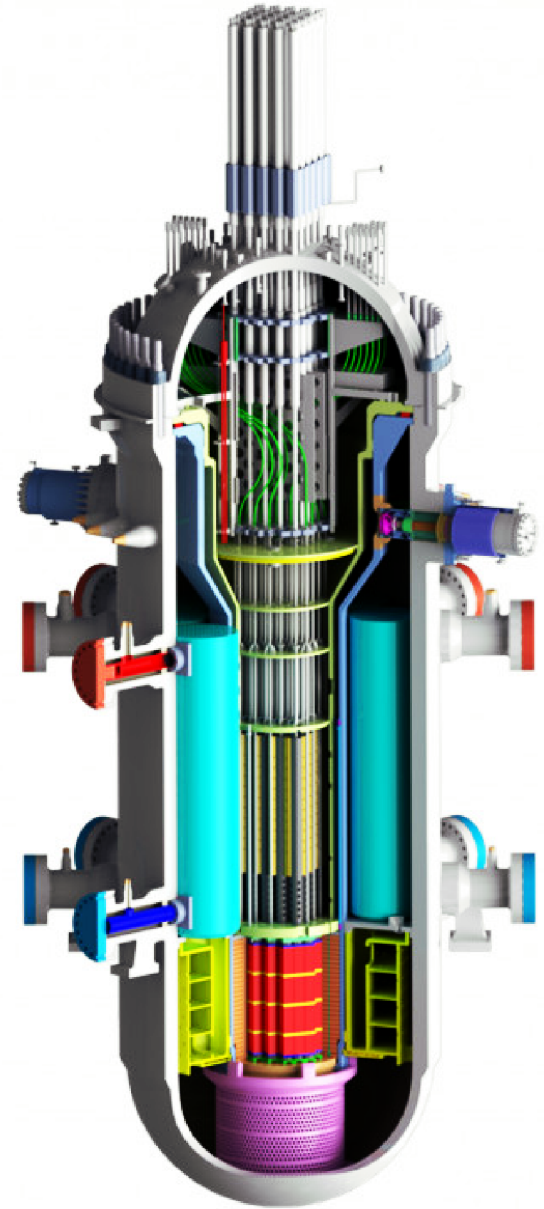
AGENDA

1 INTRODUCTION

2 SMR & MMR DEVELOPMENT STATUS

3 ACTIVITIES IN THE REPUBLIC OF TURKEY

4 Q&A AND DISCUSSION



SMR & MMR | Introduction

SMR: Small-sized modularized nuclear reactor with power levels of 10 to 300 MWe

Special sub-section of SMRs called Micro Modular Reactors (MMRs) with power ratings less than 10 MWe



INTERNATIONAL ATOMIC ENERGY AGENCY (IAEA)

Up to 300 MWe per module



NUCLEAR ENERGY AGENCY (NEA)

Between 10 and 300 MWe



WORLD NUCLEAR ASSOCIATION (WNA)

300 MWe equivalent or less



NUCLEAR ENERGY INSTITUTE (NEI)

300 MWe or less



NUCLEAR REGULATORY COMMISSION (NRC)

300 MWe or less



DEPARTMENT OF ENERGY (DOE)

Less than or equal to 1,000 MWth per module

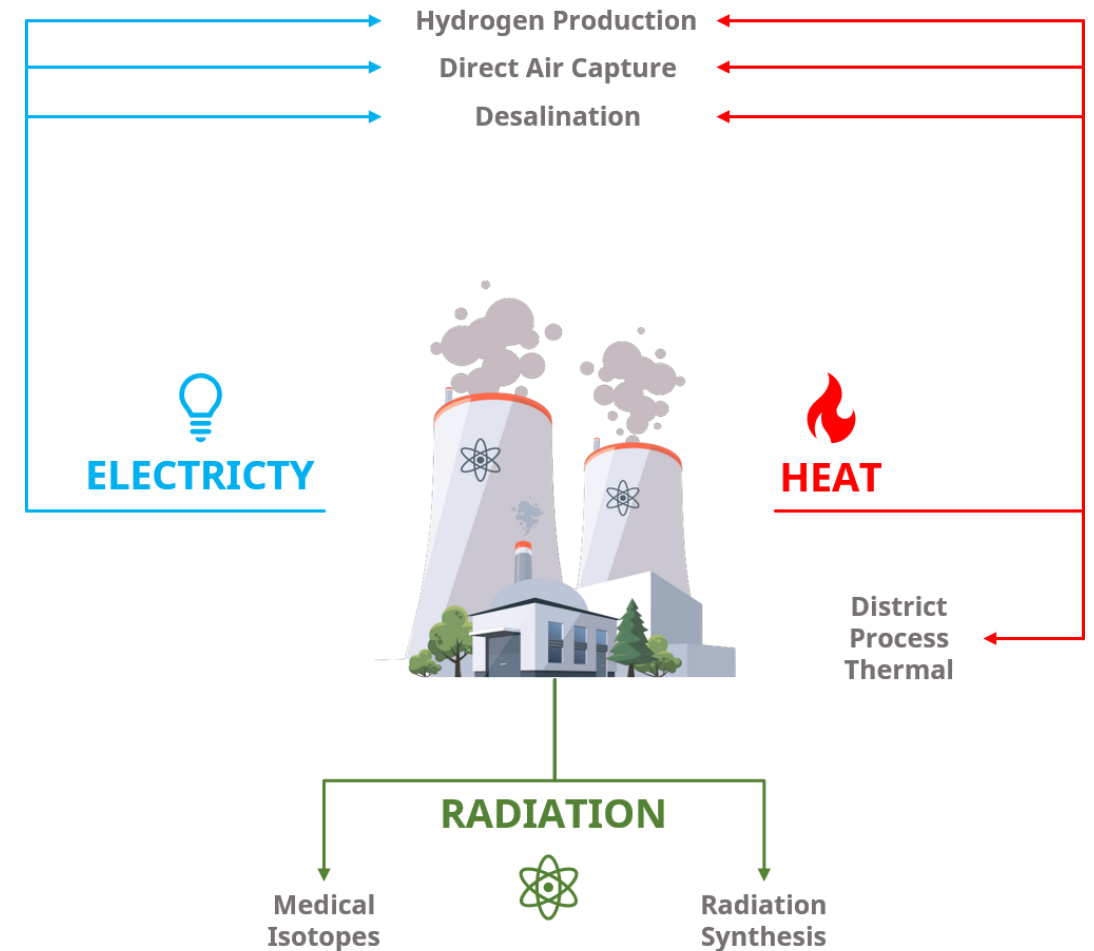
SMR & MMR | Co-Generation

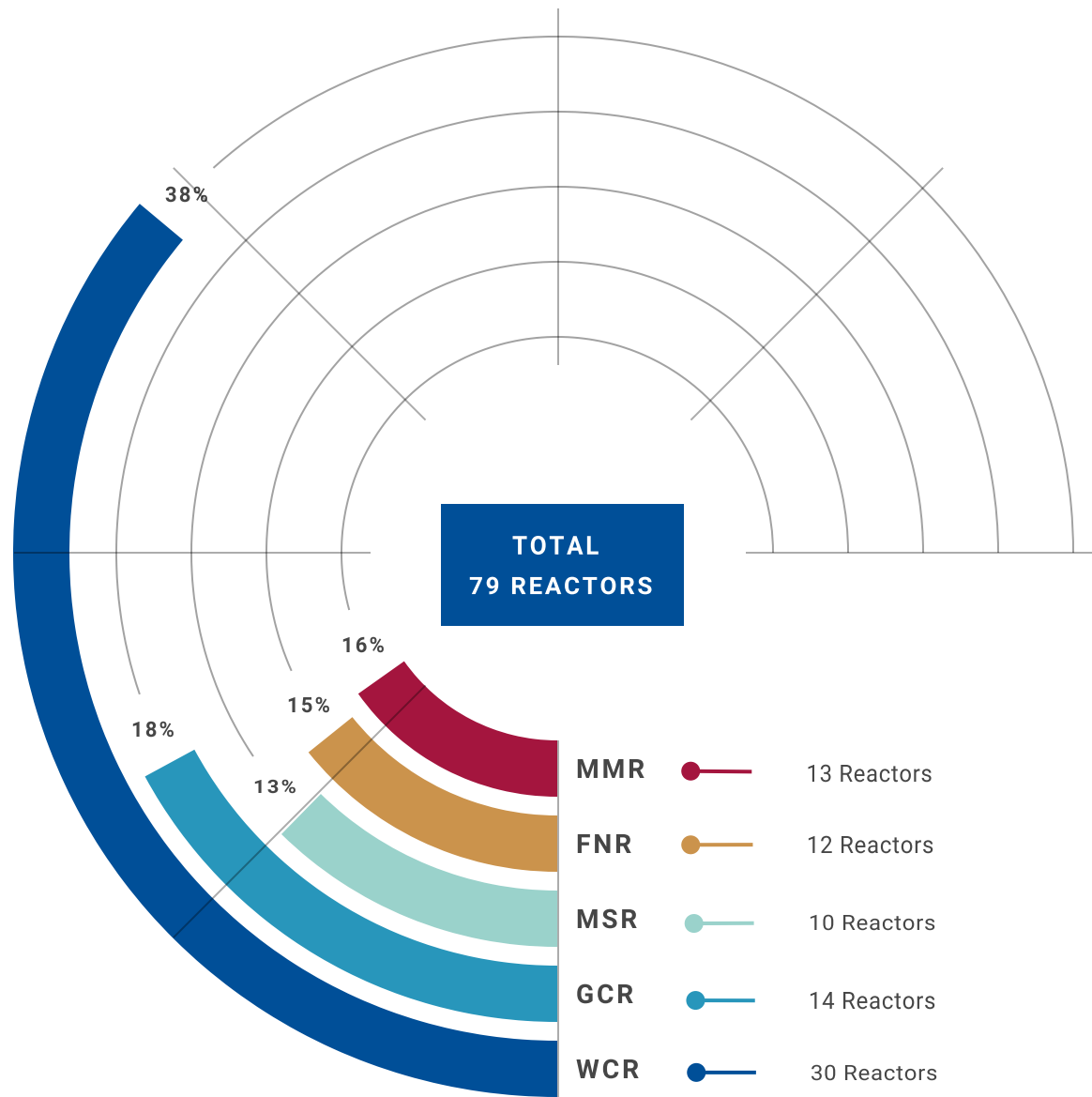
NUCLEAR CO-GENERATION

Most of the SMR and MMR designs target a specific niche application other than electricity generation where conventional nuclear power plants would be impractical

Integration of SMRs with other systems and applications is often called “nuclear cogeneration” which has certain economic and environmental advantages

As of January 2022, a total of **79 SMR designs** have been identified with various technology types and stages of designs

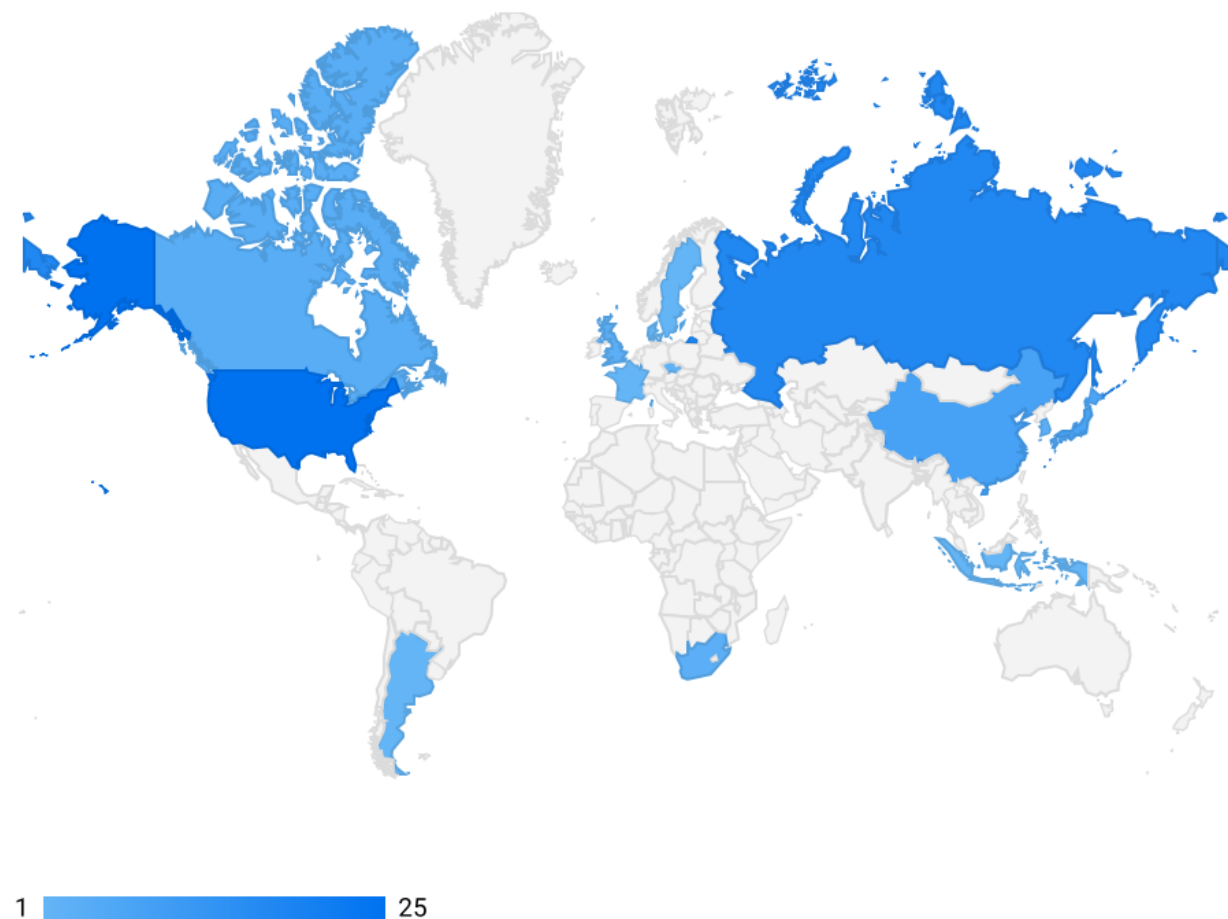
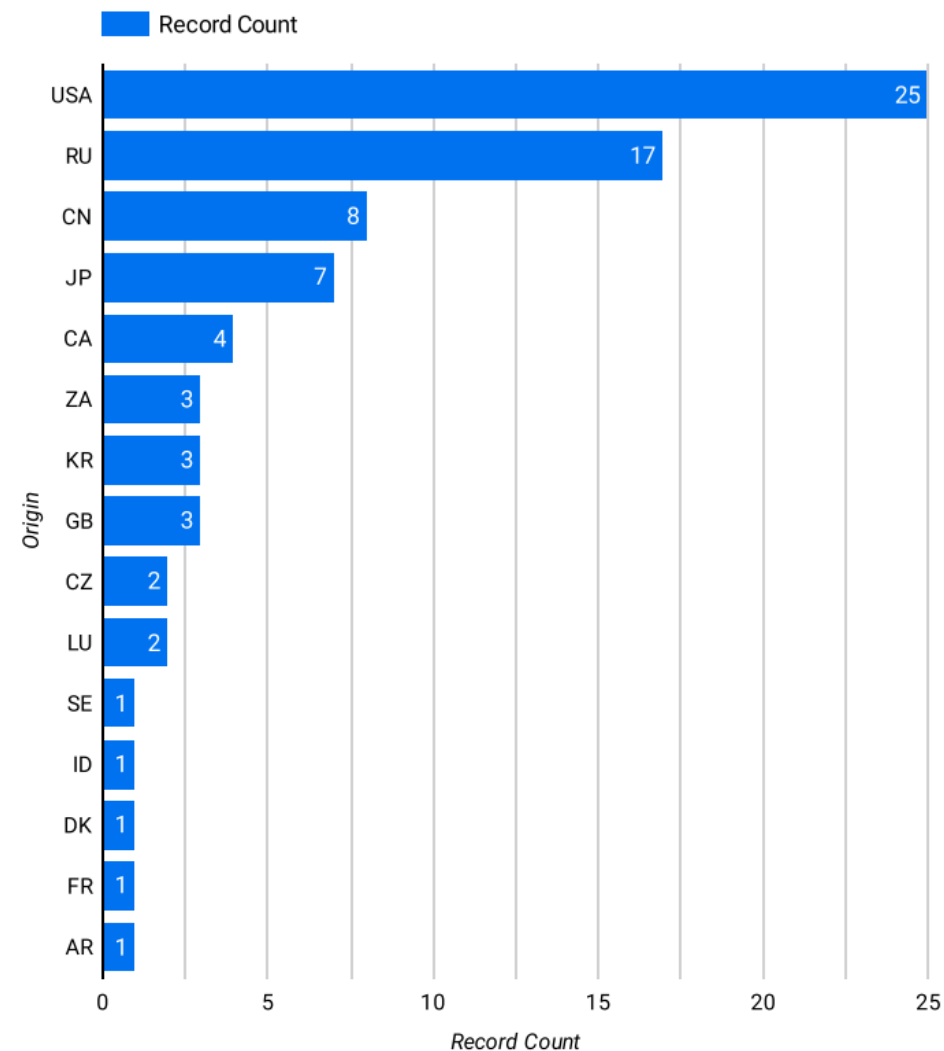




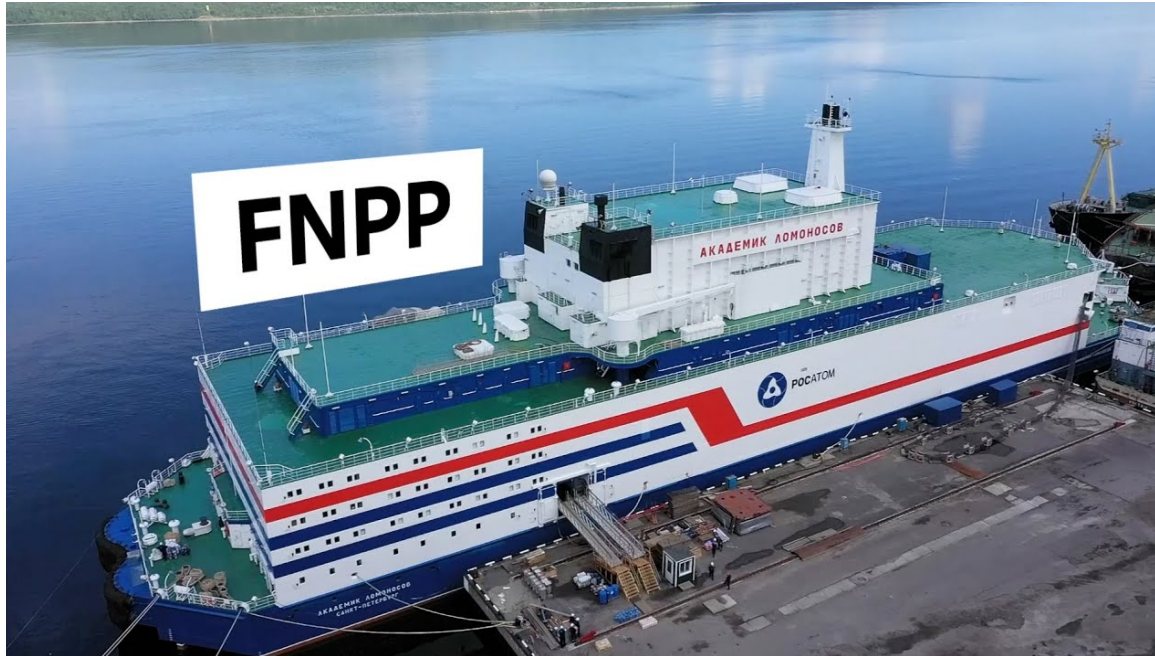
CLASSIFICATION

- **WATER COOLED REACTORS | WCR**
 - Light Water Cooled Reactors | LWR
 - Heavy Water Cooled Reactors | HWR
- **GAS COOLED REACTORS | GCR**
- **MOLTEN SALT REACTORS | MSR**
- **FAST NEUTRON REACTORS | FNR**
- **MICRO MODULAR REACTORS | MMR**

SMR & MMR | Country of Origin



SMR & MMR | Notable Mentions



SOURCE

KLT-40S | AKADEMIK LOMONOSOV

The very first floating SMR by Russian Federation based on WCR has been supplying clean energy since May 2020



SOURCE

HTR-PM | HIGH-TEMPERATURE GAS-COOLED REACTOR - PEBBLE-BED MODULE

The very first land-based industrial demonstration SMR by the People's Republic of China was connected to the grid as of December 2021

MMR | Main Features

Microreactors are non-conventional plug-and-play type nuclear reactors that are small, compact and modular



FACTORY BUILT



TRANSPORTABLE



SELF REGULATING

MMR | Attributes



KEY CHARACTERISTICS

- Less than 10 MWe generation of electricity
- Smaller footprint with no carbon emission
- Factory fabrication and on-site installation
- Easy to ship and remove
- Self-reliance with inherent safety
- Easier semi-autonomous operation
- Quick deploy-ability during emergency
- Years of operation with no re-fueling
- Easy integration with other applications



POTENTIAL USE CASES

- Remote and rural communities, islands
- Remote mining sites
- Military installations
- Power plant back-up and emergency generations
- Disaster relief and humanitarian assistance missions, load shedding
- Space missions, marine propulsion

MMR | History



1960

The U.S. Army examined MNPPs with vSMR



2011

DoD concluded reactors <300 MWe have potential but many were larger than needed



2027

The first DoD reactor is projected to be online



1963

8 reactors were built for testing, training, and proof-of-concept purposes



2019

Microreactor designs have emerged <20MWth



MMR | Involved Organizations & Initiations

- **THE DEPARTMENT OF DEFENSE (DOD) COLLABORATES WITH THE DEPARTMENT OF ENERGY (DOE)**

- The DOE Microreactor Program to enable successful demonstrations of multiple commercial microreactors

- **IDAHO NATIONAL LABORATORY (INL) IS THE LEAD NATIONAL LABORATORY TOGETHER WITH**

- Los Alamos National Laboratory (LANL)
- Oak Ridge National Laboratory (ONL)
- Argonne National Laboratory (ANL)
- Pacific Northwest National Laboratory (PNNL)

- **INDUSTRY ENGAGEMENT AND OUTREACH FOR THE PROGRAM**

- Gateway for Accelerated Innovation in Nuclear (GAIN)

- **INITIAL DEPLOYMENT OF MICROREACTORS BY DOE**

- Advanced Research Projects Agency-Energy (ARPA-E)
- The microreactor technologies below 10 MWe

- **THE U.S. NUCLEAR REGULATORY COMMISSION (NRC)**

- Regulatory framework
- Licensing Issues
- Technology-Inclusive Safety Objectives
- 10 CFR Part 53 “Licensing and Regulation of Advanced Nuclear Reactors”

- **IAEA HELD THEIR FIRST TECHNICAL MEETING (TM) IN APRIL 2021**

- OECD Nuclear Energy Agency
- European Commission

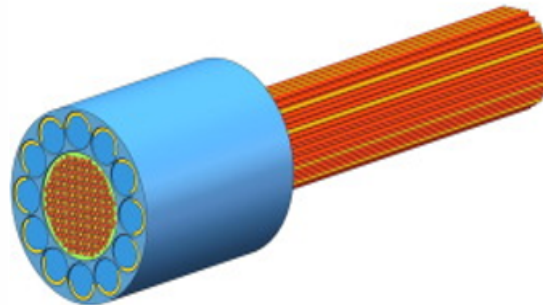
MMR | Heat Pipe

Passive Two-Phase Heat Exchanger

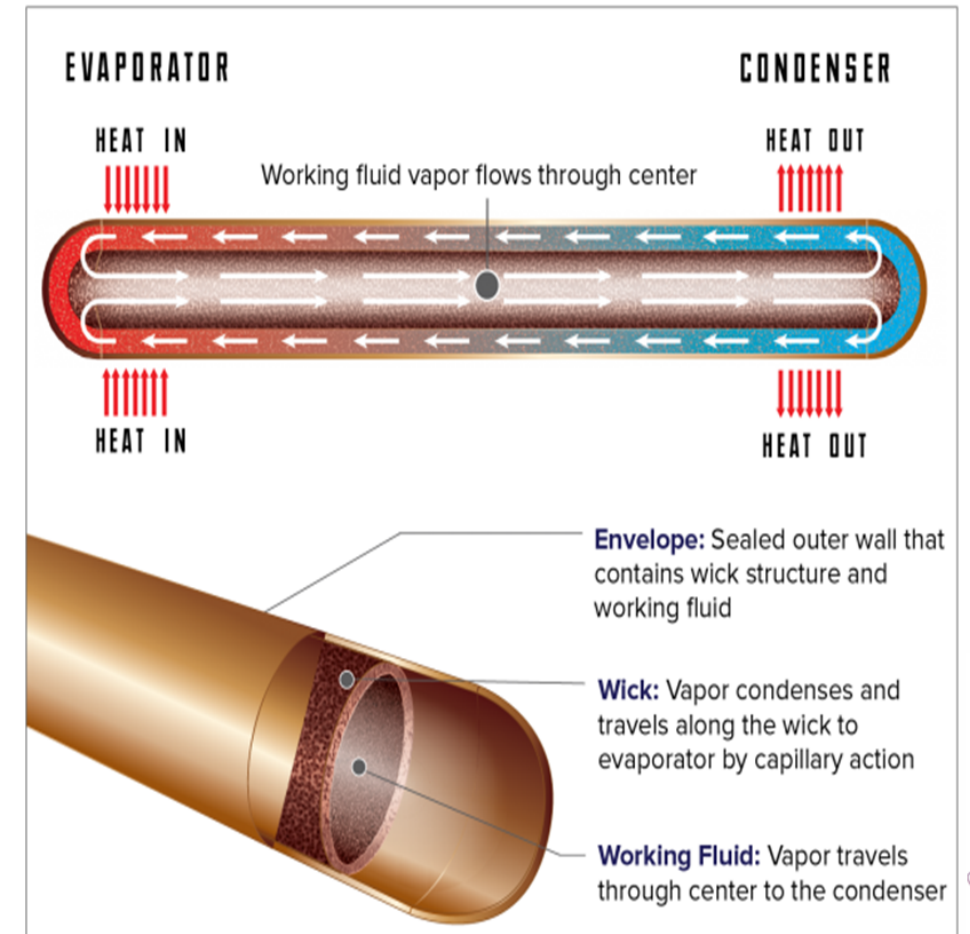
- Invented at LANL in 1963 and analogous to natural circulation loop
- Large heat transfer capability with small temperature difference
- Excellent effective thermal conductivity
- Application Areas
 - Electronics
 - Space
 - Ovens and HVAC
 - Solar, geothermal power

Nuclear microreactors

(KiloPower Program, MegaPower Reactor, SPR)



Yan et. al., 2020



MMR | TRISO & Project PELE

TRi-structural ISOtropic [TRISO] Particle Fuel

- Originally developed to be used in HTGRs in the 1950s
- The particle has its own “containment building” due to triple coated layers which retains the fission products under all operating conditions
- DoE’s conventional particles have fuel kernel composed of UO₂ and UCO

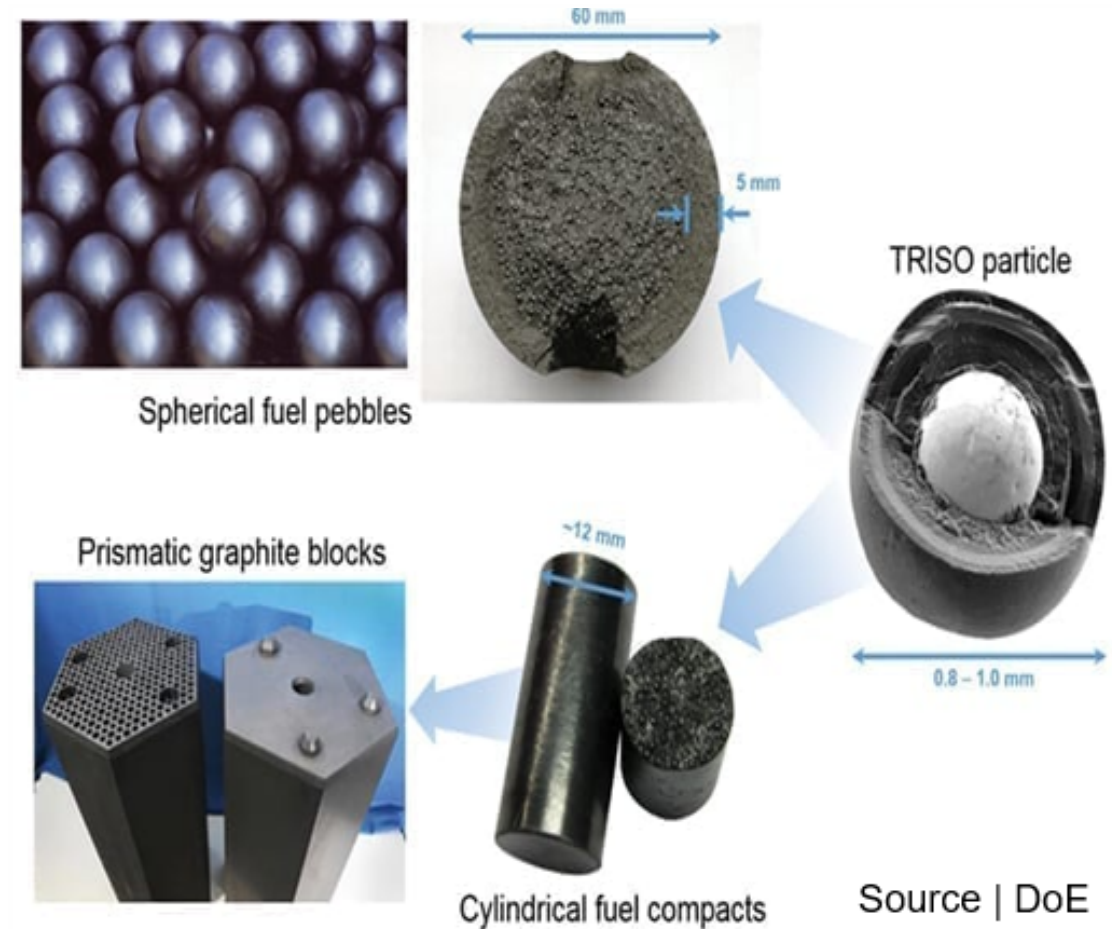
Project PELE by DoD (March, 2020 kick-off)

- Two-years competition to design TRISO
- 1-5 MWe, 3+ years lifetime, HALEU fuel, inherently safe
- <40 tons, transportable in a C-17 and by truck
- Assembled in <3 days, disassembled/transportable in <7 days
- Minimally operated, black-start capable
- Minimal proliferation/safety risks
- \$63 million (2020) and \$70 million (2021)

BWXT Advanced Technologies LLC | \$13.5 million

X-energy LLC | \$14.5 million (\$2.5 billion for XE-100)

Final design review in early 2022



Source | DoE



US Air Force confirms site for first microreactor

“The US Air Force has confirmed the Eielson base in Alaska as the facility planned to host its first small nuclear power plant. A microreactor of up to 5 MWe could be operational there as soon as 2027, according to Eielson.” - WNN, 26 October 2021

MMR | Ongoing Research in South Korea



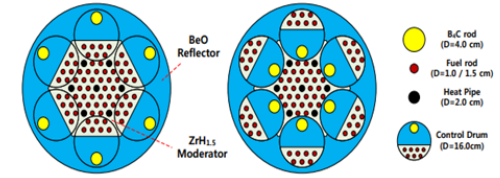
Korea Atomic Energy Research Institute | KAERI

- **Core Design and Heat Transport**
 - Design core geometry, Heat pipe and heat transport code
- **Hybrid Wick Design for Bended Heat Pipe**
 - Heat pipe design code, Novel design for a bendable heat pipe
- **Heat Pipe Thermal Performance Test**
 - Sodium heat pipe, Water heat pipe
- **Concept of Stirling Engine**

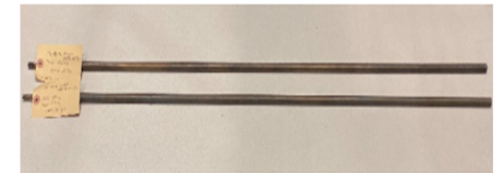


Seoul National University | SNU

- **Nuclear Battery for Underwater Drone | ESLAB**
 - Sodium heat pipe, Thermo-electric generator
- **Heat Pipe Reactor Research | NUTHEL**
 - Multiphysics simulation for a micro reactor core



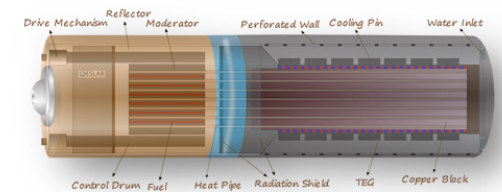
Hoon et. al., 2019



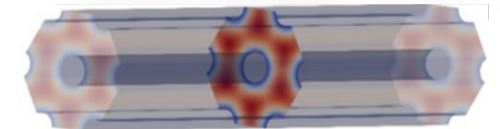
Park et. al., 2021



Hong et. al., 2021



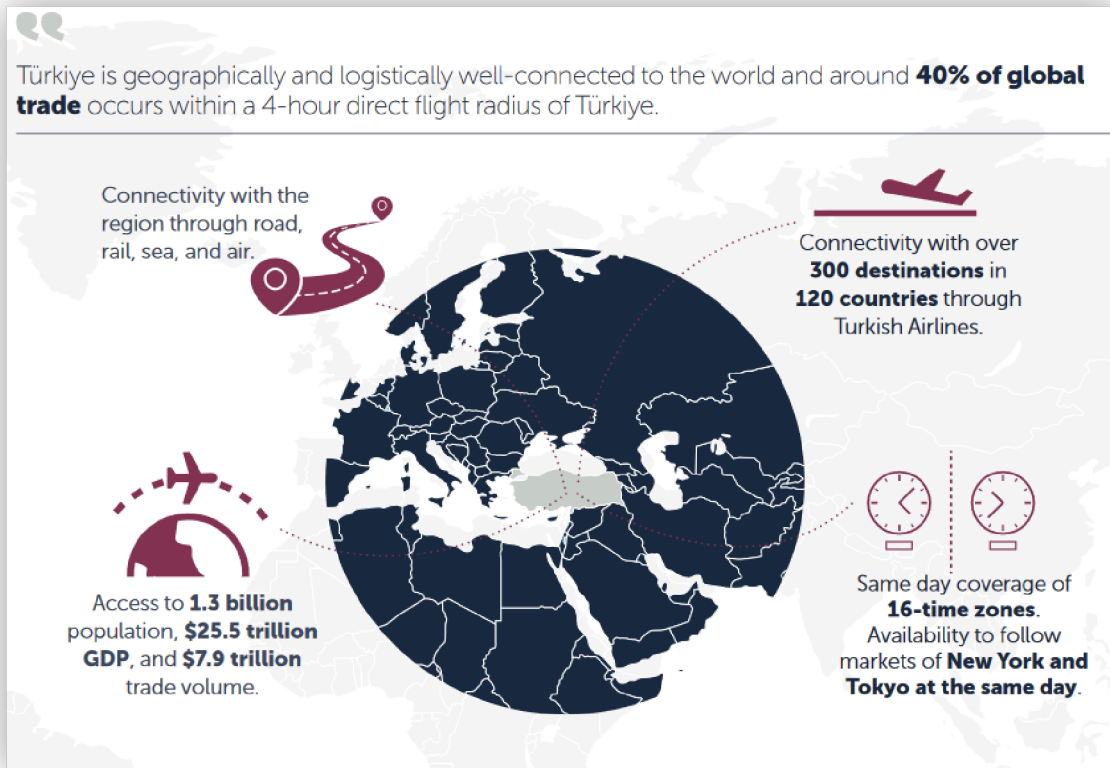
snueslab.com



Cho et. al., 2021

Türkiye | At a Glance

- Turkey's economic and population growth has increased demand for energy and natural resources
- Since 2002, it has experienced the fastest growth in the OECD, with an annual growth rate of 5.5 percent



11%
GDP growth
(2021)

5.5%
GDP growth
(CAGR, 2002-2021)

11th
Largest economy in the world
(GDP at PPP, 2020)

\$225.4 billion
Exports
(2021)



\$803 billion
GDP at current prices
(2021)

84.68 million
Population
(2021)

1st
Fastest growing economy
in the G20, OECD, and the
EU in 2021

76,737
Companies with
international capital
(2021)

33.1
Average age of population
(2021)

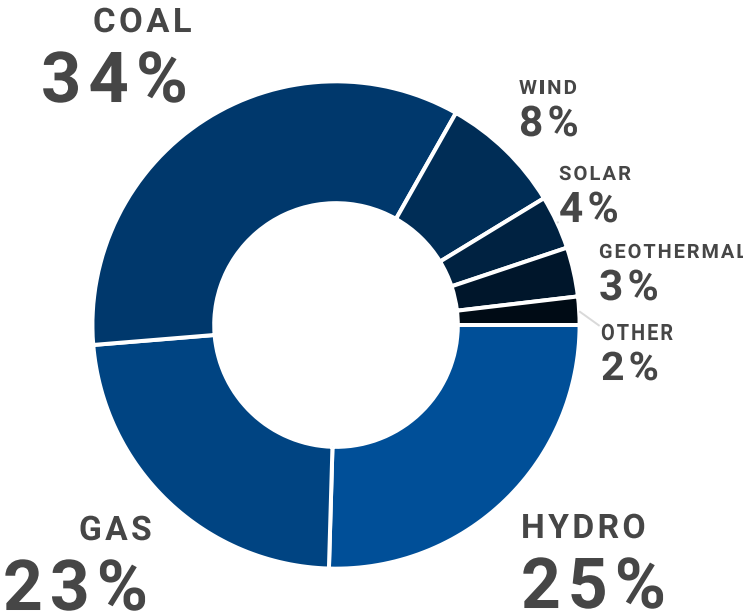
Over
1.1 million
University graduates
(2019-2020)

\$239 billion
FDI inflows
(2003-2021)

© INVEST IN TÜRKİYE

Türkiye | Energy

- The total installed capacity increased from 31.8 GW to 95.9 GW in 18 years
- By 2023, capacity is expected to reach 125 GW



Being a high-profile OECD country in terms of energy demand, Türkiye has created a solid action plan to achieve a smooth transition to **self-sufficiency**, robustness, **diversification**, supply security, competitiveness and environment-friendly energy.

Türkiye's first-ever drillships set sail on a drilling mission, eventually discovering proven reserves of **540 billion cubic meters of natural gas** in total in the Black Sea.

The first Turkish-flagged FSRU, **BOTAŞ Ertuğrul Gazı**, was commissioned in June 2021.

Out of **\$225 billion** FDI, attracted between 2003 and 2020, **\$18.2 billion** was solely channeled into the energy sector.

42.4% Share of renewable energy in total electricity production (2020).

Total Installed Capacity in Türkiye

2002 **31.8GW**

2020 **95.9GW**

30.98 GW
Türkiye's installed hydro power capacity as of 2020.

8.83 GW
Türkiye's installed wind power capacity as of 2020.

6.66 GW
Türkiye's installed solar power capacity as of 2020.

Türkiye's Rank in Europe (2020)

5th largest electricity market
5th in energy consumption
4th in gas consumption

\$11 billion
Investments to be made by 2023 within the scope of the National Energy Efficiency Action Plan.

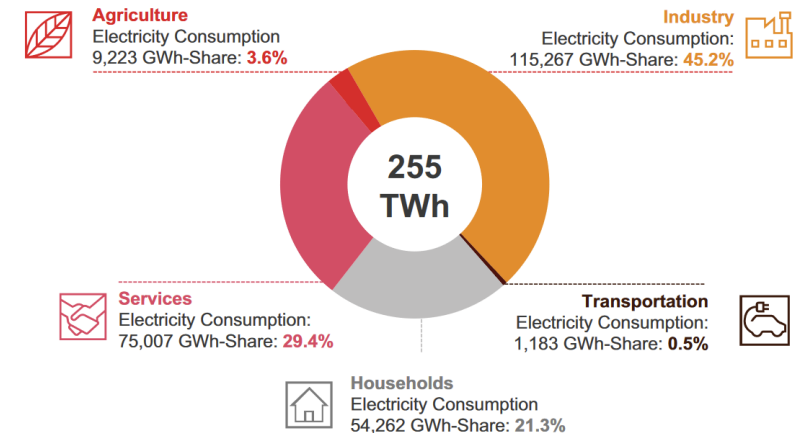
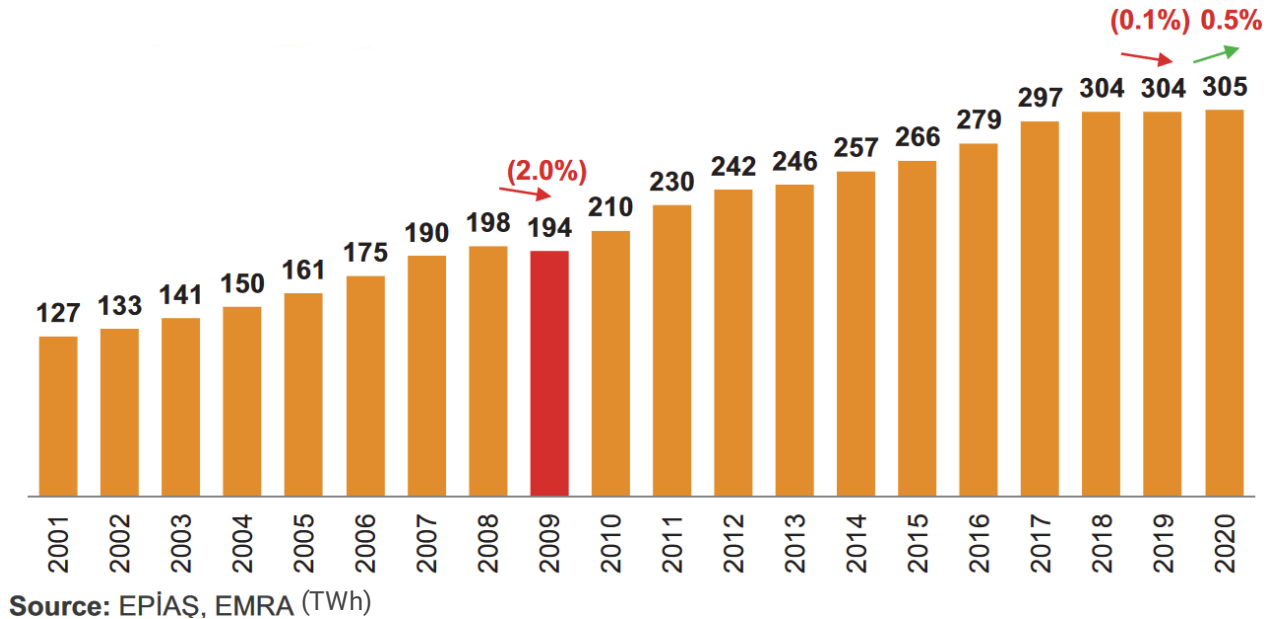
5.5% Annual growth rate of energy demand in Türkiye since 2002.

75% Share of private sector in power generation as of 2020.

4th Türkiye's rank in global geothermal power generation capacity in 2020.

Turkiye | Electricity Demand

- Consumption in the Turkish electricity market grew rapidly until the end of 2011. In 2019 and 2020 electricity consumption remained flat, mostly due to Covid-19 in 2020
- Net demand in Türkiye comes mostly from industrial production, which accounted for 45.2% of total demand in 2019 and grew by 3.8% on average annually between 2007 and 2019
- The specific demand for the transportation and agriculture sectors grew in a manner comparable to overall demand growth between 2007 and 2018, maintaining the same share of the energy balance throughout this period
- The Covid-19 outbreak resulted in decreased electricity consumption in Turkey, particularly in April and May. Demand has recovered quickly, with consumption in June reaching pre-pandemic levels

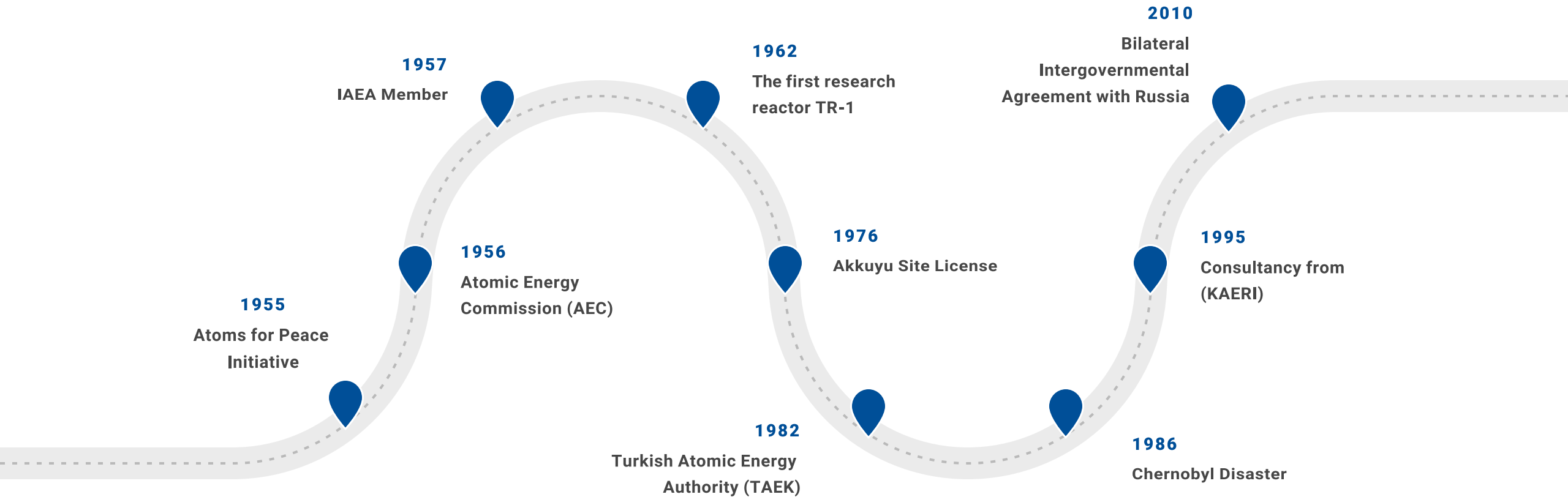


Turkiye | Baseload NPP Sites



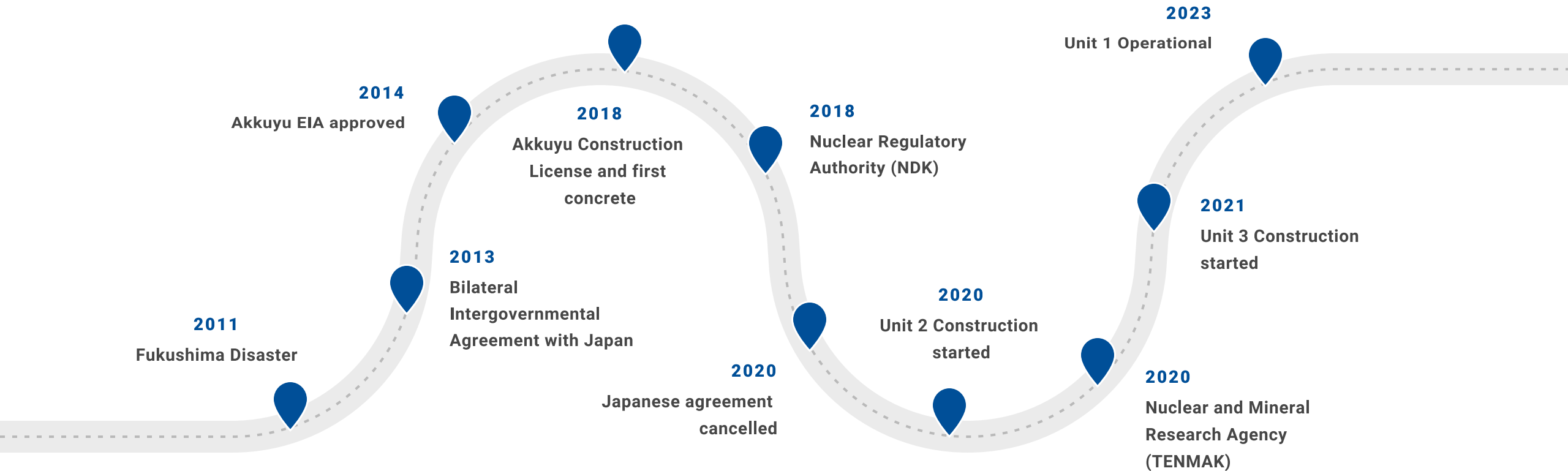
Turkiye | Nuclear History 1/2

Since the 1960s, there have been six major attempts to build a nuclear power plant, each lasting roughly a decade

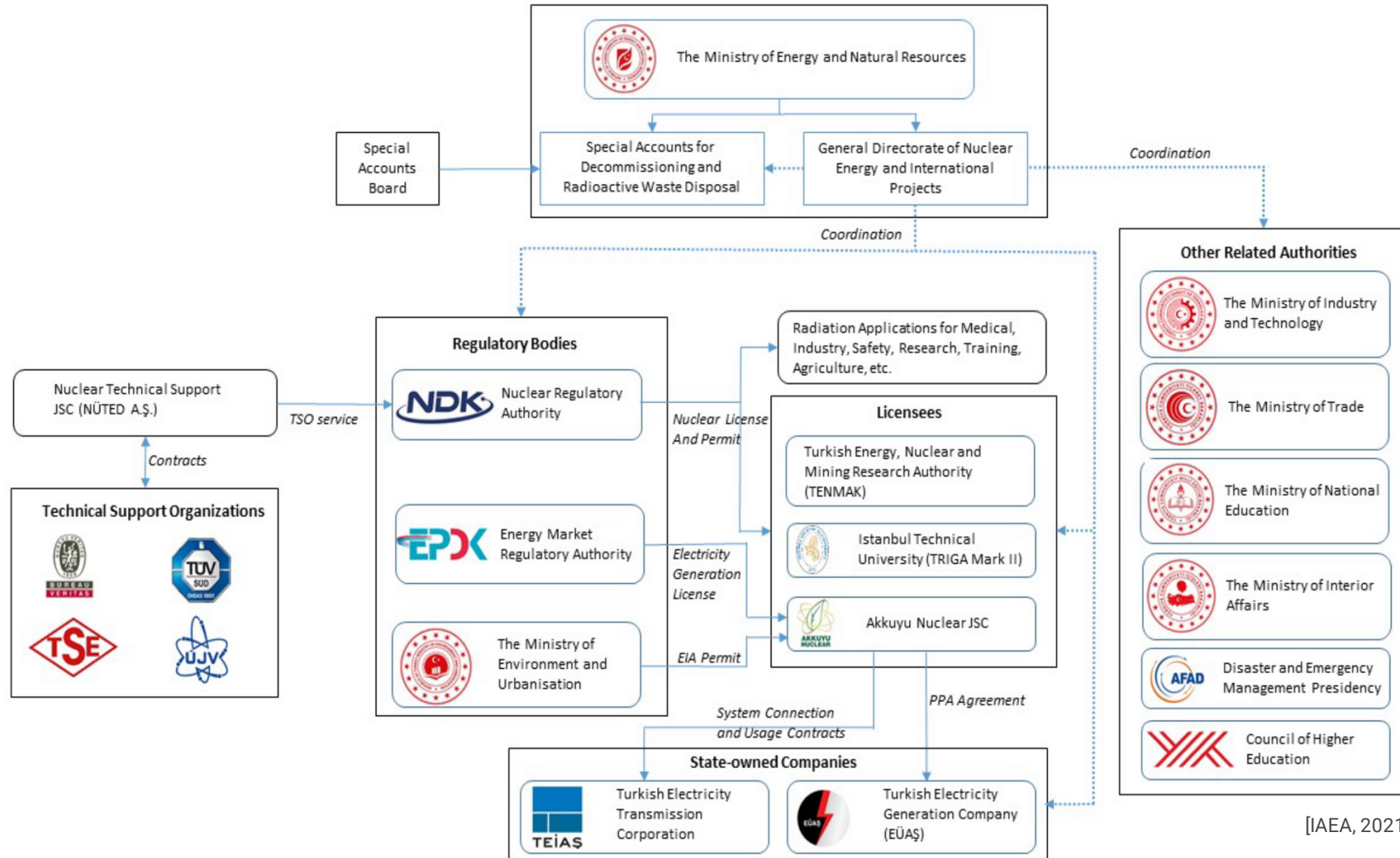


Turkiye | Nuclear History 2/2

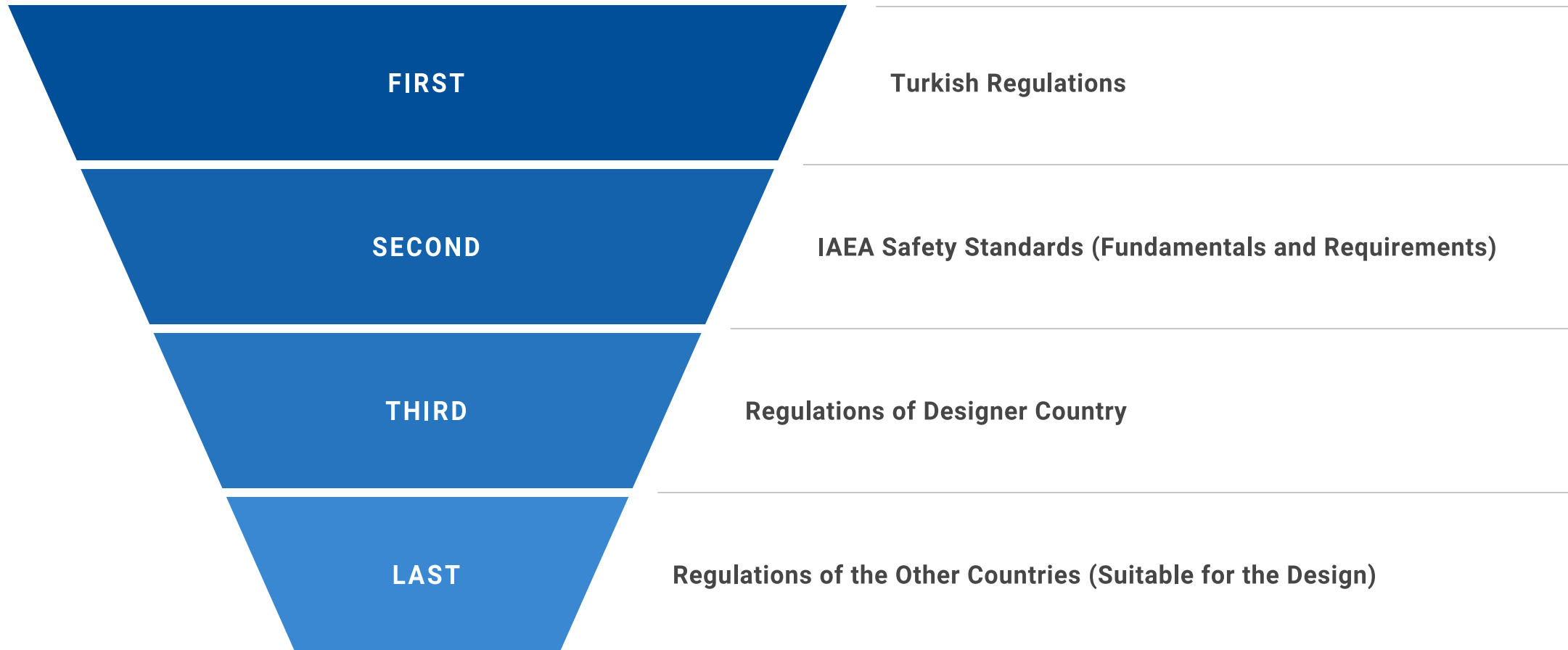
Since the 1960s, there have been six major attempts to build a nuclear power plant, each lasting roughly a decade



Turkiye | Governmental and Organizational Infrastructure



Turkiye | Regulatory Framework



Turkiye | Licensing Process



Licensing Basis

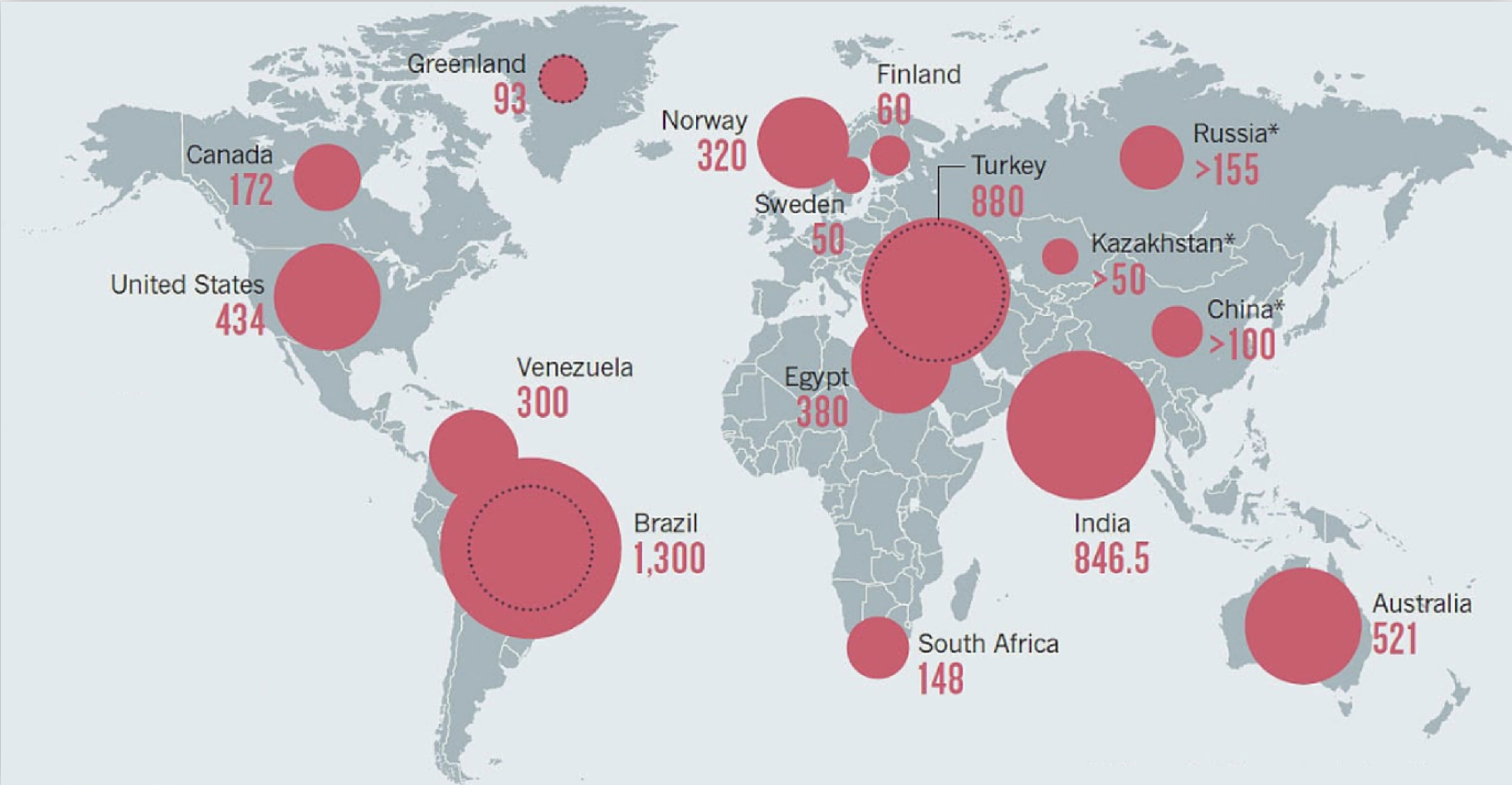
- DETERMINATION OF LICENSING BASIS AT THE BEGINNING OF LICENSING PROCESS
- UTILIZATION OF IAEA REQUIREMENTS AND VENDOR COUNTRY REGULATIONS IN LICENSING



Reference Plant

- PROPOSAL OF A SIMILAR DESIGN AS REFERENCE PLANT
- SUBMISSION OF RELEVANT SAFETY ANALYSES AND EVALUATION REPORTS TO FACILITATE THE ASSESSMENT OF NDK

Turkiye | Thorium Deposits



[IAEA]

Turkiye | SMR Activities

ASO NUKSAK - Umbrella Organization



- Within the Clustering Support Program of the Ministry of Industry and Technology of Turkey, ASO NUKSAK was established in 2016
- Main activities are complex analyses, nuclear quality management, and certification systems, consultancies, research technology training specific to the nuclear sector, R&D studies for stainless steel and infrastructure activities for the technical support organization
- ASO NUKSAK's network is comprised of various chambers, universities, and about 75 companies in Turkey
- **ASO NUKSAK is planning to build an R&D Center for MSR activities**

Turkiye | SMR Activities



EUAS International ICC

EUAS INTERNATIONAL ICC - Prospective Utility

- Established in 2015 by the Council of Ministers resolution with the vision of transferring new technologies in the nuclear field to Turkey
- Commenced its activities in September 2016
- The main target of EUAS International ICC is to realize nuclear power plant new build projects in international partnerships, developing a domestic nuclear supply chain and a local human capital in the quality and quantity capable of meeting the needs of the projects
- While EUAS International ICC is solely responsible for the planning phase of new nuclear power plants, it will share the responsibility during the development, construction and operation phases with its international partners
- **Rolls-Royce and EUAS International ICC have signed an MoU to carry out a study to evaluate both the technical, economical and legal applicability; and also the possibility of joint production of compact nuclear power stations (SMR) to underpin clean economic growth**

Turkiye | SMR Activities

FİGES A.Ş. - Private Company



- Pioneering engineering company of Turkey, was founded in 1990 to introduce, teach, and implement the simulation-based advanced engineering techniques in Turkey
- Developing a domestic Molten Salt Reactor design, performing technical support services in the field of nuclear technology, and separating Rare Earth Elements, focusing on producing radiopharmaceutical medication
- FİGES is taking the necessary steps to be authorized as a Technical Support Organization (TSO) to support the nuclear safety and licensing works of the regulatory body in Türkiye
- Collaboration has been initiated with the Germany Reactor Safety authority

Turkiye | SMR Activities

ASELSAN - Defense Electronics Company

aselsan

- ASELSAN is the largest defense electronics company in Turkey established in 1975
- The company is one of the top 50 defense companies in the world, with the Turkish Armed Forces owning three-quarters of the stock and the rest traded on the Istanbul Borsa stock exchange
- The company has over 8,000 employees working in various fields of activities including energy
- The company received more than 2 billion USD of new business in 2021 and the backlog stood at 8.5 billion USD by the end of 2021
- **FNC Technology signed a contract with ASELSAN to perform Small and Micro Modular Reactor Technology Analyses**

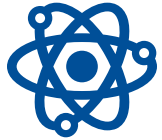
ASELSAN | Project Development

Purchase Order Date: 2021.12.20

ITEM #	DELIVERABLE	CONTENT
1	SMR/MMR WP #1	Literature and Technology Review
2	SMR/MMR WP #2	Technical Feasibility Analysis
3	SMR/MMR WP #3	Commercial Feasibility Analysis

Final Remarks

South Korea's nuclear sector can benefit more in emerging markets!



ENGINEERING & IMPLEMENTATION

- Safety assessment
- Design modification
- Inspection and test
- 3rd party review



OPERATION & MAINTENANCE

- Procedures preparation
- Guidelines improvements
- Project Management
- Customized Services



VALIDATION & VERIFICATION

- Design
- Implementation
- Installation
- Software V&V



RESEARCH & DEVELOPMENT

- Consultation
- Regulatory Support
- Licensing Support
- Training



한수원-협력사 동반성장을 위한

'Atom Pioneers! 나가자! 세계로!' 터키시장개척단

TURKEY-KOREA, Let's Go Together

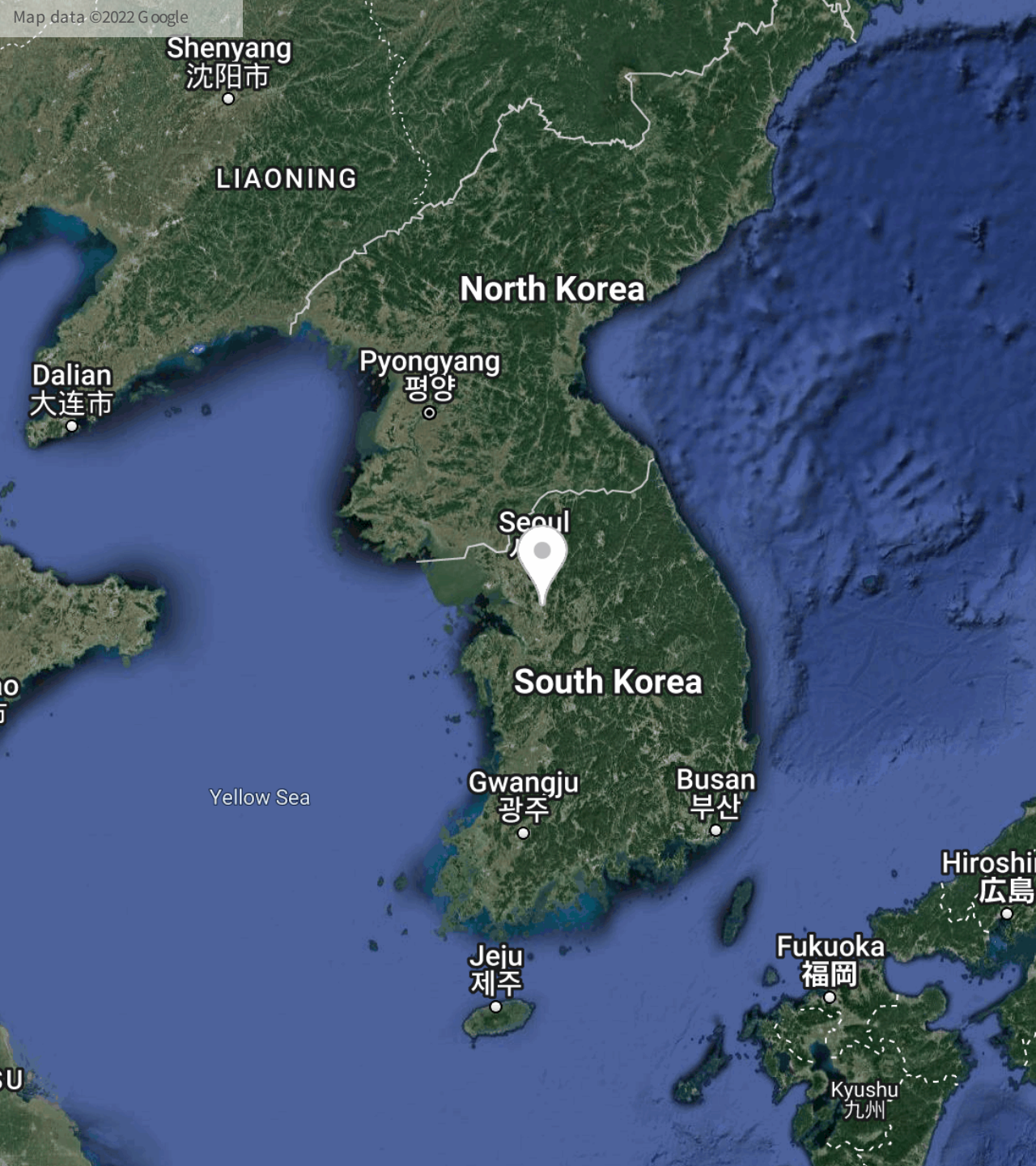
2019. 03. 08 Istanbul

KOEMA

JAHOON CHUNG
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Turkish Atomic Energy Authority

NURETTIN ÖZDEBİR
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