



LSA Factors and External Costs for ARIES System Code

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Contents

- **Review of LSA factors:**
 - History and definition
 - ARIES approach
 - Impact on COE of ARIES studies.
- **External costs:**
 - Definition and rationale
 - Health and environmental impacts of energy sources
 - Applications to several EU non-fusion energy sources
 - Impact on COE of EU **fusion** studies.
- **Q:** Should external costs be included in ASC along with LSA factors?

LSA History

- **Fission** costing models assumes **nuclear grade** construction with required QA.
- Safety assurance (LSA) factors **originally derived from fission AP600 advanced Westinghouse design**, claiming ~25 % cost reduction from **passive-safety features** and **elimination of some active-safety components**.
- **Cost credits represent:**
 - Savings for **passive safety and simplifications** resulting from **elimination of active safety** system
 - **Reduction in cost of QA requirements**
 - Substitution of **conventional components** for nuclear-safety-grade (N-stamped) components, representing reduction of bulk materials and labor costs
 - Considerations related to **extreme loads** (e.g., seismic, missiles, tornadoes, hurricanes, airplane crash, etc.)
 - **Investment protection** considerations (e.g., no meltdown during severe accident, structural integrity during disruption/VDE/ELMs in fusion, etc.).
- In 1980s, **two sets** of cost reduction factors were developed by **Maya & Schultz** (GA) for inertial fusion and by **Perkins** (LLNL) for magnetic fusion.
- Set of **4 LSA factors** for MFE was defined in **ESECOM study**¹, updated later by **Delene**, and used in Generomak code².
- Standard **PWR** would have **LSA=4** and **coal plant** would have **LSA=1**. **Advanced PWR** with passive safety features may fall into **LSA=3** category.
- Subsequent updates and **detailed breakdown of LSA** factors were issued by **Delene in 1990s** for **advanced fusion power plants**.

¹ J. P. Holdren, *et al.*, “Report of the Senior Committee on Environment, Safety, and Economic Aspects of Magnetic Fusion Energy,” Lawrence Livermore National Laboratory report UCRL-53766 (Sept. 1989).

² J. Delene *et al.*, “GENEROMAK Fusion Physics, Engineering and Costing Model”, ORNL/TM-10728 (1988).



LSA Rationale and Definition

- LSA represents potential cost savings in direct and indirect costs of fusion power plant during construction and operation.
- **Rationale:** Translate attractive safety features into cost savings.
- **Definition:**

LSA = 4
(fission)

Denotes **active protection** (i.e., active engineered safety systems are required); the system does not meet minimum requirements for inherent safety.

LSA = 3
(Adv. fission)

Safety is assured by **passive mechanisms** of release limitation as long as severe violations of small-scale geometry are avoided (e.g., large coolant pipe breaks).

LSA = 2
(ARIES-I,RS,CS)

Safety is assured by **passive mechanisms** as long as severe reconfiguration of large-scale geometry is avoided.

LSA = 1
(Coal &
ARIES-AT)

Safety is assured by **passive mechanisms** of release limitation for any accident sequence; radioactive inventories and material properties preclude fatal release regardless of power plant's condition.



LSA Factors for ARIES Designs

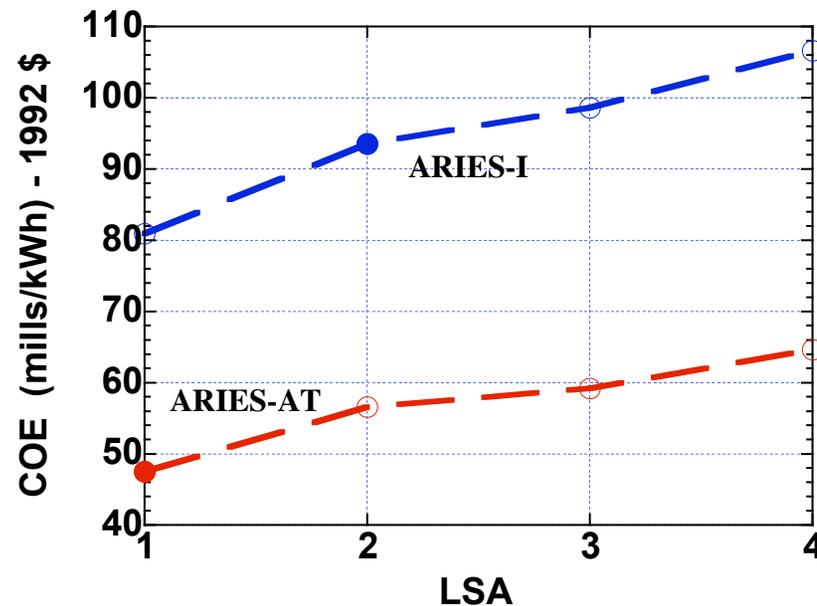
(1997 SPPS report; missing items in table marked in red)

Table 3.2-VIII.

Level of Safety Assurance (LSA) Cost-Credit Factors^(a)

LSA:	1	2	3	4
Primary structure & support	0.85	0.95	0.95	1.0
Blanket ^(b)	0.90	0.95	1.0	1.0
Shield ^(b) / Vacuum Vessel	0.90	0.95	1.0	1.0
Coils ^(b) / Cryostat	0.90	0.95	1.0	1.0
Reactor & hot-cell buildings	0.60	0.90	0.96	1.0
Other structures and improvements	0.60	0.67	0.67	1.0
Heat transfer and transport	(c)	1.0	1.0	1.0
Other Reactor Plant Equipment	0.85	0.94	0.94	1.0
Turbine Plant Equip. & building	1.0	1.0	1.0	1.0
Electrical Plant Equipment	0.75	0.84	0.84	1.0
Miscellaneous Plant Equipment	0.85	0.90	0.93	1.0
Heat reject system	1.0	1.0	1.0	1.0
Land	1.0	1.0	1.0	1.0
All other direct cost areas	1.0	1.0	1.0	1.0
Indirect costs, Acct. No.:				
91. Constr. Ser. & Equip. ^(d)	0.113	0.120	0.128	0.151
92. Home Off. Engr. & Ser. ^(d)	0.052	0.052	0.052	0.052
93. Field Off. Engr. & Ser. ^(d)	0.052	0.060	0.064	0.087
94. Owner's Cost ^(e)	0.150	0.150	0.150	0.150
95. Process Contingency ^(f,g)	NA	NA	NA	NA
96. Project Contingency ^(f)	0.150	0.173	0.184	0.195
O&M costs ^(h)	0.70	0.85	0.925	1.0
D&D allowance, $C_{D\&D}$ (mill/kWeh):				
nominal \$	0.38	0.75	1.13	1.50
constant \$	0.25	0.50	0.75	1.00

Economic Impact of LSA Factors: Applications to ARIES-I and -AT



LSA=1 reflects ~25% cost saving relative to LSA=4

Quotes:

- **Delene** (in 1990): LSA factors are uncertain and may change as costs become better defined.
- **McCarthy** (in 1994):
 - Get away from extremely conservative LSA-type analysis.
 - Do not compare fusion LSA analysis to fission's. Their analyses are different.
 - No details or alternative methodology.



Remarks on LSA Factors

- Continue using **and** updating LSA factors for ARIES studies.
- Sum of **direct and indirect costs** does not reflect total cost estimated by energy producers.
- Total cost = direct/indirect costs + **external costs** (i.e., social costs of mitigating harms to health and environment).



External Costs

(also called Externalities)

- Well known concept in economics.
- Introduced in 1912 by A. Pigou in “Theory of Economics.”
- **Definitions:**
 - Social costs related to impacts (+ve or -ve) on health and environment and not included in direct+indirect cost paid by costumer
 - Monetary measurement of socio-environmental **damage** of energy production and consumption
 - Damages not included in market price.
- **Goals:**
 - Encourage energy concepts to refine environmental and safety studies for entire lifecycle.
 - Balance socio-environmental dimensions with economics to promote clean energy and improve quality of life.
- **Why?**
 - Provide policymakers with means and scientific background to make decisions for environmental, energy, and transport policies.
 - Analytical tool to compare different energy conversion techniques

External Costs (Cont.)

- Include **items that people and/or society will pay for in future**, but that are not included in transaction prices. Examples:
 - Public health effects leading to reduction of life expectance, cancers, heart failure, asthma, bronchitis, etc.
 - Medical treatment of affected persons
 - Environmental damage to building materials, crops, soil, water, etc.
 - Climate change and global warming due to CO₂
 - Degradation of agricultural lands, depletion of natural resources, etc.
 - Degradation of quality of life (noise level, traffic, eyesores, odors, etc.)
 - Degradation of property value of houses (e.g., near airports or power plants).
- **CO₂ example:** Power station generating CO₂, causing damage to human health or building materials, imposes external costs to power station. They are real costs to members of society. Such environmental costs are “external” to power station owner and not taking into account when making decisions ⇒ Price paid by costumers do not reflect all costs of goods and services.
- **Damage** represents:
 - Welfare losses for individuals
 - Drop in market price for crops, materials, houses, etc.
 - Air pollution, occupational disease, and accidents
 - Global warming.
- **Impacts could be local, regional, or global.** For example, air pollutants are transported and cause considerable damage 100s km away from source.

External Costs (Cont.)

- External costs are incurred at various stages of energy lifecycle
⇒ complete lifecycle should be considered.
- **Every energy technology** has side effects:
 - Production of building/construction materials
 - Mining, fabrication, and transportation of fuel
 - Constructions, operation, and maintenance of facility
 - Air pollution
 - Management of liquid/solid wastes
 - Decommissioning
 - Restoration of affected land, lake, and ocean areas.
- External costs are **technology dependent** (older power plant have large external costs).
- **Problems** assessing external costs:
 - Some impacts cannot to be valued (such as global warming) or have uncertain damages.
 - Value of human life?
 - Future damage is not treated as current damage
⇒ External costs for long-lived radionuclides is zero!

External Costs (Cont.)

- **Measures to improve environmental performance of energy sector:**
 - Encourage cleaner technology
 - Subsidize new plants that avoid external costs
 - Taxation for damaging technologies according to external costs caused.
Legislations started setting limits on carbon emission (per Kyoto agreement) and adding carbon tax on coal power plants (> 20 mills/kWh).
- **Overall, external costs are problematic to quantify and still facing numerous technical problems** ⇒ document basic assumptions used in evaluation.
- Positive external costs may lead to energy taxation.
- Negative external costs mean benefits not properly reflected in market place.
Example: Availability of reliable, long-term energy source (such as nuclear: fission and fusion) that is immune to changing international circumstances (unlike natural gas and oil) and less sensitive to weather-related conditions (unlike solar and wind).



European Socio-economics Research

- **Numerous studies** performed in Europe using software package **EcoSence**.
- **EcoSence features:**
 - Integrated air quality and impact assessment model
 - Database for Europe
 - All stages of lifecycle (e.g., construction, transport of materials and fuels, fuel lifecycle, dismantling, etc.).
- **Applications:**
 - Energy production: Fossil fuel, Nuclear system, Renewables.
 - Transportation system: passenger vehicles, trains, aircrafts, ships, etc.
- Methodology criticized for **large uncertainties** in data, model, policy, and future technology. However, knowledge of possible range of external costs is better aid for policy decisions than no info at all.



External Costs for Energy (ExternE)

- Major EU **project started in 1991**. Originally, planned jointly by EU and DOE, but U.S. dropped out.
- Results **allow different fuel cycles and technologies to be compared** by assessing entire lifecycle of power station, including materials manufacturing, construction, operation, dismantling, site restoration, and waste management.
- **At each stage, several factors are considered:**
 - Hazardous chemical emission
 - Radioactive emission, road accidents
 - Occupational accidents
 - Occupational exposure to hazards
 - Plant accidents exposing public to risks.
- **Adverse effects are quantified in monetary terms, summed** to produce total external costs, then **divided by net electric output** (€ / kWh).
- Methodology applied to various technologies in different EU countries producing different external costs.
- 2001 report proposes two ways of incorporating external costs:
 - Taxing the costs
 - Subsidizing alternatives (preferred option in EU but does not extend to EU nuclear power).
- Besides ExternE, other methods were developed and results vary considerable.

EU External Costs for Energy System*

(in €cent/kWh)

<u>EU Countries</u>	Coal	Oil	Gas	Nuclear	Biomass	Hydro	PV	Wind
Denmark	3-6	5-8	1-2	0.2	3		0.6	0.05
France	7-10	8-11	2-4	0.3	1	1		
Germany	5-8	3-5	1	0.4	0-0.8	1		0.25
UK	4-7	3-5	1-2	0.25	1			0.15

Well located renewable energy sources have low external costs.

Fission nuclear power:

- Low external costs:
 - Compare well with winds and solar
 - Order of magnitude lower than fossil
- Very low greenhouse effect
- Impacts of fuel cycle and very low accident probability with very high consequences are included.

* European Commission, "External Costs," EUR 20198 (2003). <http://www.externe.info/externpr.pdf>

Applications to EU Fusion Studies

External Costs for Future Fusion Plants

T. Hamacher et. al. (*Fusion Engineering and Design* 54 (2001) 405-411)

SEAFP Models:	Model 1 (Li ₂ O/ He/V)	Model 2 (LiPb/ H ₂ O/FS)
External Costs (€cent/kWh)	0.13 (0.04 - 0.5)*	0.27 (0.07 - 1.2)*

Conclusions:

- **Main contributors** to fusion external costs:
 - Material manufacturing (25%)
 - Occupational accidents (18%)
 - Decommissioning (25%).
- Fusion is in group of technologies with **low external costs**.
- **Local impacts are negligible**, even during severe accident.
- **Radiological impact** is one source, but not dominant.

* Range of uncertainties.



Applications to EU Fusion Studies (Cont.)

Economically Acceptable Fusion Power Stations with Safety and Environmental Advantages

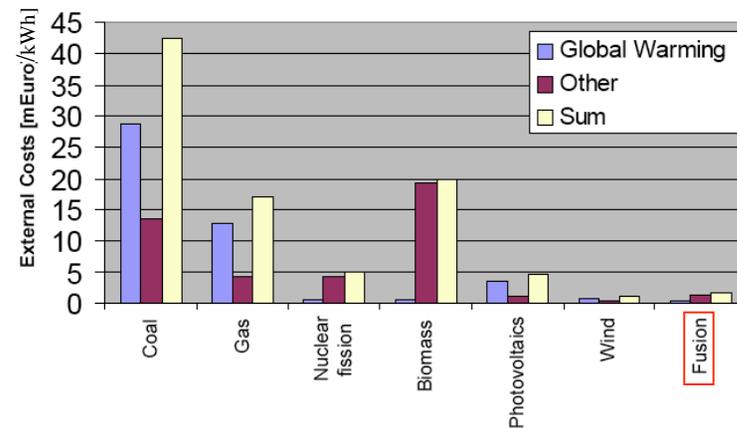
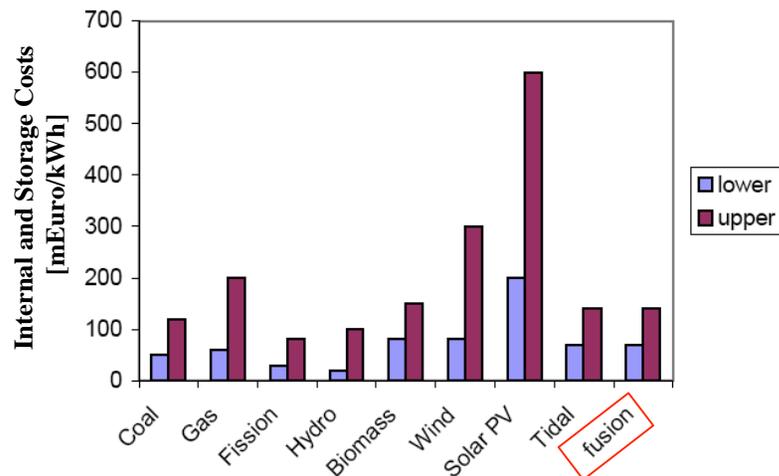
D. Ward, N. Taylor, I. Cook (*Fusion Engineering and Design* 58-59 (2001) 1033-1036)

- With inclusion of external costs, fusion is competitive with “clean coal” even with conservative assumptions.
- Adding cost of energy storage system for intermittent renewables (such as wind and solar) would make them uncompetitive with fusion in internal cost terms.
- Economically acceptable fusion power plants, embodying all safety and environmental advantages of fusion, are achievable without major advances in physics and technology.

Applications to EU Fusion Studies (Cont.)

Prospects for Economic Fusion Electricity

I. Cook, R. Miller, D. Ward (*Fusion Engineering and Design* 63-64 (2002) 25-33)



- Fusion belongs to class of **low external cost sources**.
- Expected **economic performance of fusion improved because of low external costs** compared to competitions,
- Relative **importance of external costs** is expected to be **greater in future**.
- Development of **fusion would bring substantial economic benefits**.
- **Wrong to add external costs to internal costs** because:
 - External costs are calculated with present-day prices
 - No credit was taken for changes that could be made to designing and operating practices with intention of reducing external costs.



Applications to EU Fusion Studies (Cont.)

Power Plant Conceptual Studies in Europe

D. Maisonnier et. al. (*Nuclear Fusion* (2007 ?))

PPCS Models:	Model A (LiPb/ H ₂ O/FS)	Model C (LiPb/He/FS) (ARIES-ST type blkt)	Model D (LiPb/SiC) (ARIES-AT type blkt)
Costs (€cent/kWh):			
Internal costs	5-9 [#]	4-7 [#]	3-5 [#]
External costs	0.09	0.06	0.06

Remarks:

- External costs scaled from results from EU Socio-economics Research in Fusion.
- To ensure consistency, fusion assessment carried out by group that assessed other energy sources*.
- External costs for fusion are very low: 0.5 - 1 m€/kWh (0.7-1.5 mills/kWh).

[#] 1st of kind and 10th of kind.

* D. Ward et. al., “The Economic Viability of Fusion Power”, *Fusion Engineering and Design* 75-79 (2005) 1221-1227.



Remarks on External Costs

- **ExternE is useful tool** despite uncertainties in costing models.
- External costs strongly **depend on location and technology** of energy source.
- **Nuclear power prospects look better if carbon taxation goes into effect.**
- **EU results indicate fusion:**
 - Has minimal effect on public health and environment
 - Belongs to group of energy systems with low external costs (such as solar and wind)
 - Will be economically competitive in future energy market (with inclusion of external costs).
- **ARIES COE should include 1-2 mills/kWh to account for fusion external costs.**
- **Fusion community** should take advantage of fusion's low externalities, emphasizing competitive COE that includes external costs, requesting more funding to accelerate fusion development.
- **Policymakers** should tax most damaging fuels and technologies (like coal and oil) and/or encourage/subsidize those with lower external costs (such as nuclear and renewables), assuming energy isn't a political issue.