La Sapienza
Università degli Studi di Roma

MARS ©

MULTIPURPOSE ADVANCED REACTOR INHERENTLY-SAFE

Potential penetration in the European Market: An analysis with MARKAL model

Maurizio Cumo, Federico Santi

International Energy Workshop 2004
Paris – June 24, 2004

1

La Sapienza
Università degli Studi di Roma

The Future of Nuclear Power

1000 GW new capacity by 2050 to keep nuclear power at the current share (17%) in the electricity market

21th Century Challenges for Nuclear Power

Cost: Long lifetime and modular, low-cost construction

Safety: Adverse Public perception

Waste: Management of long-term nuclear waste

Proliferation: Potential Security risk

The Future of Nuclear Power – An interdisciplinary MIT study

2

La Sapienza
Università degli Studi di Roma

MARS ©

Multipurpose Advanced Reactor Inherently Safe

A small-size, inherently-safe Pressurized Water Reactor developed from 1983 at the University of Rome in collaboration with other Italian and international organizations

- Combined heat and power, and drinkable water production
- Low investment cost
- Short construction time
- Modularity for in-shop construction and on-site assembling
- Minimum waste production
- Low radiological dose
- Easy decommissioning

3

La Sapienza
Università degli Studi di Roma

MARS © Safety Features

- IN-DEPTH DEFENSE AGAINST RADIOLOGICAL HAZARD FOR PERSONNEL AND POPULATION
- CAPABILITY TO MANAGE WITH EVEN SEVERE ACCIDENTS WITH NO RISK AND IMPACT ON POPULATION AND ENVIRONMENT
- RELIANCE ON PHYSICAL LAWS FOR ACTIVE INTERVENTION ("INHERENT AND PASSIVE SAFETY") IN FAULTED OPERATING CONDITION
- NO SENSITIVITY TO HUMAN ERRORS
- EXTREMELY LIMITED PRODUCTION OF NUCLEAR WASTE
- NEGLIGIBLE DOSE TO PERSONNEL

4

La Sapienza
Università degli Studi di Roma

MARS © Design Features & Data

- MULTI-PURPOSE UTILIZATION
- PLANT SIMPLICITY
- USE OF PROVEN TECHNOLOGIES
- SHORT CONSTRUCTION TIME
- EASY AND FAST PLANT TESTING
- EASY REMOVAL OF COMPONENTS
- FAST DECOMMISSIONING
- EASY OPERATION AND MAINTENANCE
- REDUCED AND CERTAIN COSTS

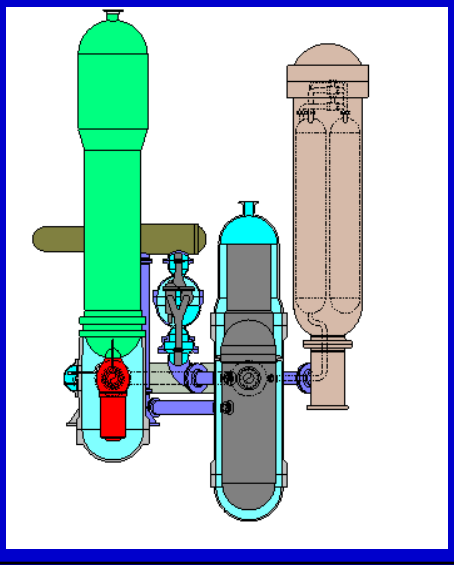
PRESSURIZED LWR WITH SINGLE PRIMARY LOOP

THERMAL POWER	600 MWt
OPERATING PRESSURE	75 bar
COOLANT FLOW-RATE	3227 kg/s
INLET TEMPERATURE	214 °C
OUTLET TEMPERATURE	254 °C
FUEL RODS ARRAY	17x17
FUEL BUNDLES	89
CONTROL ROD CLUSTERS	45

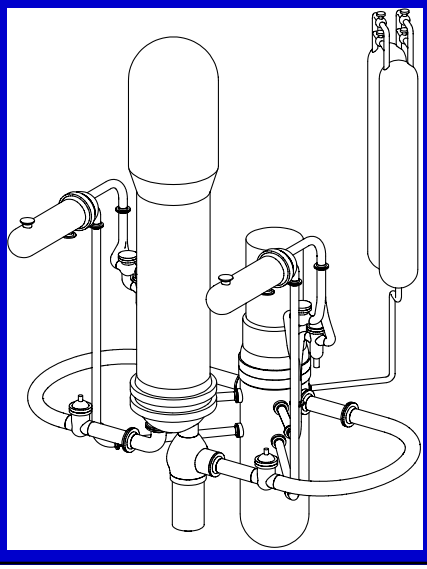
5

La Sapienza
Università degli Studi di Roma

MARS © Pressurized, Double-Containment Primary Loop

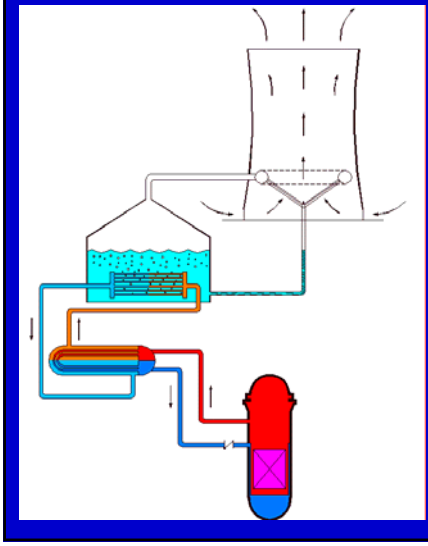


MARS © Passive, Primary Loop Emergency Cooling



La Sapienza
Università degli Studi di Roma

MARS © Passive-Safety Cooling System



SEVERE ACCIDENTS

SEVERE ACCIDENTS
ARE PHYSICALLY IMPOSSIBLE.

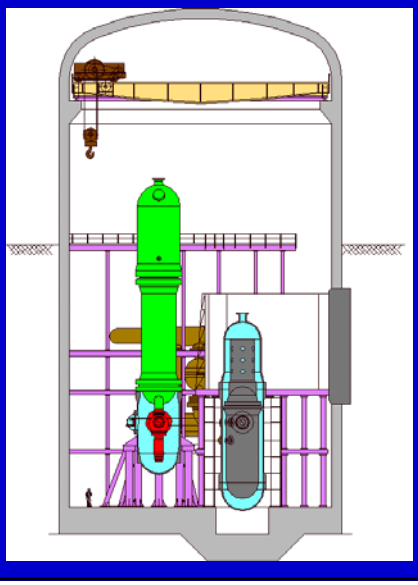
NEVERTHELESS ACCIDENTAL CORE MELTING HAS BEEN CONSIDERED AND THE CORE COOLING ASSURED.

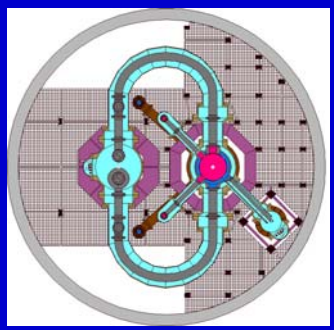
PRESSURIZED WATER
IN PRIMARY LOOP DOUBLE CONTAINMENT MAKES IT POSSIBLE IN-VESSEL COOLING, AND MANAGEMENT OF EVEN SEVERE ACCIDENTS

7

La Sapienza
Università degli Studi di Roma

MARS © Reactor Building





8

La Sapienza
Università degli Studi di Roma

MARS © New Construction Approach

PRESSURIZED CONTAINMENT OF PRINCIPAL COMPONENTS

FLANGED CONNECTIONS FOR PRIMARY LOOP AND COMPONENTS TO EASY ASSEMBLING AND MAINTENANCE

LOCAL GASKET WELDING FOR CIRCUIT LEAK TIGHT

MINIMISE ON-SITE ASSEMBLING OPERATIONS

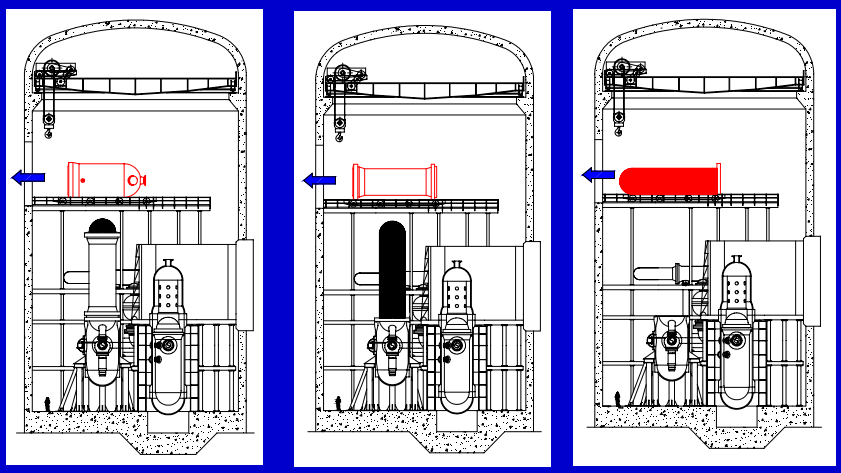
MAXIMIZE IN-SHOP FABRICATION

EASY PLANT DECOMMISSIONING

9

La Sapienza
Università degli Studi di Roma

MARS © Decommissioning (1)

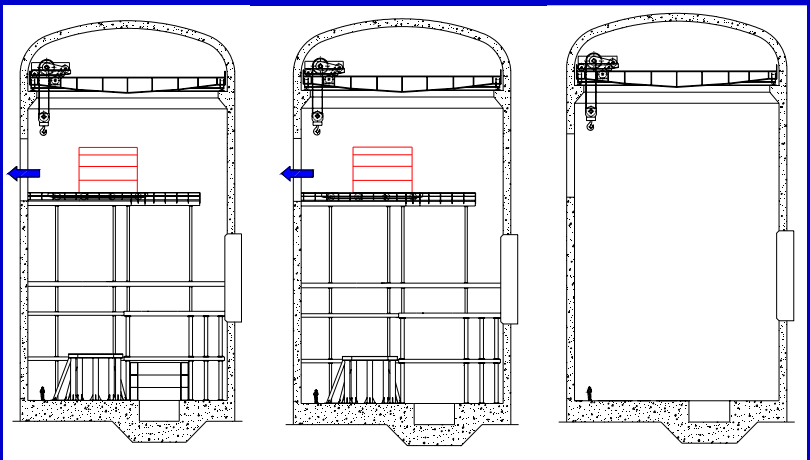


Vessel and Steam Generator Removal

10

La Sapienza
Università degli Studi di Roma

MARS © Decommissioning (2)

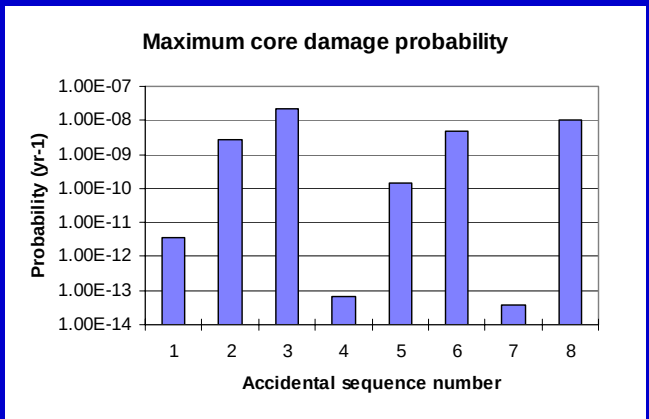


Removal of biological shield and internal structures of the reactor building

11

La Sapienza
Università degli Studi di Roma

MARS © Safety Analysis - Results



1 - Primary pump stop
2 - Relief/safety valves stuck open
3 - S.G. Exchanged power degradation
4 - Loss of on/off site power
5 - Loss of coolant from auxiliary systems
6 - Steam generator tube rupture
7 - Primary pump trip
8 - Steam line break

12

La Sapienza
Università degli Studi di Roma

MARS © Waste Production (m^3/y)

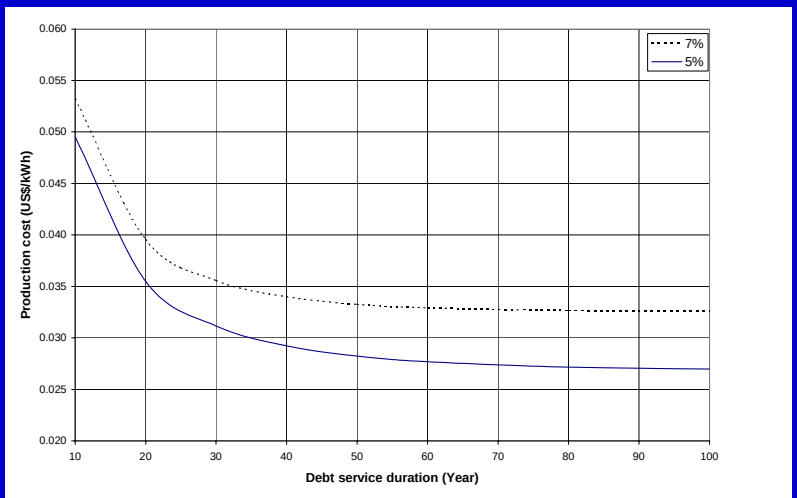
Type	Original production	Waste production after traditional conditioning	Waste production after advanced conditioning	Traditional PWRs with traditional conditioning (same power level)
resins	0.65	1.3(1)	0.05(4)	
filter cartridges	1.7	1.9(1)	0.32(5)	
compactable DAW	7.5	1.4(2)	0.45(5)	
non comp. DAW	0.65	0.7(1)	0.7(5)	
mixed wastes	0.12	0.13(1)	0.13(1)	
chemicals	1	0.5(3)	0.04(6)	
total	**11.62**	**5.93**	**1.69**	**20**

(1) cask filling
(2) low-pressure compacting and cask filling
(3) neutralization and cask filling
(4) incineration and cask filling
(5) high pressure compacting and cask filling
(6) drying and cask filling

13

La Sapienza
Università degli Studi di Roma

MARS © Cost of Electricity ($/kWh)



14

La Sapienza
Università degli Studi di Roma

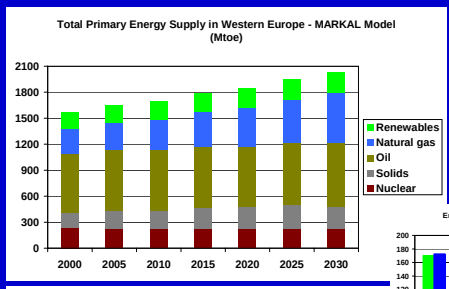
West EU MARKAL-ED Model

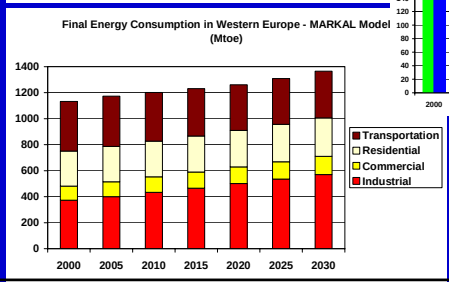
WEU MARKAL Model Geographical Coverage

Austria
Belgium
Denmark
Finland
France [a]
Germany
Gibraltar
Greece
Greenland
Iceland
Ireland
Italy [b]
Luxembourg
Malta
Netherlands
Norway
Portugal
Spain
Sweden
Switzerland [c]
United Kingdom

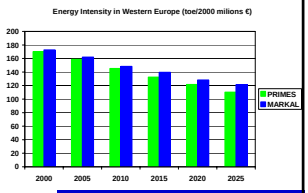
a Includes Monaco
b Includes San Marino and Vatican City
c Includes Liechtenstein

About 75 Mtoe/yr (TPES) more than EU-15





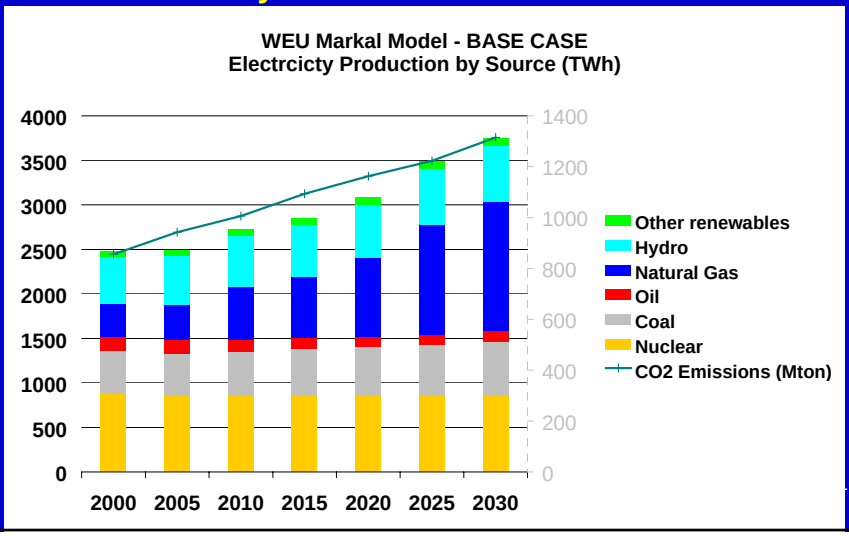
Energy Intensity in the WEU: a comparison between MARKAL and PRIMES



15

La Sapienza
Università degli Studi di Roma

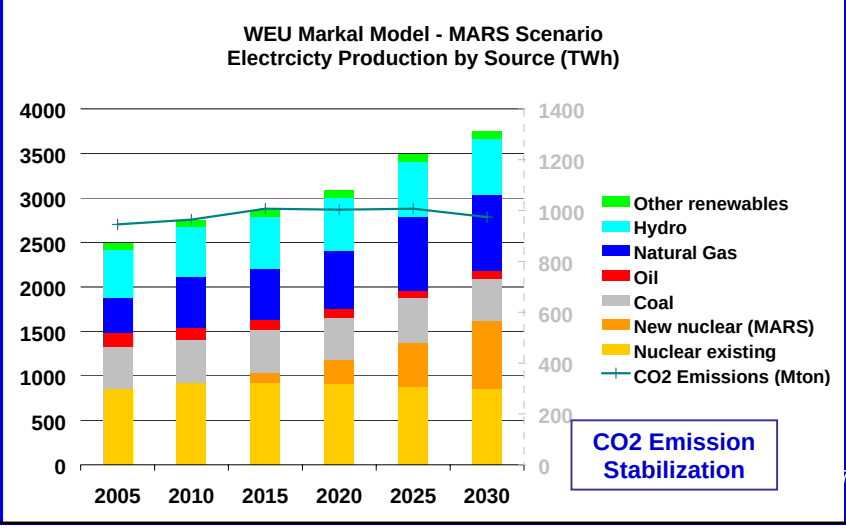
WEU MARKAL-ED Model
BAU Scenario
Electricity Production and CO2 Emissions



16

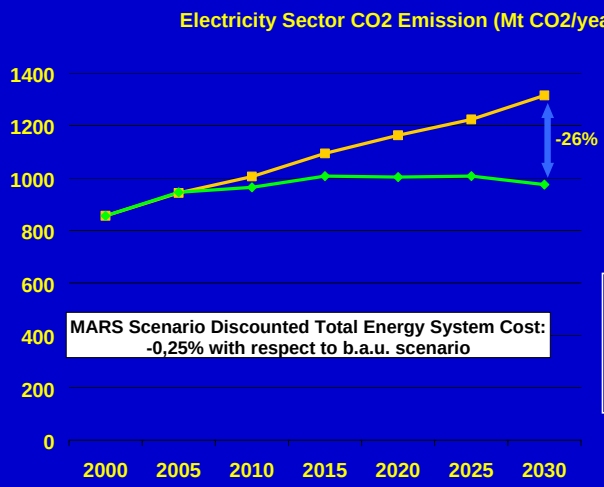
La Sapienza
Università degli Studi di Roma

WEU MARKAL-ED Model
MARS Scenario
Electricity Production and CO2 Emissions



La Sapienza
Università degli Studi di Roma

WEU MARKAL-ED Model
CO2 Emissions and Total Energy System Cost



MARS Technology
=
CO2 Emission Reduction
Negative Cost

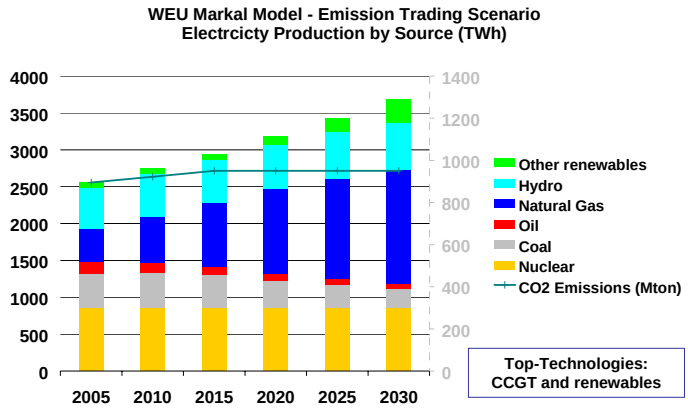
18

La Sapienza
Università degli Studi di Roma

WEU MARKAL-ED Model

MARS vs. CO2 Emission Trading Scenario (1)

CO2 Emission Permits System (Black Certificates)



Top-Technologies:
CCGT and renewables

Power Sector Emission Reduction Target

- 40% in 2030, compared to the b.a.u. Scenario;

+ 11% in 2030, compared to the year 2000 level.

STABILIZATION

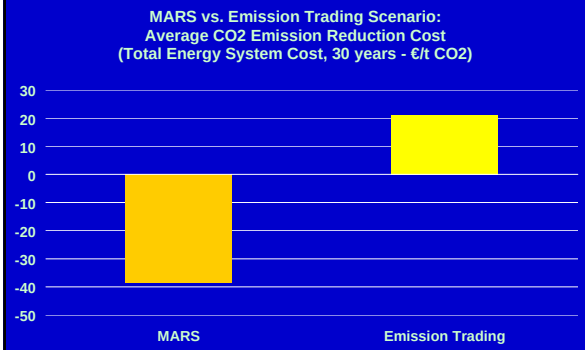
19

La Sapienza
Università degli Studi di Roma

WEU MARKAL-ED Model

MARS vs. CO2 Emission Trading Scenario (2)

The difference between the two CO2 emission reduction options is around 60 €/t CO2, in terms of total (discounted) energy system cost (30 years)



Estimated Emission Permit Price:

25 €/t CO2

To assign Emission Permits to MARS Power Plants: an economic way to stimulate the construction of MARS first movers

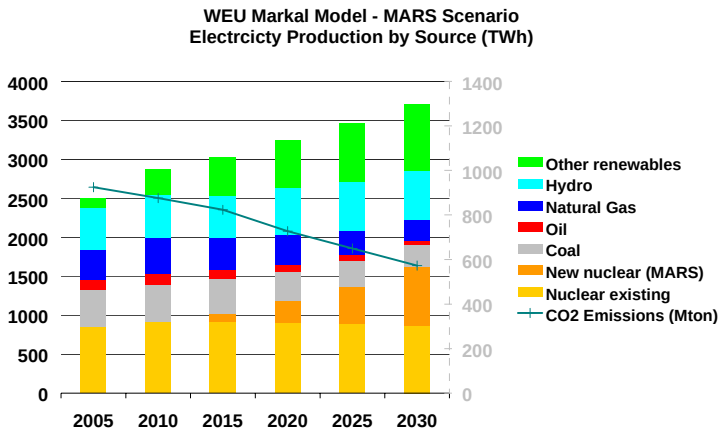
20

La Sapienza
Università degli Studi di Roma

WEU MARKAL-ED Model

MARS + Renewables: a Low-Carbon Western European Energy System

Renewable Energy Obligation (Green Certificates)



Total Electricity Production from Non-Hydro Renewable Energy Sources:

10% in 2010 (EU Directive target);

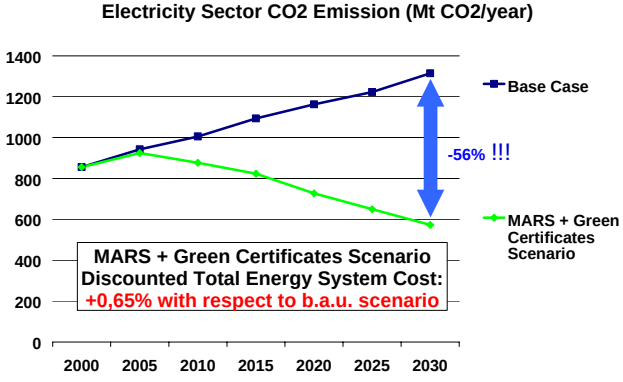
20% in 2030 (assumption).

La Sapienza
Università degli Studi di Roma

WEU MARKAL-ED Model

MARS + Renewables: a Low-Carbon Western European Energy System

only MARS:	CO2: – 26%;	tot cost: – 0,25%;	CO2 reduction av. cost: – 39 €/t CO2
only Green Certificates:	CO2: – 30%;	tot cost: + 0,84%;	CO2 reduction av. cost: + 89 €/t CO2
MARS + Green Certificates:	CO2: – 56%;	tot cost: + 0,65%;	CO2 reduction av. cost: + 39 €/t CO2



RES policy already implemented + MARS option = – 56% CO2 emission from power sector in 2030

La Sapienza
Università degli Studi di Roma

MARS © can contribute to the future of nuclear energy

- **Cost:** Lower than other reactor options and competitive with Coal and CCGT
- **Safety:** Inherently safe + incontrovertible safety mechanism (social acceptance)
- **Waste:** Reduced in comparison with other reactor technologies
- **Proliferation:** One-through scheme to controll in/output balance of fuel elements.

23

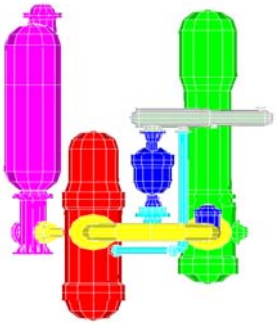
La Sapienza
Università degli Studi di Roma

MARS © can contribute to the future European Union energy system

Security	Reduction of imported oil and natural gas. Low vulnerability to terroristic attack.
Health & Safety	Extremely low radiological hazard. Severe accidents physically impossible.
Economy	Low energy system cost Low power production marginal cost Low volability of the market electricity price
Environment	No pollutants, no GHG emissions no radiological impact, High energy efficiency with CHP

24

La Sapienza
Università degli Studi di Roma



THANKS

25