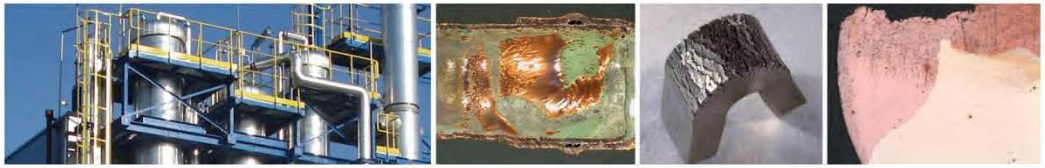
TEES & AMPP-NACE Desalination Consortia Workshop Presentations

consortia.corrosion@nace.org

AMPP™

MATERIALS



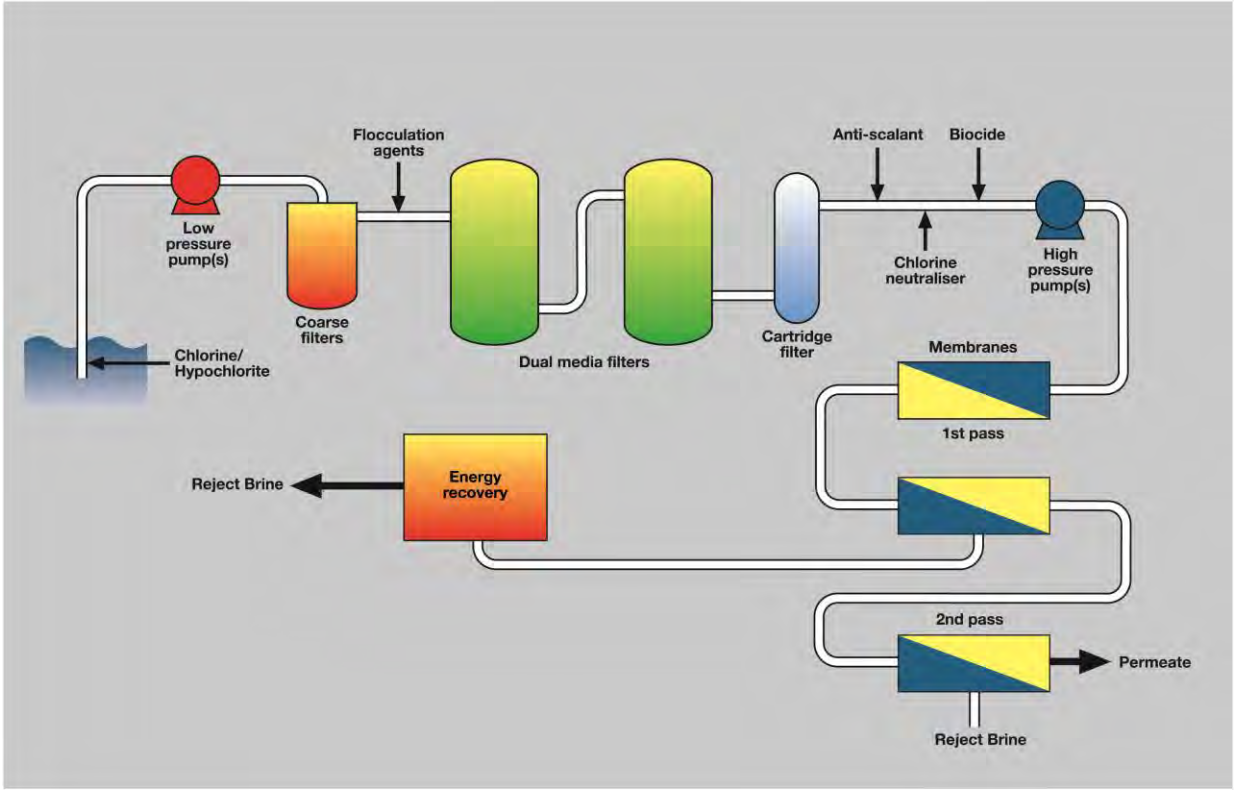
Selecting and Testing Alloys for the HP Section of SWRO Desalination Plants

Roger Francis

INTRODUCTION

- With the increasing world population there is an increasing demand for freshwater for drinking and irrigation.
- In many parts of the world there is insufficient water from rivers and wells, so desalination is increasingly being used to provide fresh water.
- For new build, seawater reverse osmosis (SWRO) desalination is prevalent, and many new SWRO plants are currently being built or are being designed.
- This talk covers the selection and testing of materials for the high pressure (HP) sections of a typical SWRO plant.
- The talk will include some case histories to demonstrate the points being made.

TYPICAL LAYOUT



Schematic diagram of a typical SWRO plant

MATERIAL REQUIREMENTS

- In an SWRO desalination plant the membranes in the high pressure section are the most expensive single item.
- The life of these membranes dictates the cost efficiency of the plant.
- To increase the life, the seawater is finely filtered in the low pressure section.
- In addition chemicals are added to prevent scaling and fouling.
- The redox potential is also controlled to prevent membrane damage under strongly oxidizing conditions.
- It is important that any metals used in the HP section do not affect membrane performance.
- Copper alloys are rarely used because they release significant quantities of copper until a protective film has formed and this might affect membrane performance.
- In addition there is a WHO limit on copper in drinking water.

ALLOYS

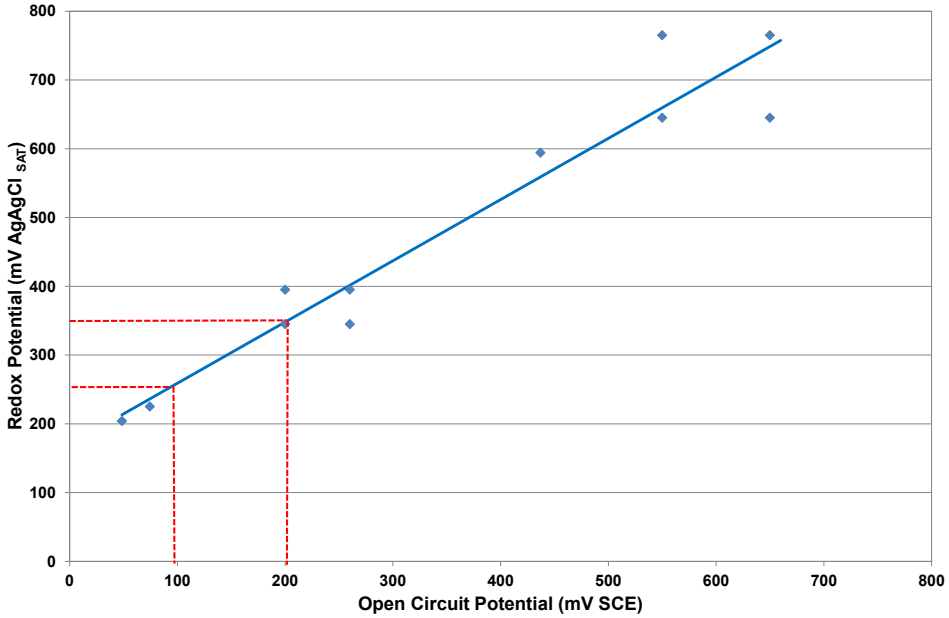
GENERIC NAME	UNS No.	NOMINAL COMPOSITION (wt.%)							PREN*
		Fe	Cr	Ni	Mo	N	Cu	Other	
NAB	C95800	4	-	4.5	-	-	Bal	9Al	N/A
316L	S31603	Bal	17	10	2	-	-	-	24
904L	N08904	Bal	20	25	4	-	1.5	-	34
6% Mo	S31254	Bal	20	18	6	0.2	0.7	-	43
6% Mo	N08367	Bal	20	25	6	0.2	-	-	43
2205	S32205	Bal	22	5	3.2	0.17	-	-	35
Z100	S32760	Bal	25	7	3.6	0.25	0.7	0.7W	>41
2507	S32750	Bal	25	7	3.6	0.27	-	-	>41

Bal = Balance
PREN = %Cr = 3.3(%Mo + 0.5x%W) + 16x%N

- The pitting resistance equivalent number, or PREN, is an empirical formula that relates an alloy's composition to its resistance to localised attack in chloride-containing solutions.
- It has been adopted by ISO 15156/ NACE MR0175, an oil and gas standard, and by many major companies around the world.

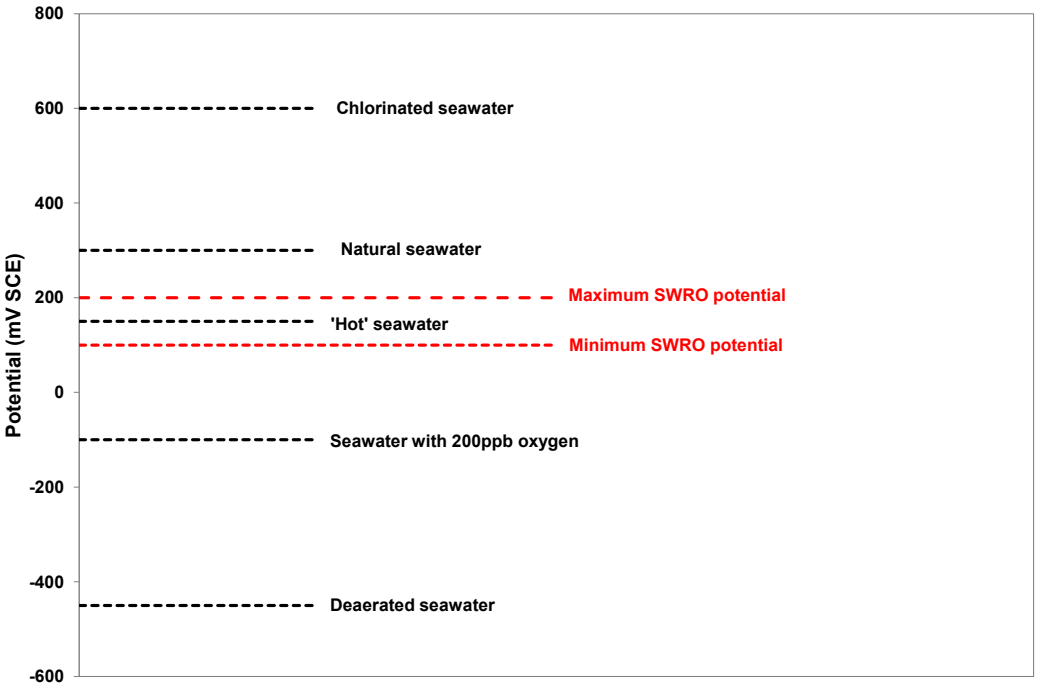
REDOX POTENTIAL AND OCP

- Before the high pressure pumps it is common to add a chemical, such as sodium metabisulphite, to the water to reduce the redox potential below 350 mV $Ag/AgCl_{SAT}$. The practical lower limit is 250 mV $Ag/AgCl_{SAT}$.
- Byrne et al carried out tests at different redox potentials in seawater to determine the open circuit potential of 6% Mo austenitic and superduplex stainless steels.
- It can be seen that the redox potential range 250 to 350 mV $Ag/AgCl_{SAT}$, corresponds to a stainless steel potential of ~ 100 to 200 mV SCE.
- In seawater, stainless steel can adopt a wide range of potentials, depending on the conditions.



POTENTIALS IN SEAWATER

- In natural seawater a biofilm forms in 2 days to 2 weeks and this depolarises the cathodic reaction, raising the potential to ~300 mV SCE.
- Chlorine is a powerful oxidizer and ~0.5 mg/L raises the potential to ~600 mV SCE.

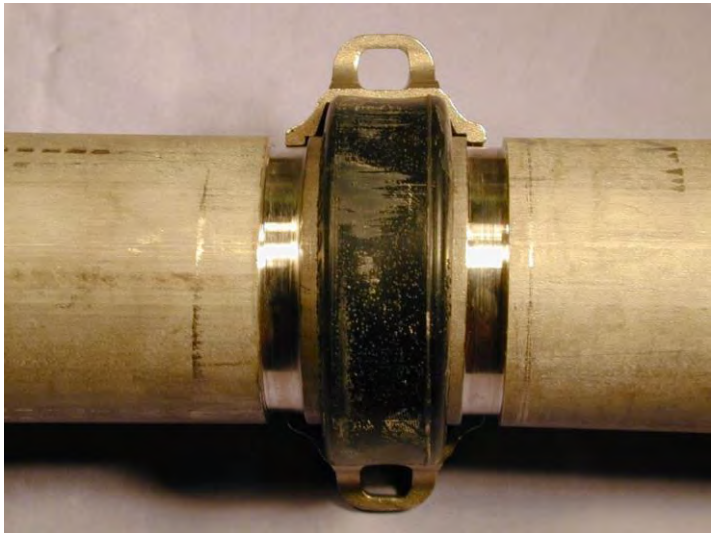


- If the seawater is heated 25 to 30°C above the normal ambient temperature, the biofilm cannot grow, and the potential is ~150 mV SCE.
- If the dissolved oxygen content is reduced the potential decreases, being ~ -500 mV SCE when fully deaerated.

COUPLINGS

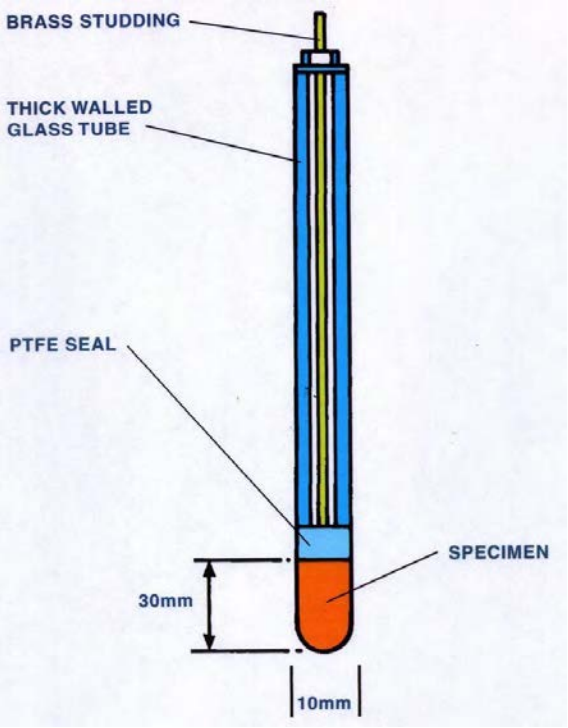
- In the HP section a lot of the joints are made with high pressure couplings so that the membrane cells can be easily removed.

- The pipe end has a square cut groove about 15mm from the end and a polymer boot (e.g. neoprene) joins the two pipes.
- A metal clamp holds the seal in place, and these may be galvanised steel or stainless steel, depending on location.
- The boot creates a tight crevice, so the piping alloy must be resistant to crevice corrosion externally under HP conditions.

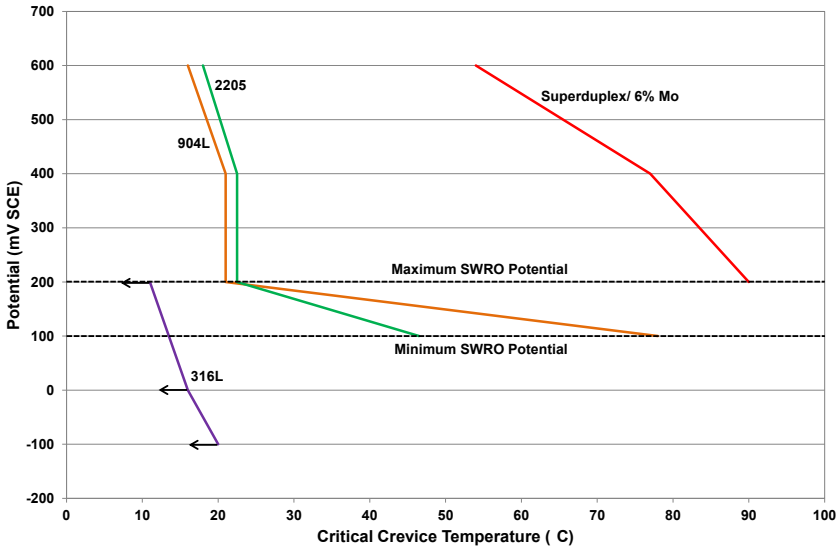


CCT TEST METHODS

- There are a lot of methods that have been used to measure the critical crevice temperature (CCT). The one used by the author for SWRO conditions has been reported extensively.
- The sample is a smooth bullet with lacquer on the flat face to prevent crevice corrosion.
- The crevice former is a silicone rubber square section washer of id 7mm and 5mm cross section.
- This creates a moderately tight crevice.
- The sample is polarised to +200 mV SCE and the current density is allowed to stabilise for 1 hour.
- Then the temperature is increased at 5°C/h until the current density exceeds 10 μA/cm^2 for 10 minutes.



CREVICE CORROSION



- The results showed that superduplex and 6%Mo austenitic had a high resistance to crevice corrosion.
- Alloys 2205 and 904L were OK up to ~22°C at potentials >200mV SCE.

- At lower potentials the CCT increased.
- 316L suffered crevice corrosion at all potentials at the current ambient temperature.
- These results show why superduplex and 6% Mo austenitic alloys have been successful in SWRO HP systems.
- Superduplex is currently preferred because of its lower cost.

PUMPS 1

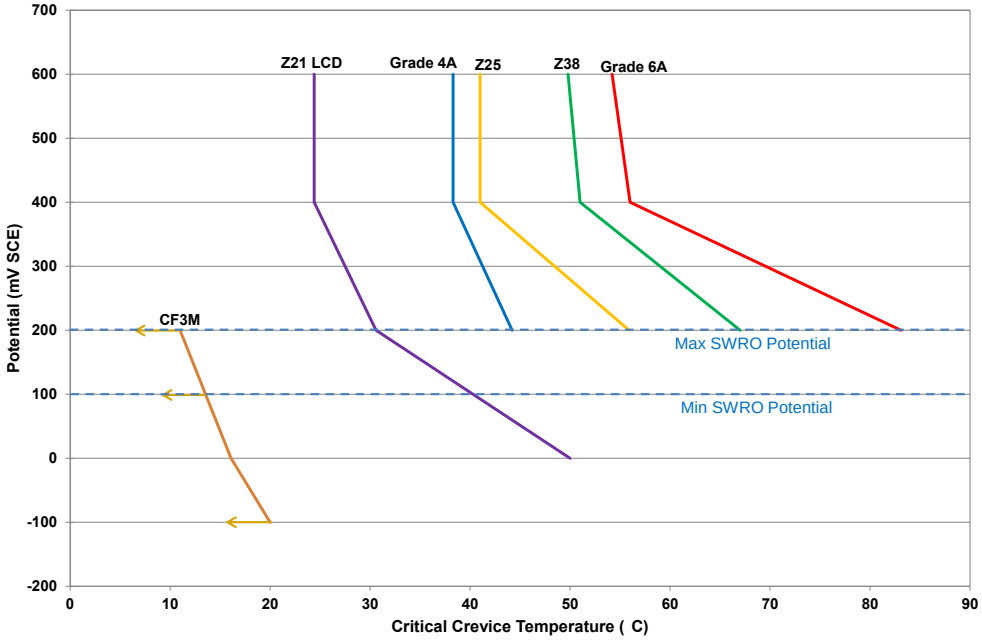
- Cast duplex stainless steels are preferred for the high pressure pumps because of their higher strength, and, therefore, reduced cross section.
- The choice of cast stainless steels is more limited in ASTM A995 than for wrought alloys.

ASTM NAME (A351 or A995)	UNS No.	NOMINAL COMPOSITION (wt.%)							PREN*
		Fe	Cr	Ni	Mo	N	Cu	W	
CF3M	J92800	Bal	18	10	2	-	-	-	24
Z21LCD	N/A	Bal	21	4	2	0.18	0.2	0.2	>30
Z25	N/A	Bal	25	6	2.5	0.14	0.4	-	35
Grade 4A	J92205	Bal	22	5.5	3.2	0.16	-	-	35
Z38	N/A	Bal	25	7	3	0.2	0.3	0.3	38
Grade 6A	J93380	Bal	25	8	3.6	0.25	0.7	0.7	>41

- Alloy Z21LCD has only been produced in low tonnage heats, but alloys Z25 and Z38 have been used extensively for pumps in a range of waters.

PUMPS 2

- Crevice corrosion tests on the cast alloys were carried out as described before, but the crevices were not so severe, as the bullets were accidentally machined under size.
- The CCT at 200 mV SCE increased with PREN, as expected.
- The unusual result was that the 25Cr Z25 was better than the 22Cr Grade 4A with the same PREN.
- This suggests that higher chromium is more important than higher molybdenum.



PUMPS 3

- The two critical crevice areas in a pump are the shaft and the cast-in flanges.
- If there is crevice corrosion on the shaft it can act as a stress raiser, which will be followed shortly after by a catastrophic fatigue failure.
- Hence, superduplex is preferred for shafts to prevent this scenario.
- Grade 4A has been used for seawater pumps in the North Sea and it has failed by crevice corrosion.
- Z25 has been used in seawater successfully up to ~10°C with excursions to 15°C.
- Alloy Z38 has been used in seawater successfully at around 25°C with excursions to 30°C.
- Grade 6A has been used successfully in seawater up to ~40°C.

VALVES

- It is important that the valves in the high pressure section are galvanically compatible with the piping and the pumps.
- This means that they are going to be superduplex stainless steel, as it is an alloy that is regularly used for valves.

- There have been failures of NAB drain valves in the HP section.
- This is not surprising given the well publicized problems of NAB galvanically coupled to superduplex stainless steel.

SERVICE EXPERIENCE 1

- The seawater temperature in most SWRO plants is in the range 25 to 40°C.
- Under these conditions the previous data show that only superduplex and 6% Mo austenitic alloys will be satisfactory.
- There have been numerous cases where 904L, 2205 duplex, and even 316L have been used in the HP section with disastrous consequences.

- There are a few plants where lower alloy stainless steels have worked, but these have been where the redox potential is closer to + 250 mV $Ag/AgCl_{SAT}$. This involves a much higher ongoing cost in chemicals.

SERVICE EXPERIENCE 2

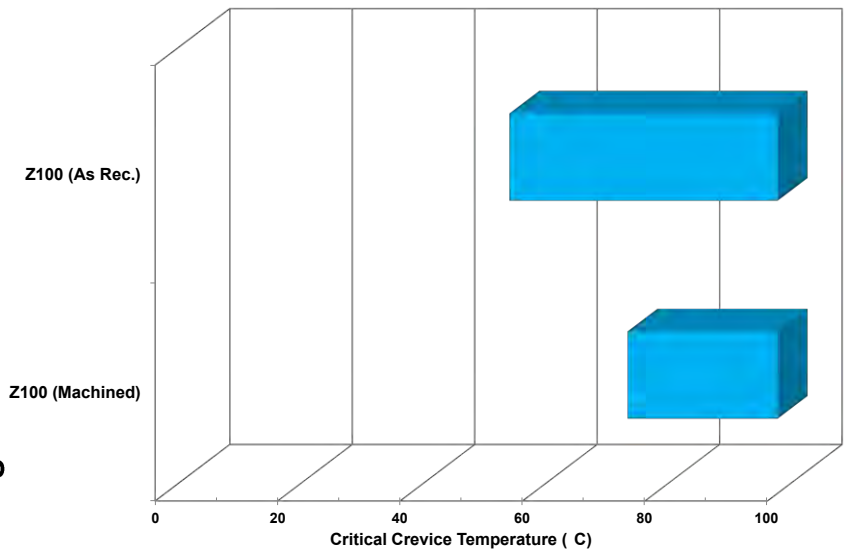
- There are a lot of welded joints in the HP feed pipes to the membrane cells.
- Some plants have experienced failures at welds after a few months service.
- Such joints are at high pressure (~70 bar) and such leakage is unacceptable.
- The corrosion is caused by sigma phase that precipitates at too high heat input and/or interpass temperature.

SERCICE EXPERIENCE 2

- It is important to follow the manufacturer's recommendations when qualifying a weld procedure for superduplex stainless steel.
- In addition to the requirements of the fabrication code (e.g. ASME) it is important to add supplementary tests as follows:
  - An impact toughness test at -46°C. Pass is 40J average, 35J minimum.
  - An ASTM G48A test at 35°C for 24 hours. Pass is no pitting and weight loss < 4g/m^2.
  - A microsection at x500 (double etched). No third phases and the ferrite content should be 35 to 65%.
- The impact toughness test ensures the weld has adequate toughness.
- The corrosion test shows that there are insufficient third phases to significantly affect the corrosion resistance.
- The microsection enables the phase balance to be determined and can suggest remedial action in the event of failing one or both of the other tests.

SERCICE EXPERIENCE 3

- One plant experienced crevice corrosion of superduplex under the boot of some of the HP couplings, but not all, at a seawater temperature of ~30°C.
- Crevice corrosion tests were conducted on samples cut from several heats of pipe, with special curved crevice washers.
- The critical crevice temperature was determined at a potential of 200 mV SCE.
- Some of the pipes were slightly skimmed to ensure the outer surface was circular and smooth.
- The results showed a large scatter range for the as-received pipes.
- The skimmed pipes had no higher CCT, but a much smaller scatter range.
- Since skimming the outside of HP joints, there have been no further failures.



REJECT BRINE 1

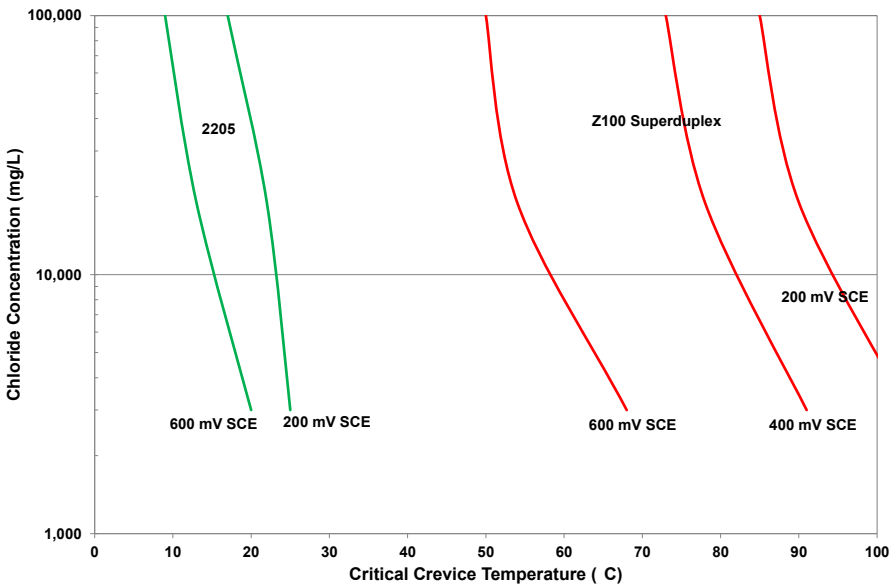
- In SWRO the permeate is at low pressure (~1bar), while the reject brine contains most of the energy (~69 bar).
- It is important to recover this energy to reduce operating costs.
- Modern plants do this with hydraulic energy recovery, because of its high efficiency.

- There are a number of proprietary devices on the market but they are all constrained by the same operational parameters.
- Because of the high flow rates and pressures the devices must be very resistant to erosion corrosion and the various designs typically use a combination of ceramics and superduplex stainless steel.
- The recovered energy is fed into the HP pump suction or discharge depending on the plant design.

BRINE REJECT 2

- The chloride content in the reject brine is typically up to around 40 g/L, about twice that in the seawater.
- Crevice corrosion tests have been conducted at constant potential and different chloride concentrations to determine the effect on CCT.

- These were conducted with a moderately tight crevice.
- The results show that from 10,000 to 100,000 mg/L chloride the CCT only reduces by 5 to 10°C.
- Hence, superduplex will be satisfactory in the reject brine section.
- The results for austenitic alloys follow the same trends with chloride content.

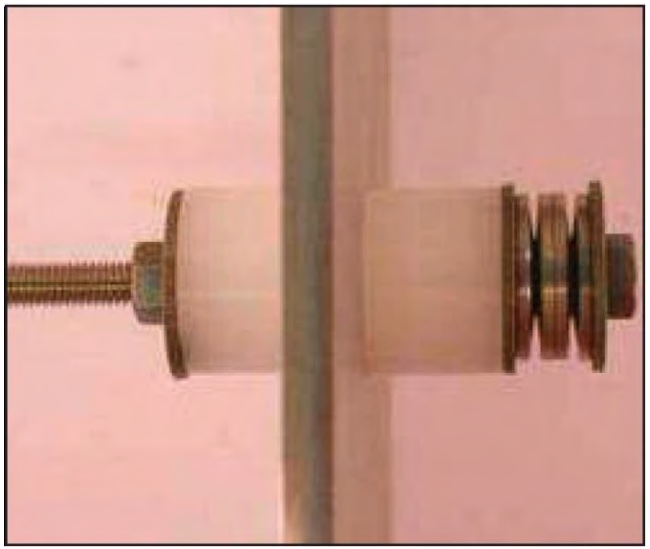


FUTURE DEVELOPMENTS

- In current SWRO plants the final filters in the low pressure section generally go down to ~1μm, but there are advantages in finer filtration, if it can be made reliable and economic.
- Microfiltration would be down to ~0.1μm, while ultrafiltration would be to ~0.01μm and nanofiltration would be to ~0.001μm.
- While micro or ultrafiltration could extend membrane life, they do not remove the need to inject anti-scaling chemicals and biocides.
- The advantage of nanofiltration would be that chemical dosing of anti-scalants and biocides prior to the high pressure pumps would be unnecessary and the finer filtration should also prolong membrane life.
- It is not known if this very fine filtration would further reduce the redox potential to enable lower alloyed stainless steels to be used.
- Crevice corrosion testing would be advisable before going ahead with a low alloy in the high pressure section, in a plant with nanofiltration.

TESTING 1

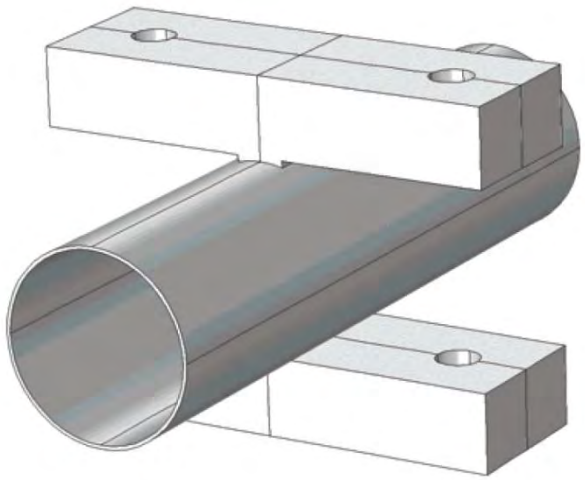
- In the high pressure section the tightest crevices are under the boot of the HP couplings.
- To do representative crevice corrosion testing it is advisable to do the testing on the outside diameter of real pipes.
- To obtain reproducible results it is also best to use spring washers to obtain a constant pressure on the crevice, as described in ISO 18070.



- The ISO standard gives recommendations for different pressures to represent different types of crevice.
- The crevice formers may be polyacetal or PEEK.

TESTING 2

- The ISO standard also gives recommendations for the design of crevice washers for curved surfaces.
- More recently Thierry et al have described an improved geometry for greater reproducibility with pipes (NACE 2018).



- They show results to demonstrate the greater reproducibility.
- They also include guidance on appropriate pressures to simulate different types of crevice.
- It is important that any corrosion test is long enough to allow corrosion to initiate, but not too long to delay material selection.

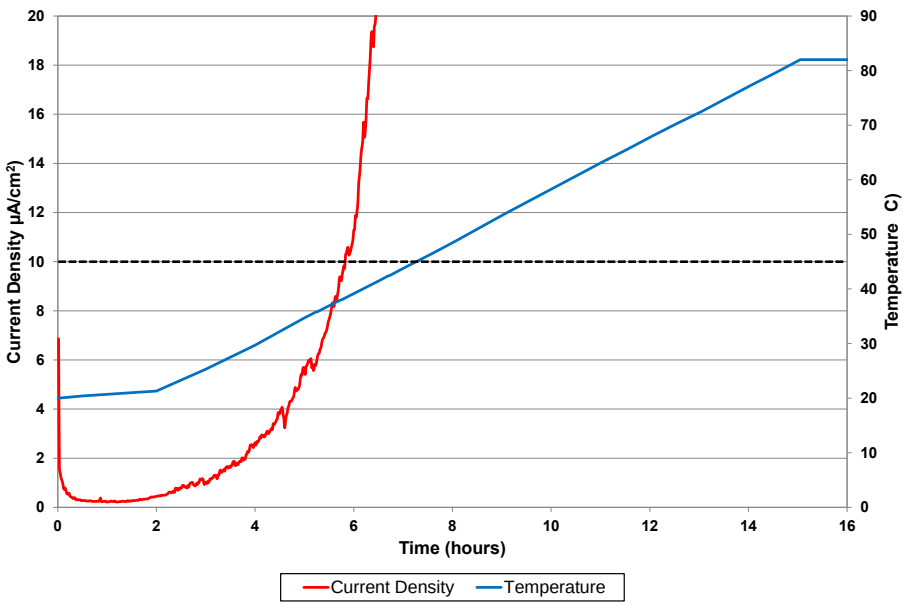
TESTING 3

- The author has found that electrochemical testing can provide reliable data in a relatively short time.
- The creviced sample is immersed in aerated synthetic seawater and is polarised to a suitable potential.
- This can be +200 mV SCE for conventional SWRO or a lower potential determined from the actual redox potential and the chart shown earlier, if nanofiltration is being used.

- The sample is allowed to stabilise for 1 hour and then the temperature is increased at 5°C/hour.
- When the current density exceeds 10 μA/cm^2 for 10 minutes, crevice corrosion has initiated.

TESTING 4

- The author experimented with different temperature ramp rates and found that at 10°C/h the CCT was increased.
- However, at 1°C/h the CCT hardly varied, and did not justify the greatly increased testing time.
- At 5°C/h a test can be conducted overnight.
- The threshold current density for initiation is taken from Oldfield.
- The temperature at which the CD first reaches 10μ/cm^2 is taken as the CCT.
- It is important to do multiple tests to allow for the variability of crevice corrosion initiation.



QUALITY

- In recent years there has been a desire to reduce costs, and this has resulted in the dropping of many companies' technical specifications for materials procurement.
- This has resulted in purchasing CRAs with little or no testing, and there have been some very expensive corrosion failures because of this.
- The problem was attempted to be solved by using ASTM standards such as G48 and A923.
- However, these were not felt to be rigorous enough and the oil and gas industry has driven the development of ISO 17781.
- This standard covers the appropriate testing for all grades of duplex stainless steel and suitable pass/fail criteria.
- It not only covers parent material, but also suitable testing for weld procedures.
- This standard should be used by the desalination industry for duplex SS to ensure that good quality material is delivered.

CONCLUSIONS

- Under current operating conditions for the high pressure and reject brine sections of an SWRO plant, superduplex stainless steel has got a good track record.
- It is important to do adequate testing when qualifying a weld procedure to ensure that it will not result in third phases, and reduced corrosion resistance.
- Crevice corrosion under the HP coupling seal can be prevented by skimming the land under the seal when the groove is being machined.
- If nanofiltration is introduced then measurement of the redox potential combined with appropriate corrosion testing will determine if lower alloy stainless steels will be acceptable.

REFERENCES (Books)

1. **R Francis, Avoiding Corrosion in Desalination Plants, NACE International, Houston, TX, 2019.**

2. **R Francis, Galvanic Corrosion: A Practical Guide for Engineers, 2nd Edition, NACE International, Houston, TX, 2017.**

3. **R Francis, The Corrosion of Duplex Stainless Steels: A Practical Guide for Engineers, NACE International, Houston, TX, 2018.**

REFERENCES

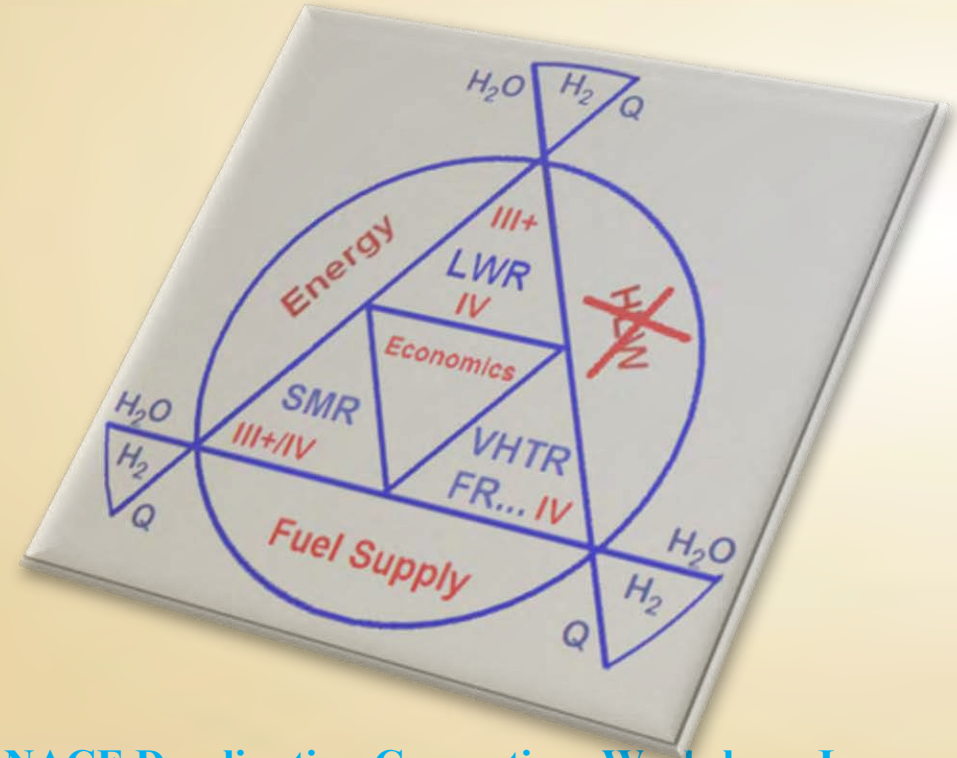
1. **R Francis and S Hebdon,** *The Selection of Stainless Steels for Seawater Pumps*, **Paper 5446, Corrosion 2015, Dallas, TX, USA, March 2015, NACE International, Houston, TX.**
2. **D Thierry, C Leboulleur and N Larche,** *A New Crevice Assembly Adapted for Tube Geometries to Test Crevice Corrosion in Seawater*, **Paper 10959, Corrosion 2018, April 2018, NACE International, Houston, TX.**
3. **R Francis, G Warburton, G Byrne and J Wilson,** *Electrochemical Potential and the Corrosion Resistance of Stainless Steels in SWRO Applications*, **IDA International Desalination Conference, Dubai, UAE, October, 2009.**
4. **J O Olsson and M M Snis,** *Don't Repeat Mistakes! An SWRO Plant Case Study*, **Paper SP050-036, International Desalination World Congress, 2005.**
5. **G Byrne, G Warburton, J Wilson and R Francis,** *Fabrication of Superduplex Stainless Steel for Optimum Seawater Corrosion Resistance*, **World Congress on Desalination and Water Reuse, Perth, Australia, September 2011, IDA.**
6. **G Byrne, R Francis, G Warburton and A Fajimi,** *Meaningful Tests for the Quality of Duplex Stainless Steels*, **Paper 10876, Corrosion 2018, Phoenix, AZ, USA, April 2018, NACE International.**
7. **ISO 18070,** *Corrosion of Metals and Alloys – Crevice Corrosion Formers with Disc Springs for Flat Specimens or Tube Made from Stainless Steel,* **ISO, Geneva, Switzerland, 2015.**
8. **ISO 17781,** *Petroleum, Petrochemical and Natural Gas Industries – Test Methods for Quality Control of Microstructure of Ferritic/Austenitic (Duplex) Stainless Steels*, **ISO, Geneva, Switzerland, 2017.**
9. **ISO 15156/ NACE MR0175,** *Petroleum and Natural Gas Industries - Materials for Use in H_2S-Containing Environments in Oil and Gas Production*, **ISO, Geneva, Switzerland; NACE, Houston, TX, USA).**
10. **J W Oldfield and W H Sutton,** *Brit. Corr. J* ***13*** *(1978) 13 & 104*

THANK YOU

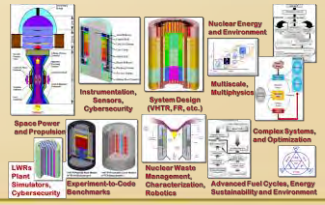
ANY QUESTIONS?

Reliability Expectations for Industrial Nuclear Desalination Applications

Pavel V. Tsvetkov
Advanced Energy Systems Lab
Department of Nuclear Engineering
Texas A&M University
tsvetkov@tamu.edu



Advanced Energy Systems Lab



Reliability Expectations for Industrial Nuclear Desalination Applications

1. References
2. Nuclear Energy
3. Global Nuclear Enterprise – Applications (Market)
4. Reliability in Nuclear: Zero Emissions and Safe
5. Nuclear Desalination
6. Deployment Strategies and Timelines
7. Reliability Expectations for Nuclear Desalination
8. Observations and Questions to Ask (Metrics)

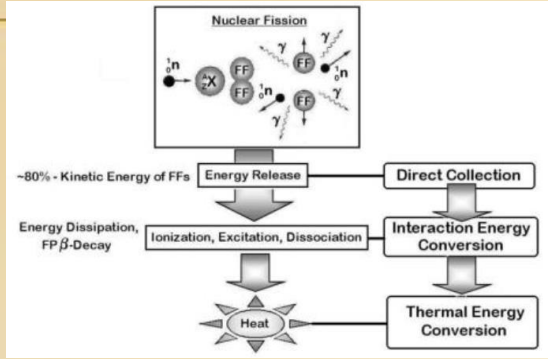
Advanced Energy Systems Laboratory

Pavel V. Tsvetkov, tsvetkov@tamu.edu

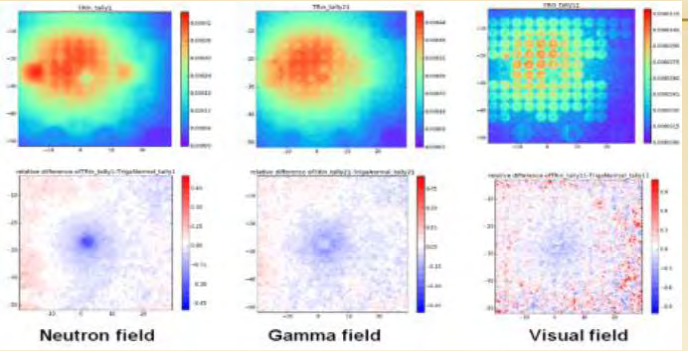
Seeking Technically and Commercially Viable Solutions

TEXAS A&M UNIVERSITY

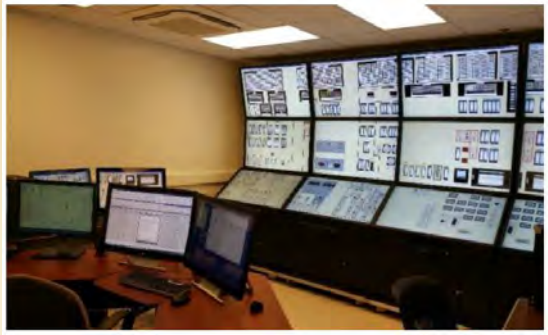
Energy Conversion



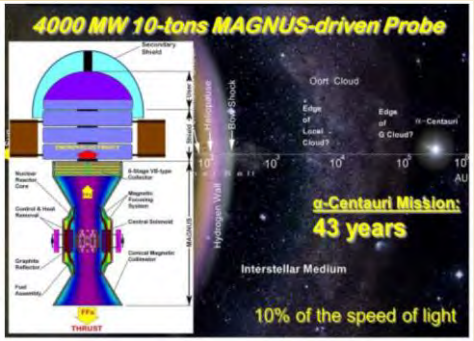
3D Mixed Field Reconstruction Methods



System Simulators & Cybersecurity

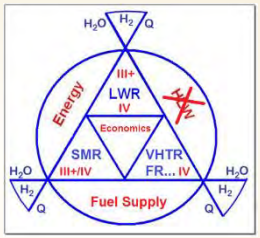


Direct Energy Conversion (DEC)



Design & Optimization

Global Surveillance

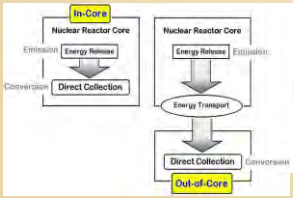


Advanced Manufacturing Signatures

Systems & Applications

VHTR, Deep Burn HTR
Fast Reactor (SFR, LFR, other)
FHR, MSR
IP, SMR/MMR
Waste Management, Robotics
Special purpose systems

Commercial Systems

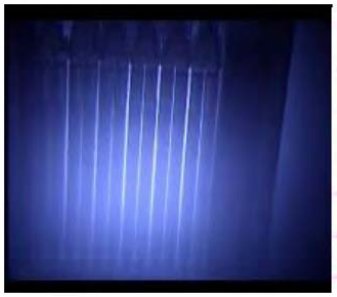


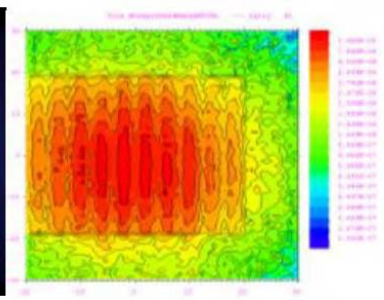
DEC3

NuGen

DEC1/DEC2 (Prometheus)

Advanced Sensing (Optical/Fiber)





Collaborators

- INL, ORNL, SNL, LANL
- Westinghouse, Sothern
- “NuGen”, “Prometheus”
- UT, GT, AU, VCU, OSU, Michigan, MIT, Wisconsin, UCB, others

Objective of this talk

The primary objective of this talk is two-fold:

1. Introduce nuclear desalination and outline its system-level considerations for deployment focusing on reliability
2. Outline existing challenges for nuclear desalination units and current envisioned solutions

The purpose is to define an R&D domain to address existing challenges for emerging nuclear technologies

Reliability Expectations for Industrial Nuclear Desalination Applications

1. References
2. Nuclear Energy
3. Global Nuclear Enterprise – Applications (Market)
4. Reliability in Nuclear: Zero Emissions and Safe
5. Nuclear Desalination
6. Deployment Strategies and Timelines
7. Reliability Expectations for Nuclear Desalination
8. Observations and Questions to Ask (Metrics)

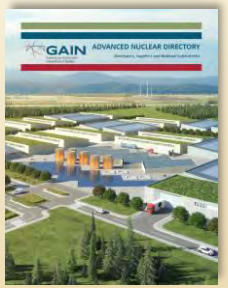
1. References

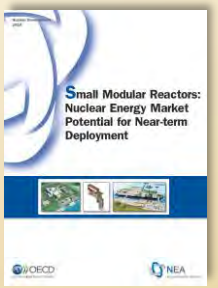
Nuclear power technology

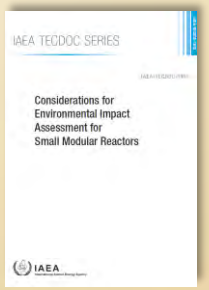
- https://www.energy.gov/ne/articles/big-potential-nuclear-microreactors
- https://inl.gov/trending-topic/microreactors/
- https://www.world-nuclear.org/information-library/nuclear-fuel-cycle/nuclear-power-reactors/small-nuclear-power-reactors.aspx
- https://www.gao.gov/products/GAO-20-380SP
- https://www.bbc.com/future/article/20200309-are-small-nuclear-power-plants-safe-and-efficient
- https://globalnews.ca/news/6243567/small-nuclear-reactors-environment/
- https://en.wikipedia.org/wiki/Small_modular_reactor
- https://www.oecd-nea.org/ndd/pubs/2016/7213-smrs.pdf

inl.gov **energy.gov** **oecd-nea.org** **IAEA.org** **world-nuclear.org**

google.com







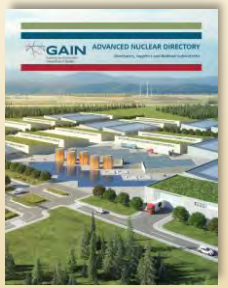
1. References

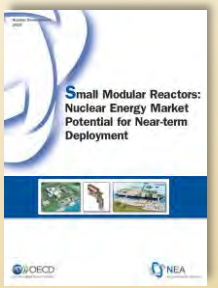
Industrial nuclear desalination

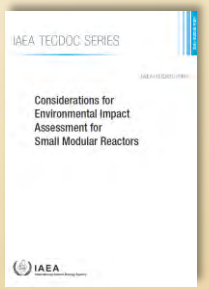
- https://www.world-nuclear.org/information-library/non-power-nuclear-applications/industry/nuclear-desalination.aspx
- https://www.iaea.org/topics/non-electric-applications/industrial-applications-and-nuclear-cogeneration
- https://www.iaea.org/topics/non-electric-applications/nuclear-desalination
- https://en.wikipedia.org/wiki/Desalination
- https://blogs.ei.columbia.edu/2020/11/23/nuclear-power-today-future/

inl.gov **energy.gov** **oecd-nea.org** **IAEA.org** **world-nuclear.org**

google.com



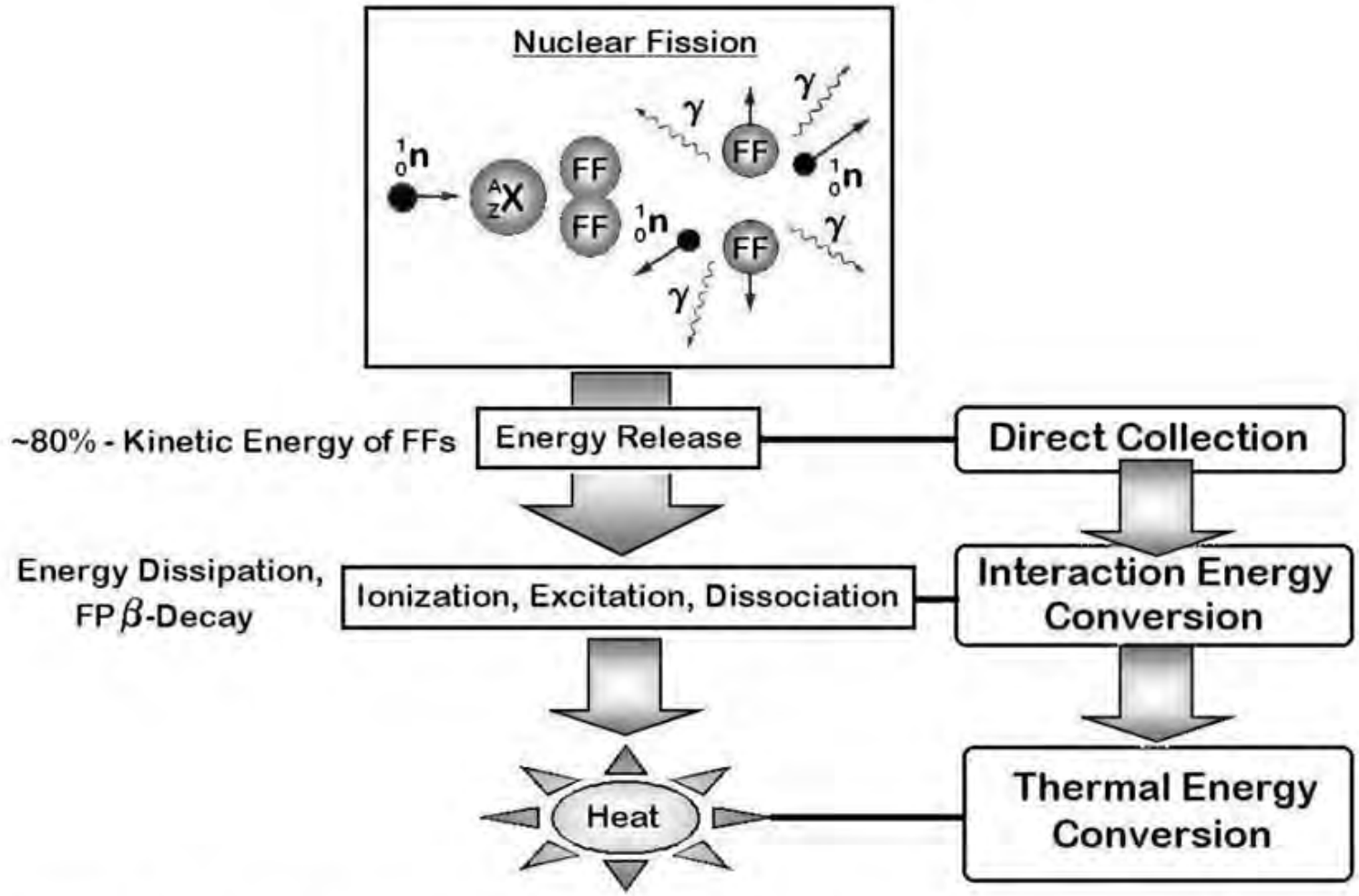




Reliability Expectations for Industrial Nuclear Desalination Applications

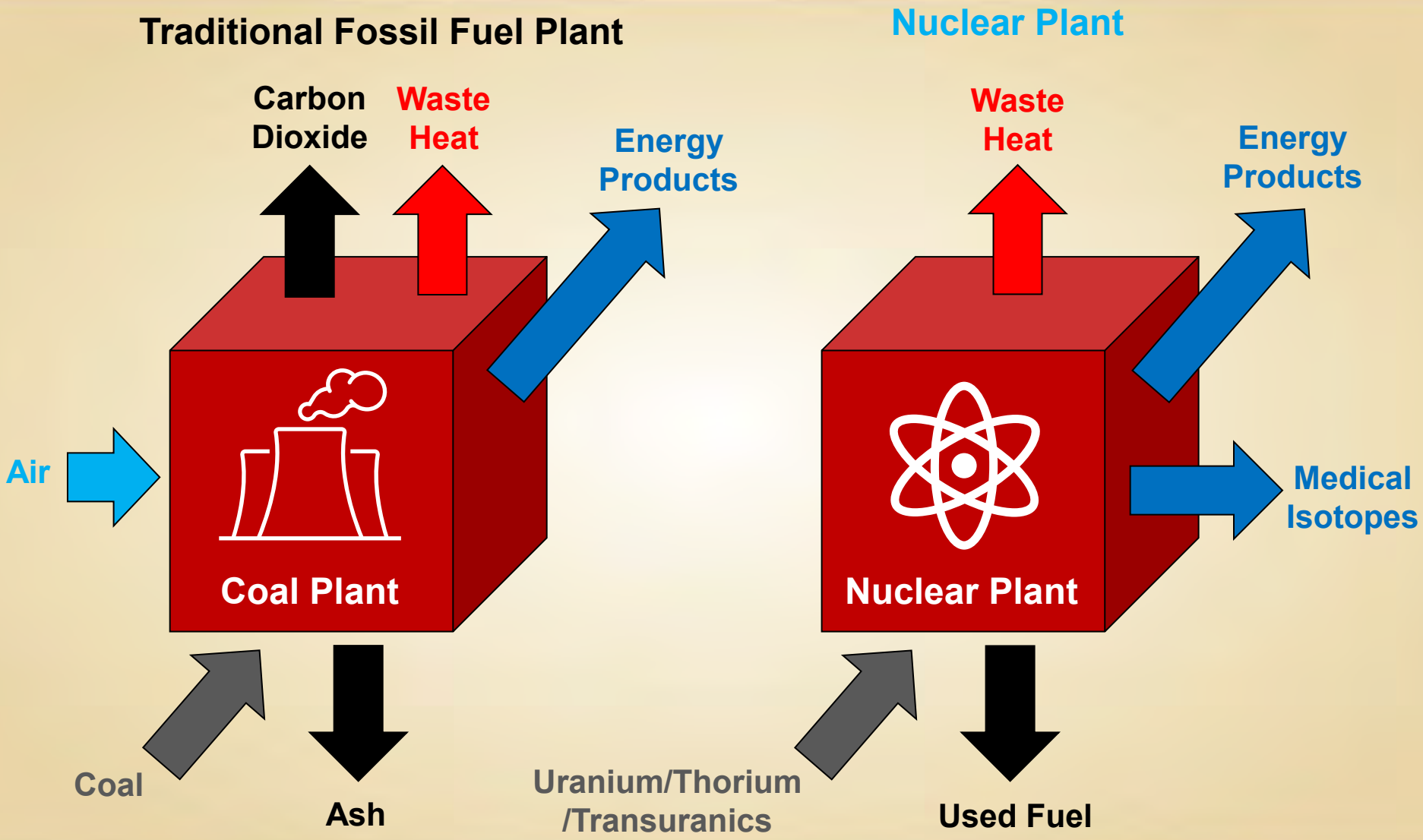
1. References
2. **Nuclear Energy**
3. Global Nuclear Enterprise – Applications (Market)
4. Reliability in Nuclear: Zero Emissions and Safe
5. Nuclear Desalination
6. Deployment Strategies and Timelines
7. Reliability Expectations for Nuclear Desalination
8. Observations and Questions to Ask (Metrics)

2. Nuclear Energy



Energy transformation processes accompanying nuclear fission.

2. Nuclear Energy



2. Nuclear Energy

Advantages (under normal operation scenarios):

- Specific energy yield from fission
- The energy process is a nuclear reaction, not a chemical process.
- Potential for long-term operation on a single batch of fuel
- Potential autonomy of operation
- Emissions are limited to the controlled thermal pollution
- Ability to deliver electricity and industrial heat

Engineering:

- Highly regulated safety design leading to low probabilities for accidents with high consequences
- Nuclear waste management
- Security

2. Nuclear Energy

Micro Reactors

Micro reactors – 1 – 20 MW output (ether for electricity generation or heat or co-generation) (DOE)

Small Modular Reactors

Small reactors – hundreds MW (on the order of 300 MW) output (ether for electricity or heat or co-generation) (DOE)

Small & Medium Reactors (SMR)

Small reactors – under 300 MWe

Medium reactors – 300 - 700 MWe (IAEA)

Small and medium-sized reactors – up to 600 MW output (ether for electricity or heat or co-generation) (OECD NEA)

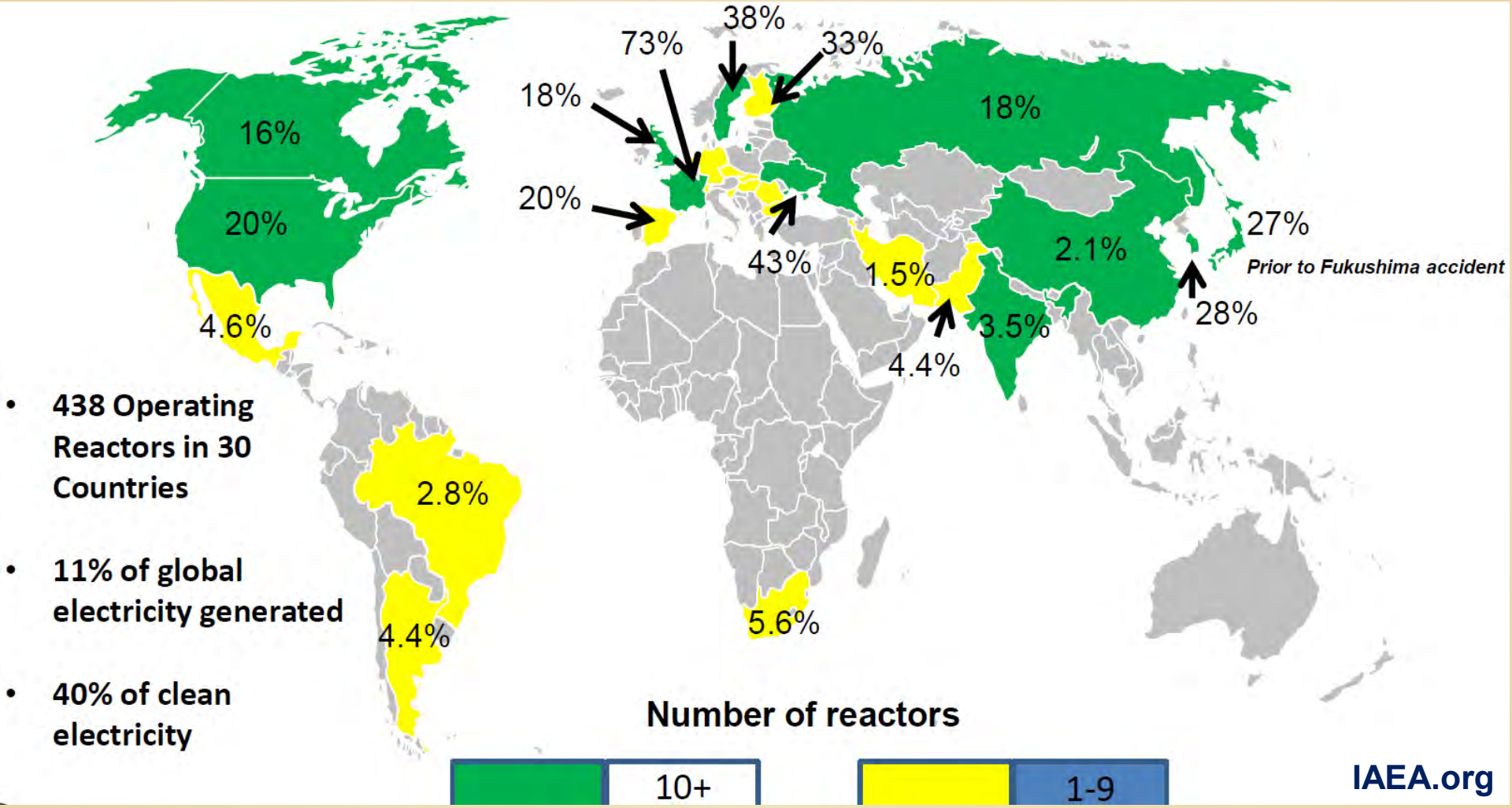
Large Power Reactors

Large reactors – 1000 MW output (ether for electricity generation or heat or co-generation)

Reliability Expectations for Industrial Nuclear Desalination Applications

1. References
2. Nuclear Energy
3. **Global Nuclear Enterprise – Applications (Market)**
4. Reliability in Nuclear: Zero Emissions and Safe
5. Nuclear Desalination
6. Deployment Strategies and Timelines
7. Reliability Expectations for Nuclear Desalination
8. Observations and Questions to Ask (Metrics)

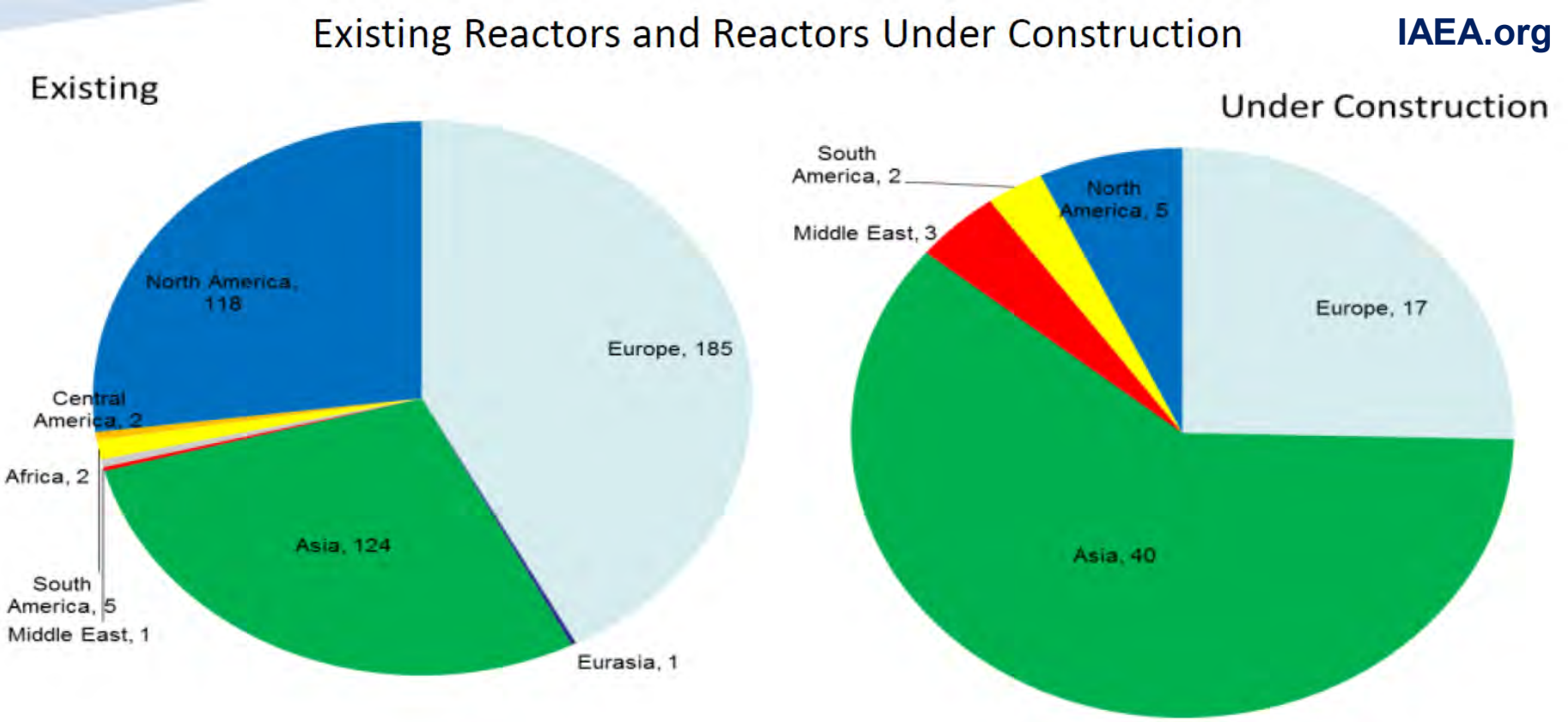
3. Global Nuclear Enterprise – Applications (Market)



- 438 Operating Reactors in 30 Countries
- 11% of global electricity generated
- 40% of clean electricity

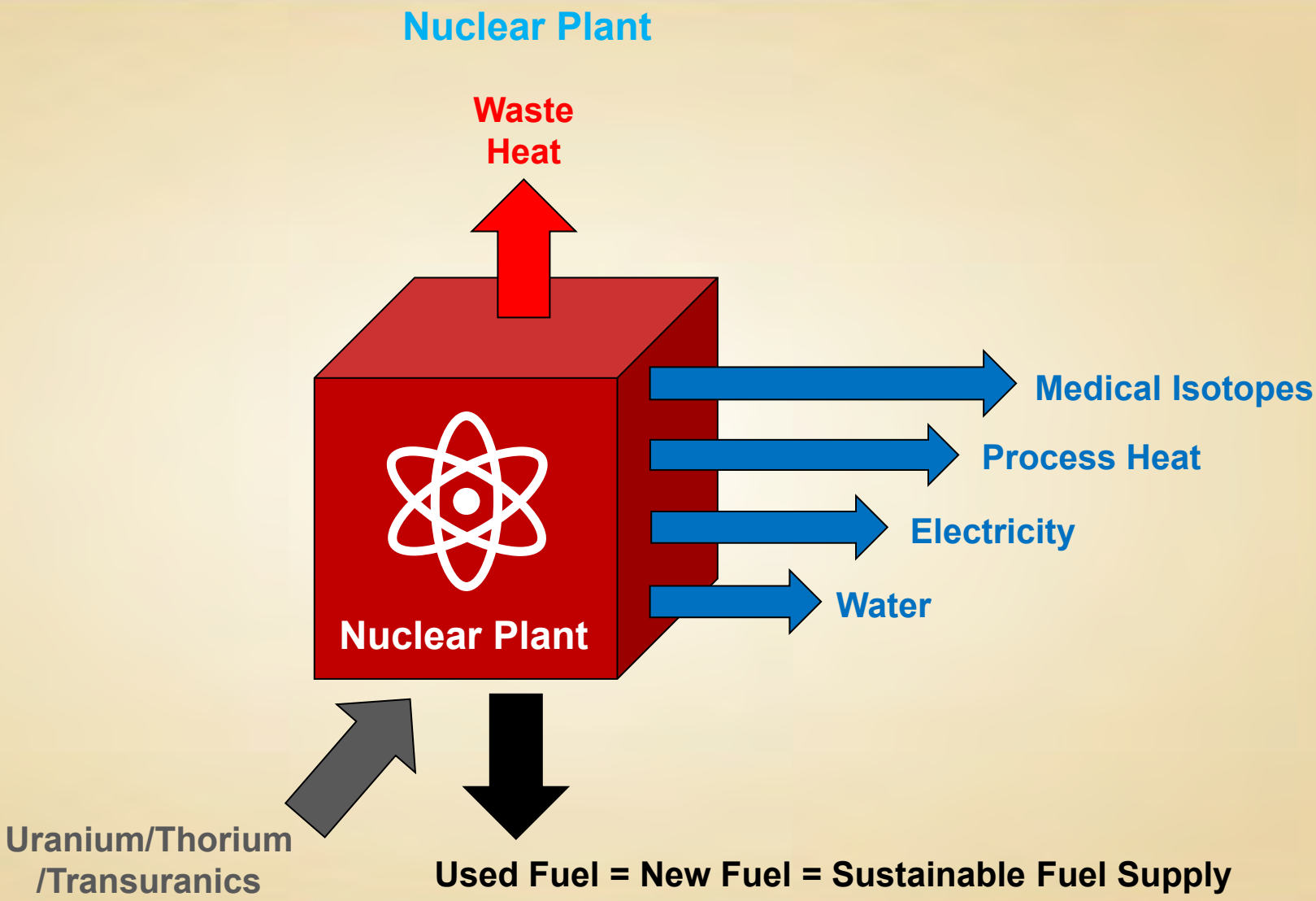
IAEA.org

3. Global Nuclear Enterprise – Applications (Market)

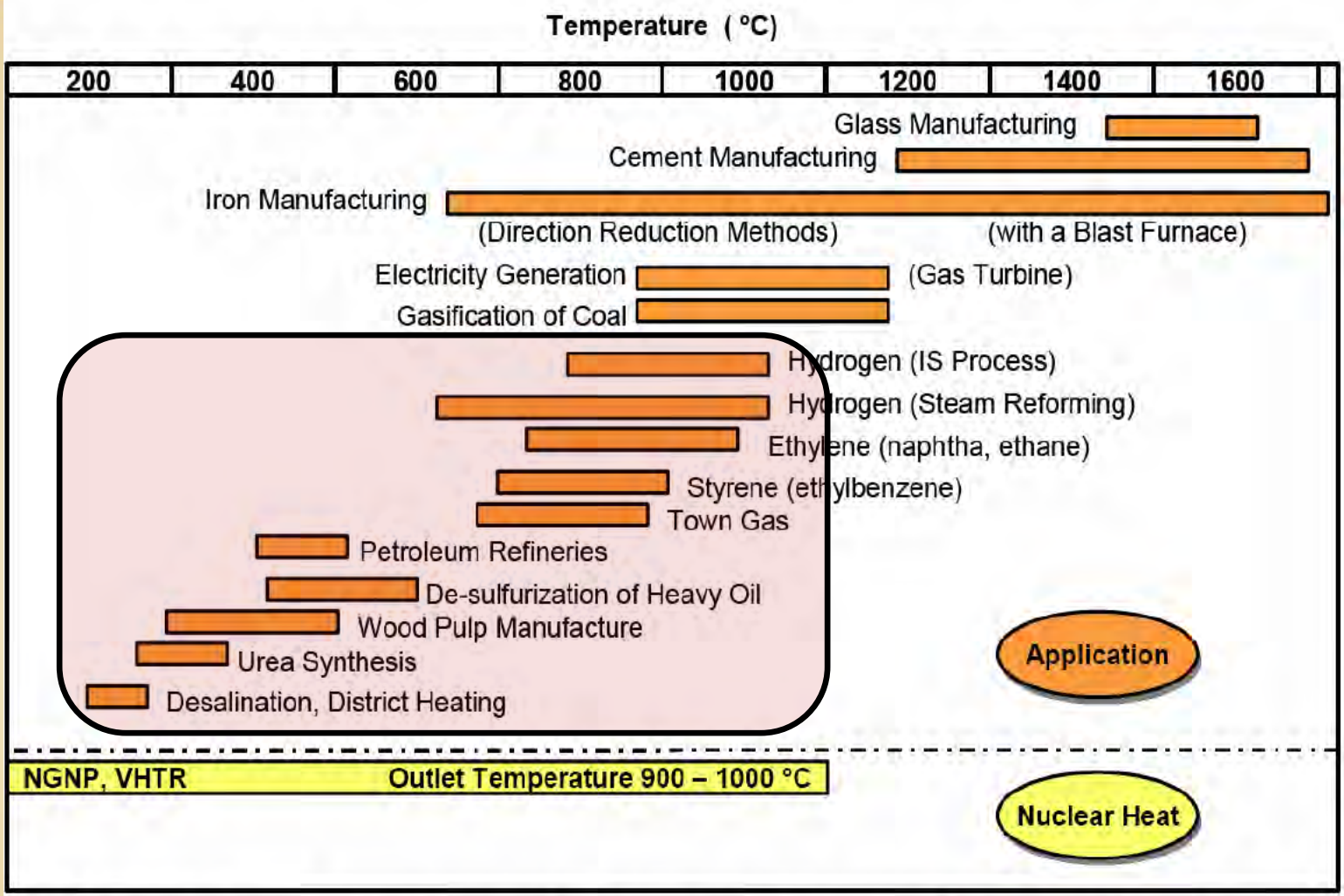


- 67 reactors currently under construction in 15 countries (26 in China)
  - ~183 reactors planned in +30 countries, worth as much as $700 billion
  - ~311 reactors proposed in 35 countries, worth as much as $1.6 trillion

3. Global Nuclear Enterprise – Applications (Market)

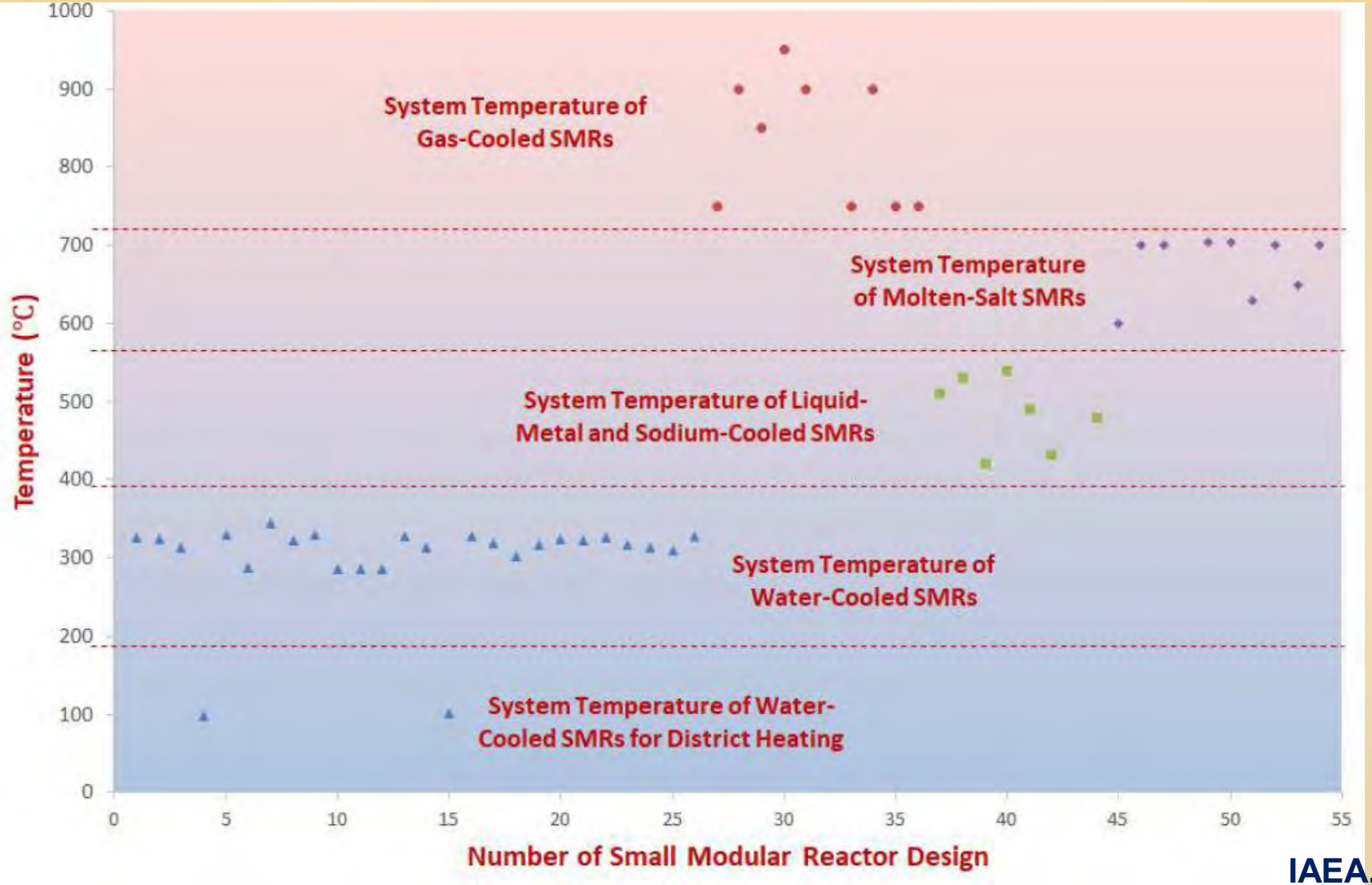


3. Global Nuclear Enterprise – Applications (Market)

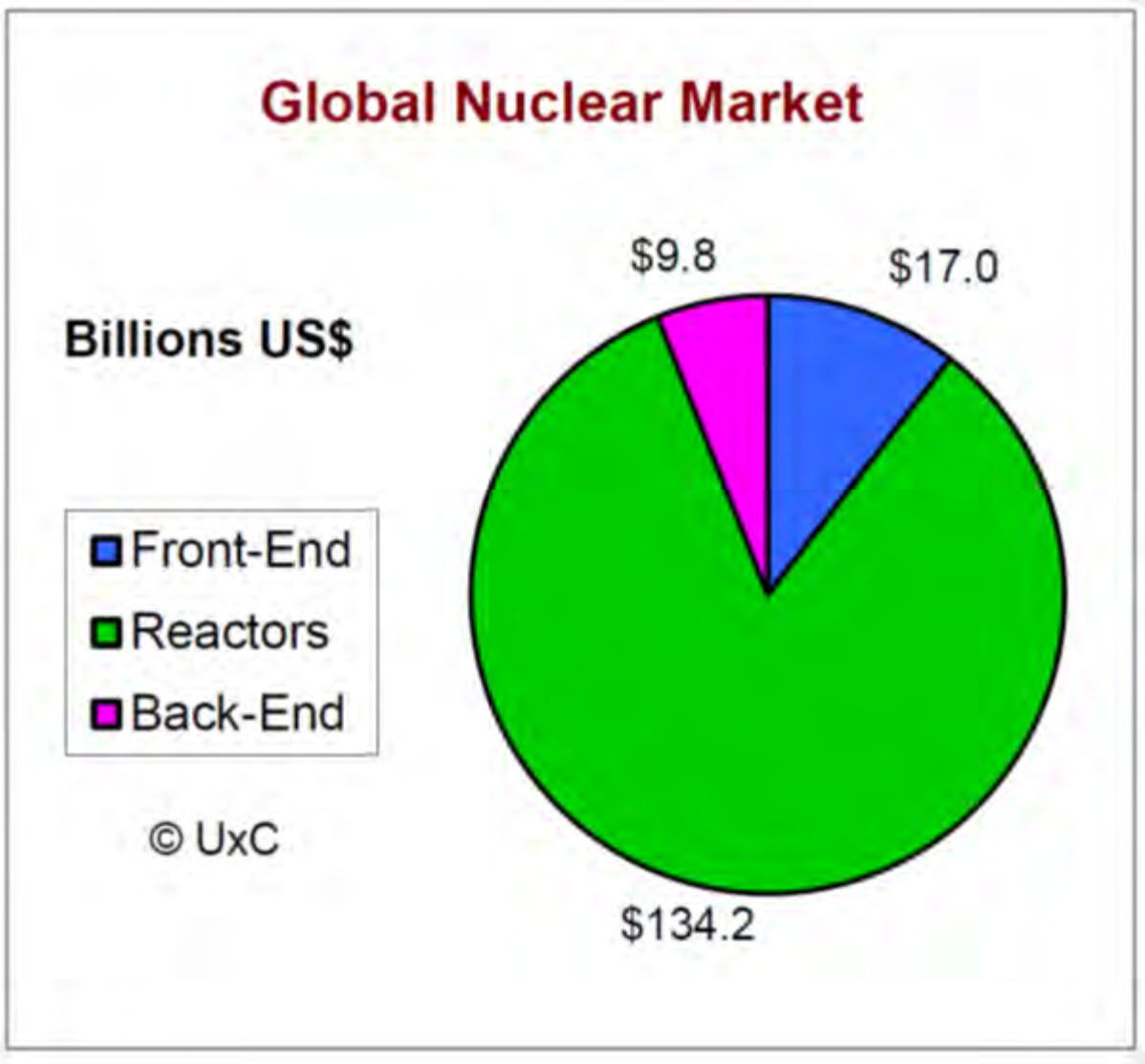


Temperature requirements for various process heat applications.

3. Global Nuclear Enterprise – Applications (Market)



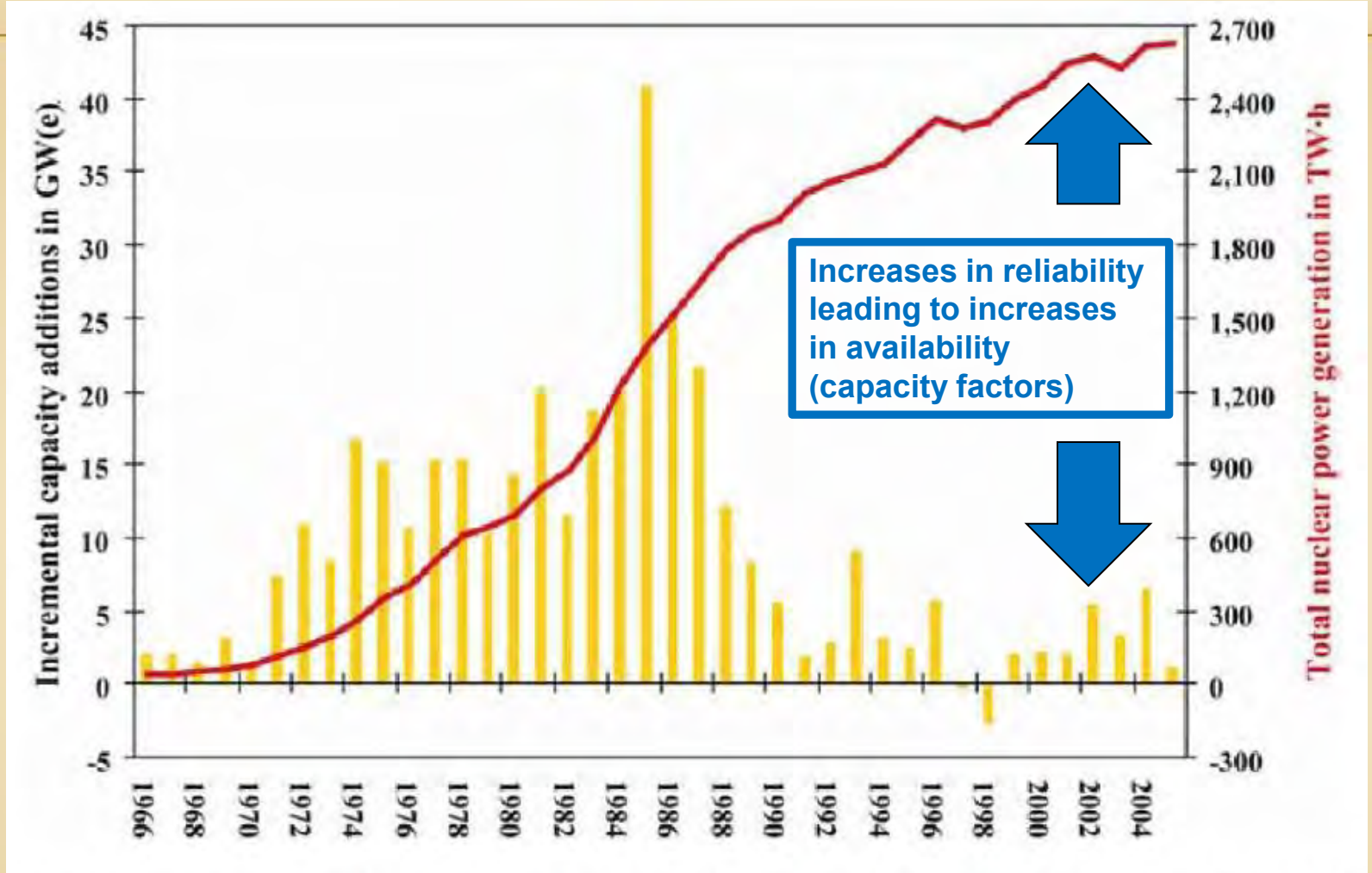
3. Global Nuclear Enterprise – Applications (Market)



Reliability Expectations for Industrial Nuclear Desalination Applications

1. References
2. Nuclear Energy
3. Global Nuclear Enterprise – Applications (Market)
4. **Reliability in Nuclear: Zero Emissions and Safe**
5. Nuclear Desalination
6. Deployment Strategies and Timelines
7. Reliability Expectations for Nuclear Desalination
8. Observations and Questions to Ask (Metrics)

4. Reliability in Nuclear: Zero Emissions and Safe

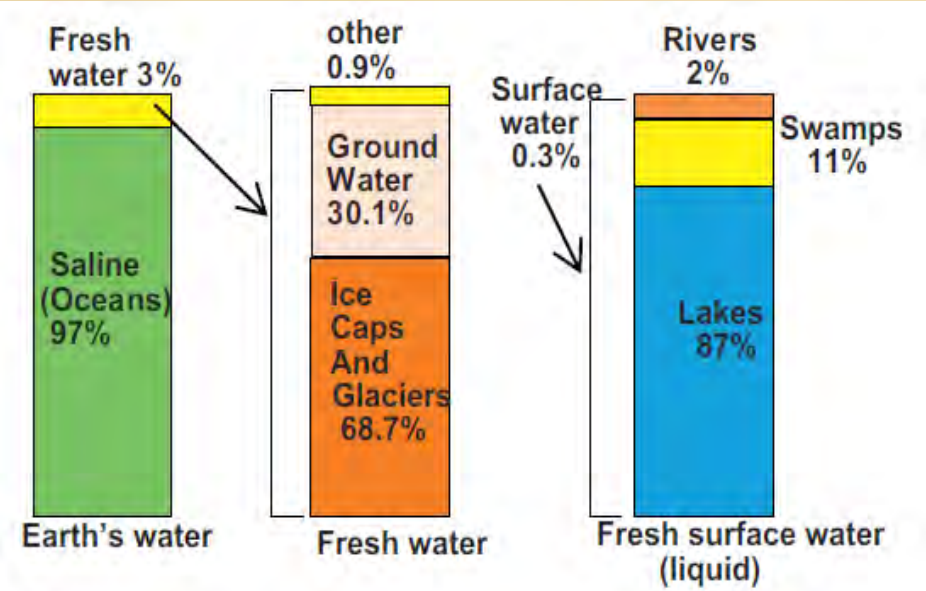


Nuclear electricity generation and capacity additions since 1966

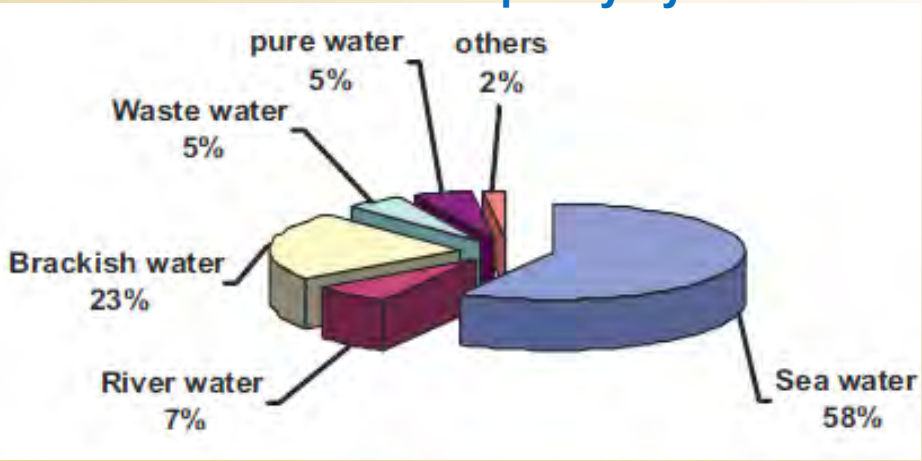
Reliability Expectations for Industrial Nuclear Desalination Applications

1. References
2. Nuclear Energy
3. Global Nuclear Enterprise – Applications (Market)
4. Reliability in Nuclear: Zero Emissions and Safe
5. **Nuclear Desalination**
6. Deployment Strategies and Timelines
7. Reliability Expectations for Nuclear Desalination
8. Observations and Questions to Ask (Metrics)

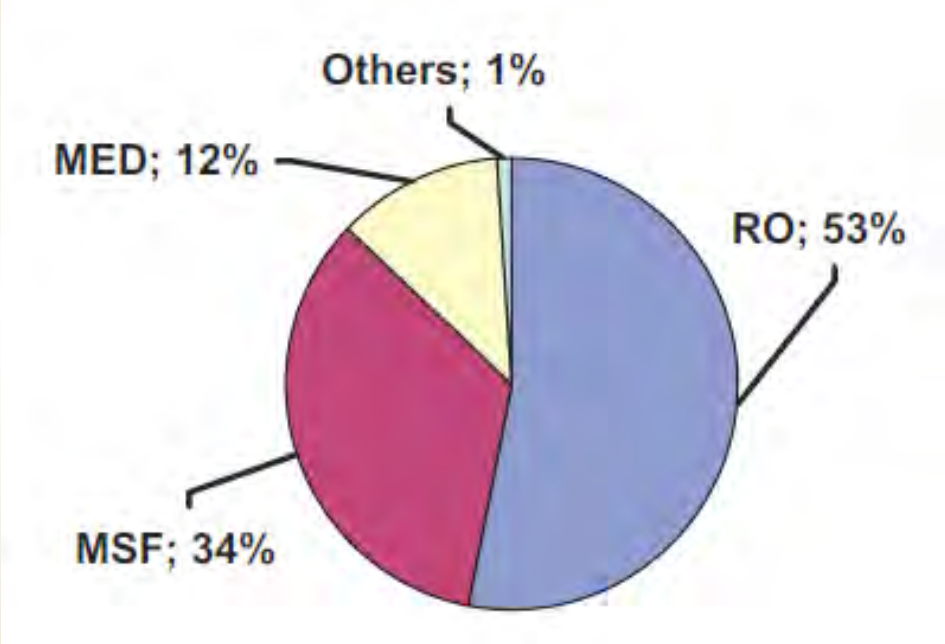
5. Nuclear Desalination



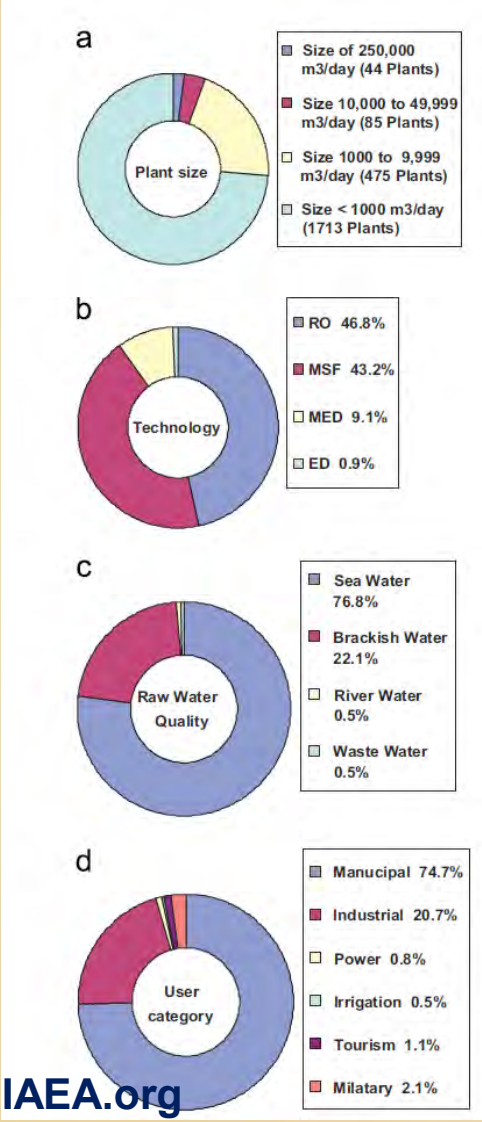
Installed desalination capacity by feed-water



Desalination technology



5. Nuclear Desalination



Micro Reactors

Micro reactors – 1 – 20 MW output (ether for electricity generation or heat or co-generation) (DOE)

Small Modular Reactors

Small reactors – hundreds MW (on the order of 300 MW) output (ether for electricity or heat or co-generation) (DOE)

Small & Medium Reactors (SMR)

Small reactors – under 300 MWe

Medium reactors – 300 - 700 MWe (IAEA)

Small and medium-sized reactors – up to 600 MW output (ether for electricity or heat or co-generation) (OECD NEA)

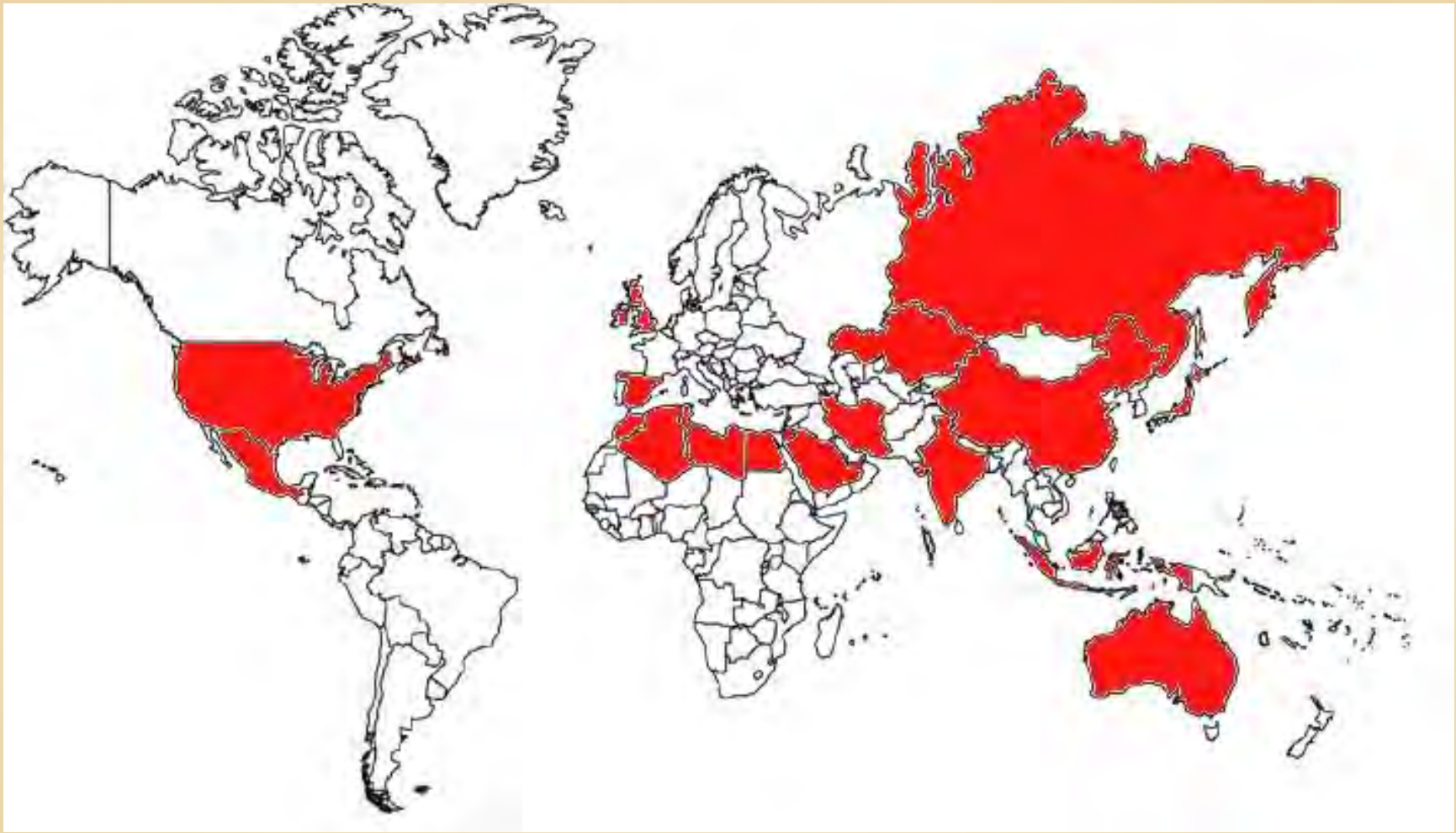
Large Power Reactors

Large reactors – 1000 MW output (ether for electricity generation or heat or co-generation)

5. Nuclear Desalination

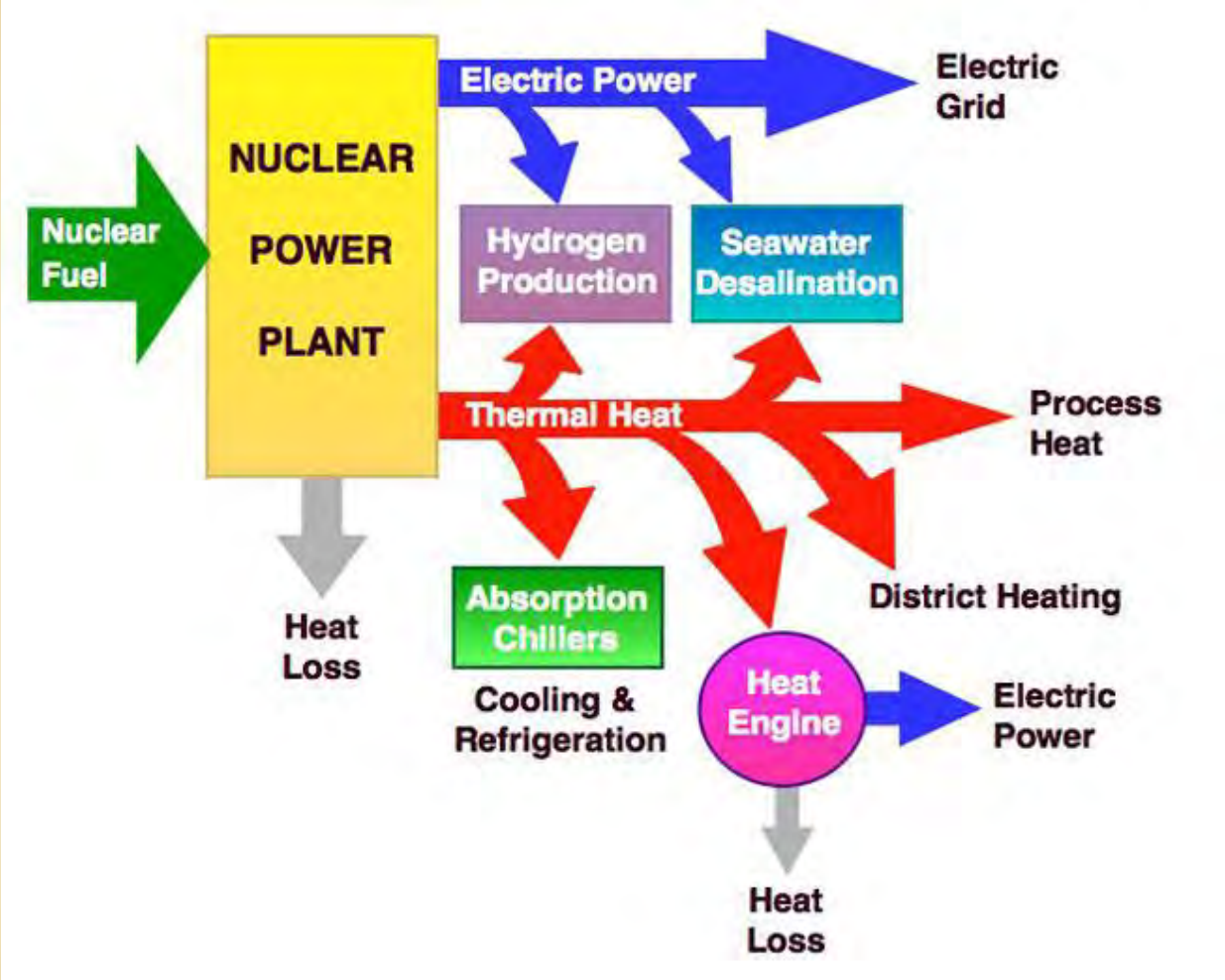
- Potable water is in short supply in many parts of the world. Lack of it is set to become a constraint on development in some areas.
- Nuclear energy is already being used for desalination and has the potential for much greater use.
- Nuclear desalination is generally very cost-competitive with using fossil fuels. "Only nuclear reactors are capable of delivering the copious quantities of energy required for large-scale desalination projects" in the future (IAEA 2015).
- As well as desalination of brackish or sea water, treatment of urban wastewater is increasingly undertaken.

5. Nuclear Desalination



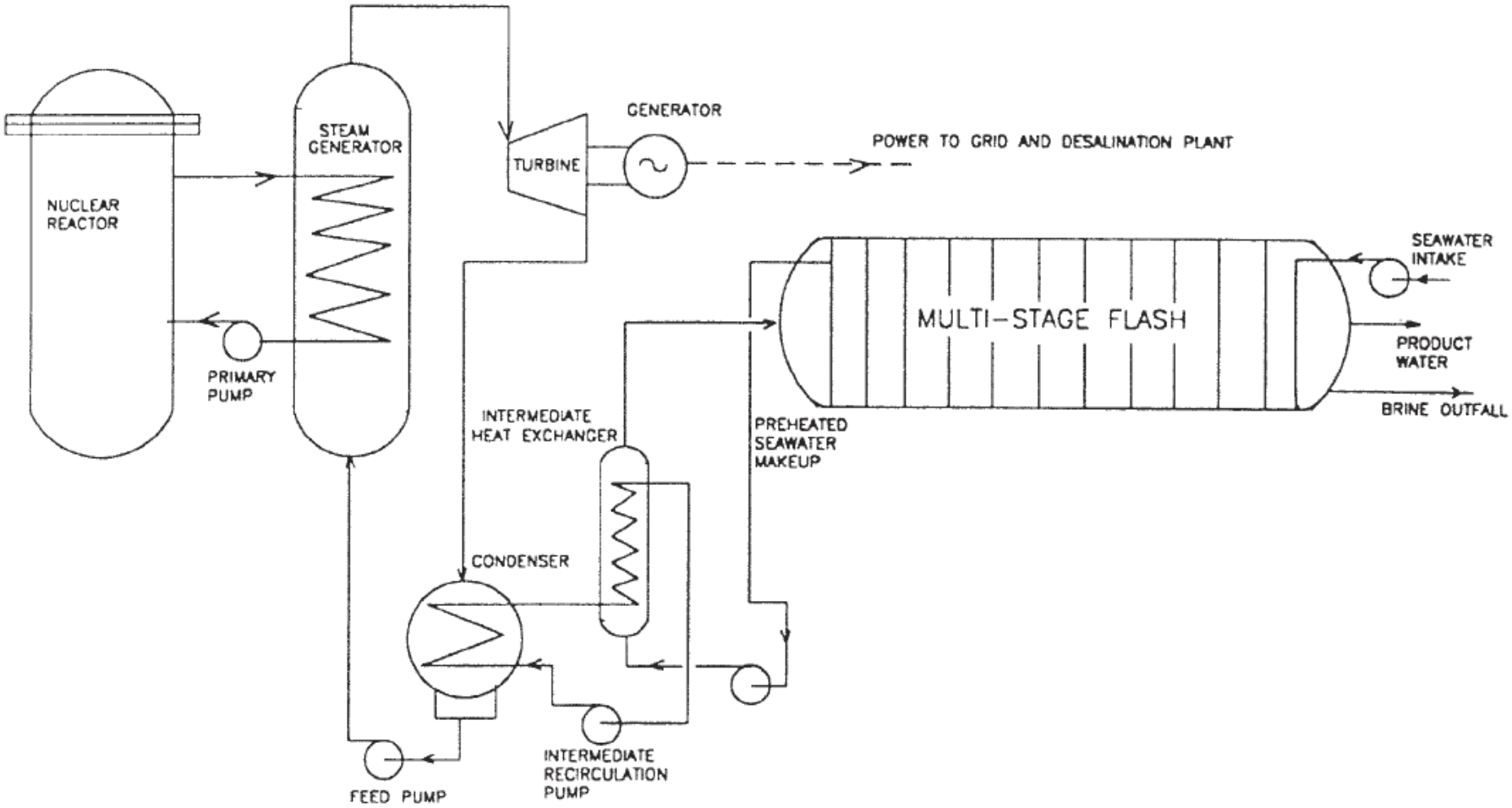
https://sites.google.com/site/kjdesalination/nuclear-desalination

5. Nuclear Desalination

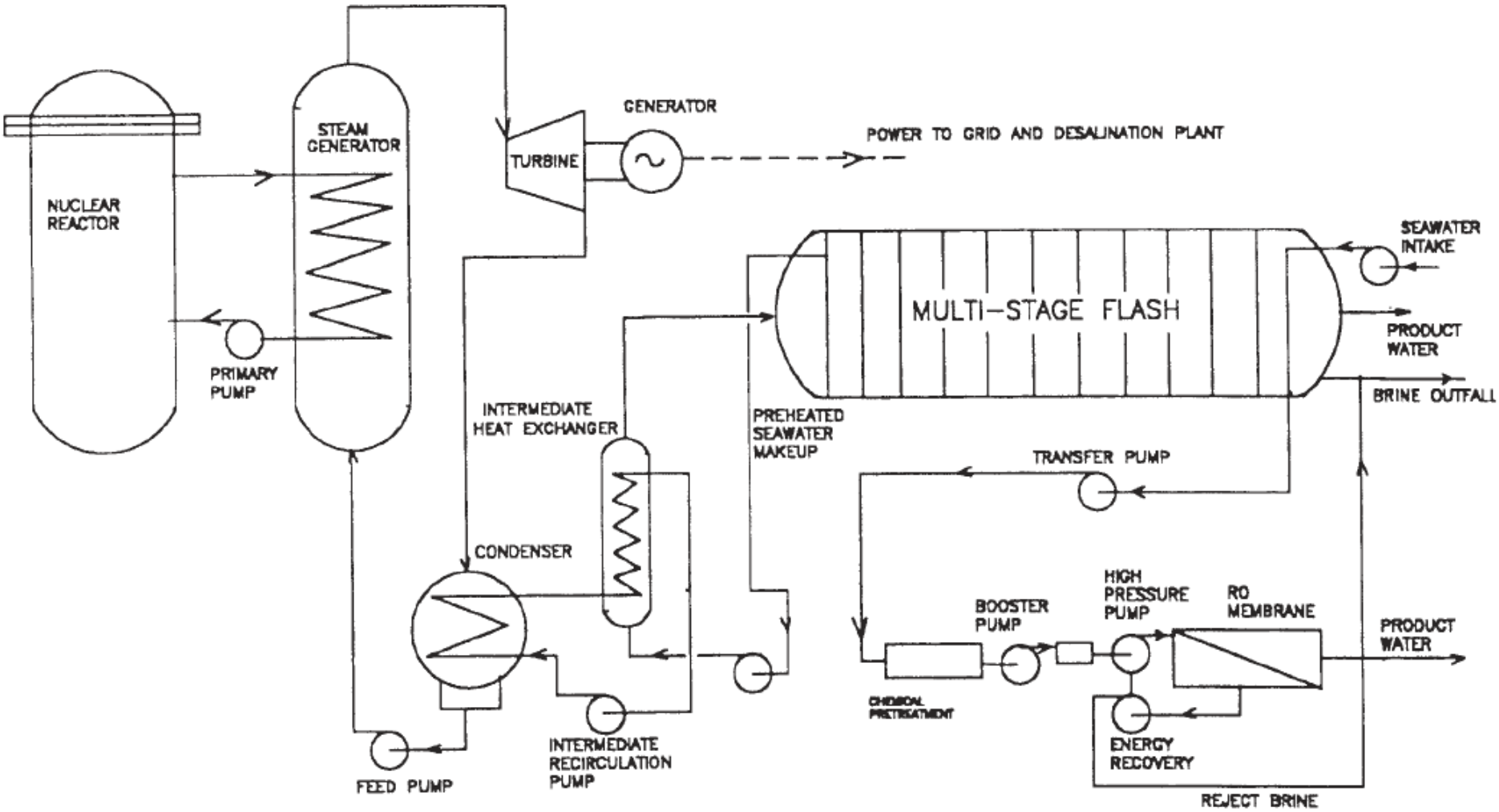


https://www.iaea.org/topics/non-electric-applications/industrial-applications-and-nuclear-cogeneration

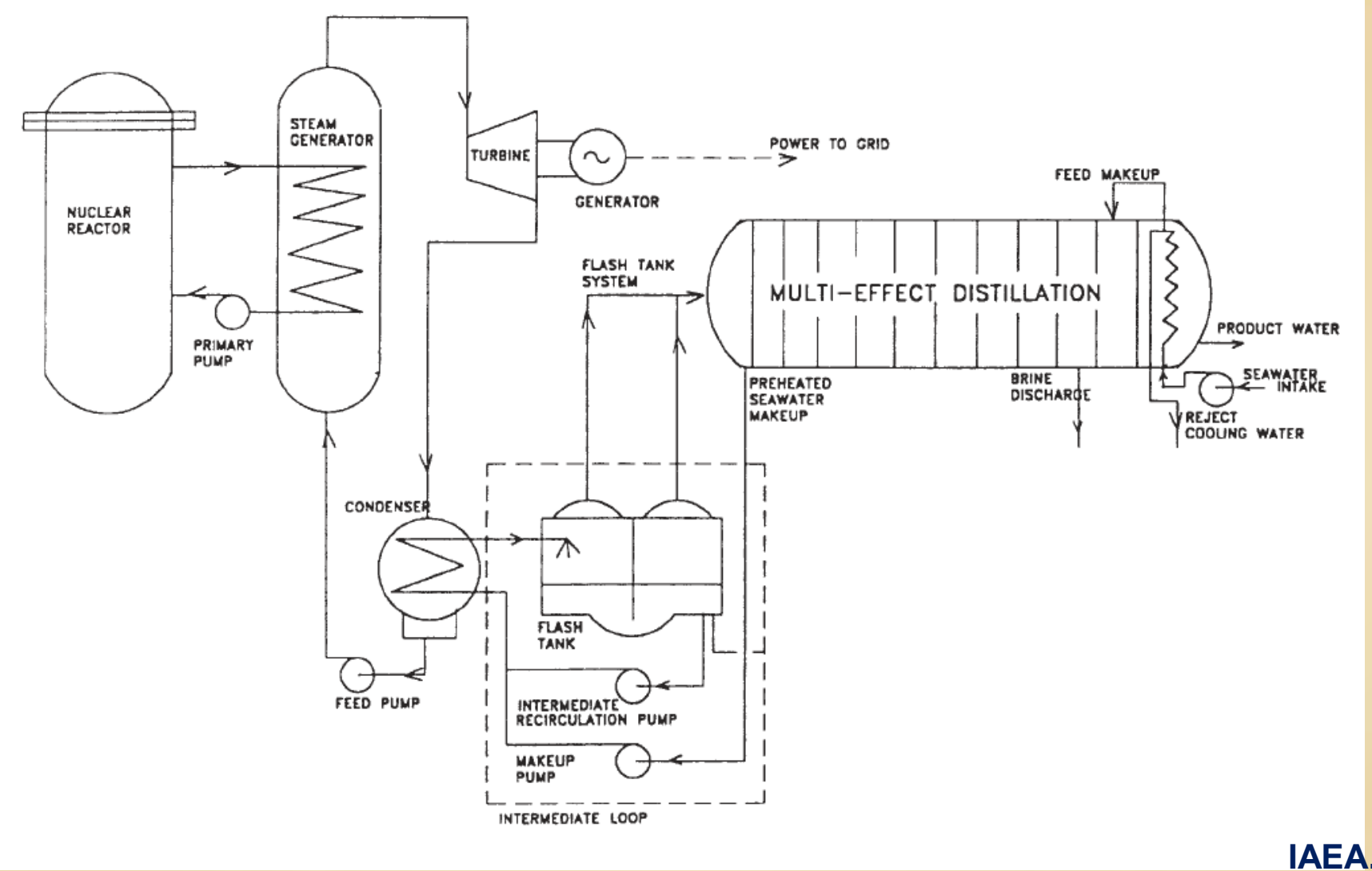
5. Nuclear Desalination



5. Nuclear Desalination



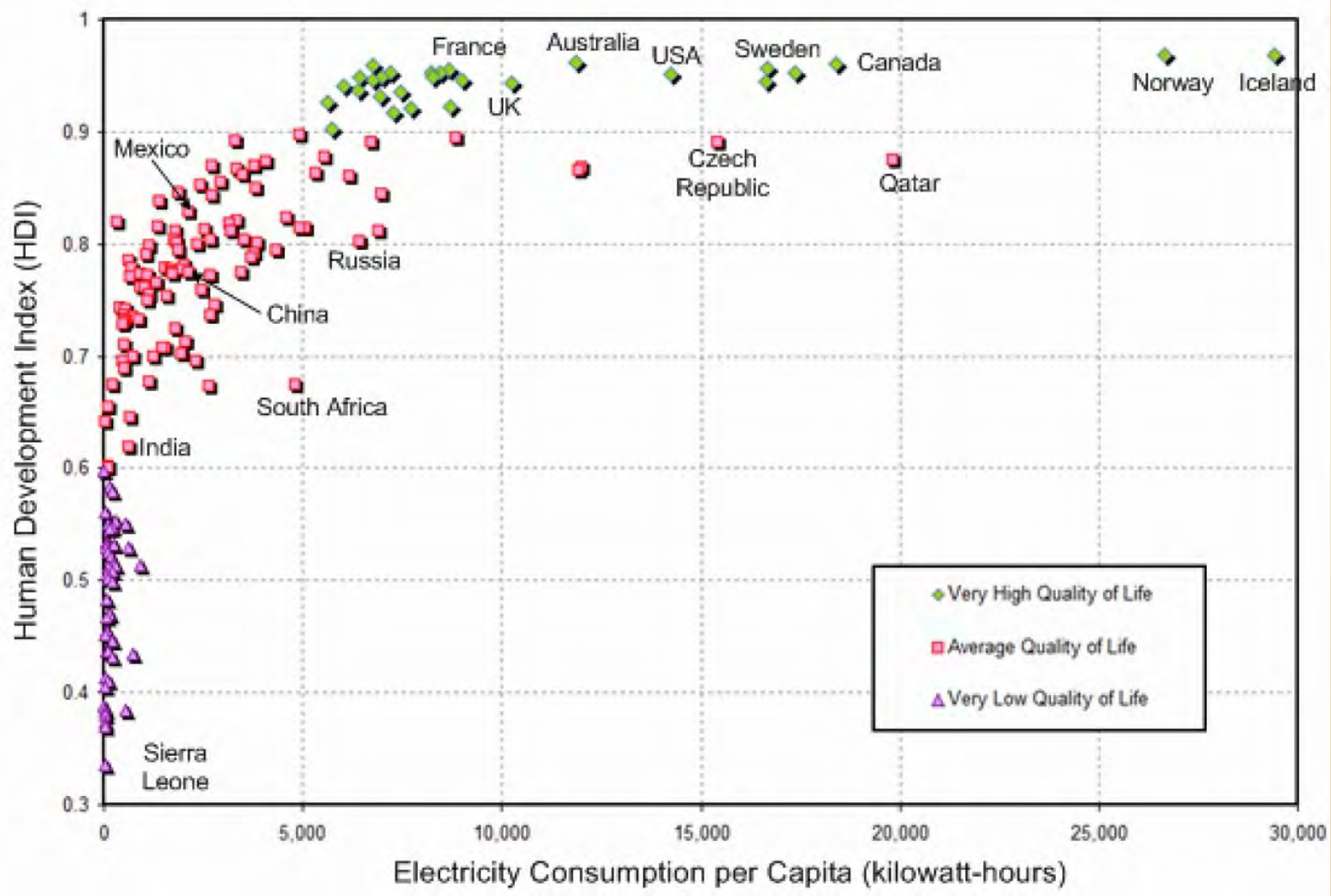
5. Nuclear Desalination



Reliability Expectations for Industrial Nuclear Desalination Applications

1. References
2. Nuclear Energy
3. Global Nuclear Enterprise – Applications (Market)
4. Reliability in Nuclear: Zero Emissions and Safe
5. Nuclear Desalination
6. **Deployment Strategies and Timelines**
7. Reliability Expectations for Nuclear Desalination
8. Observations and Questions to Ask (Metrics)

6. Deployment Strategies and Timelines

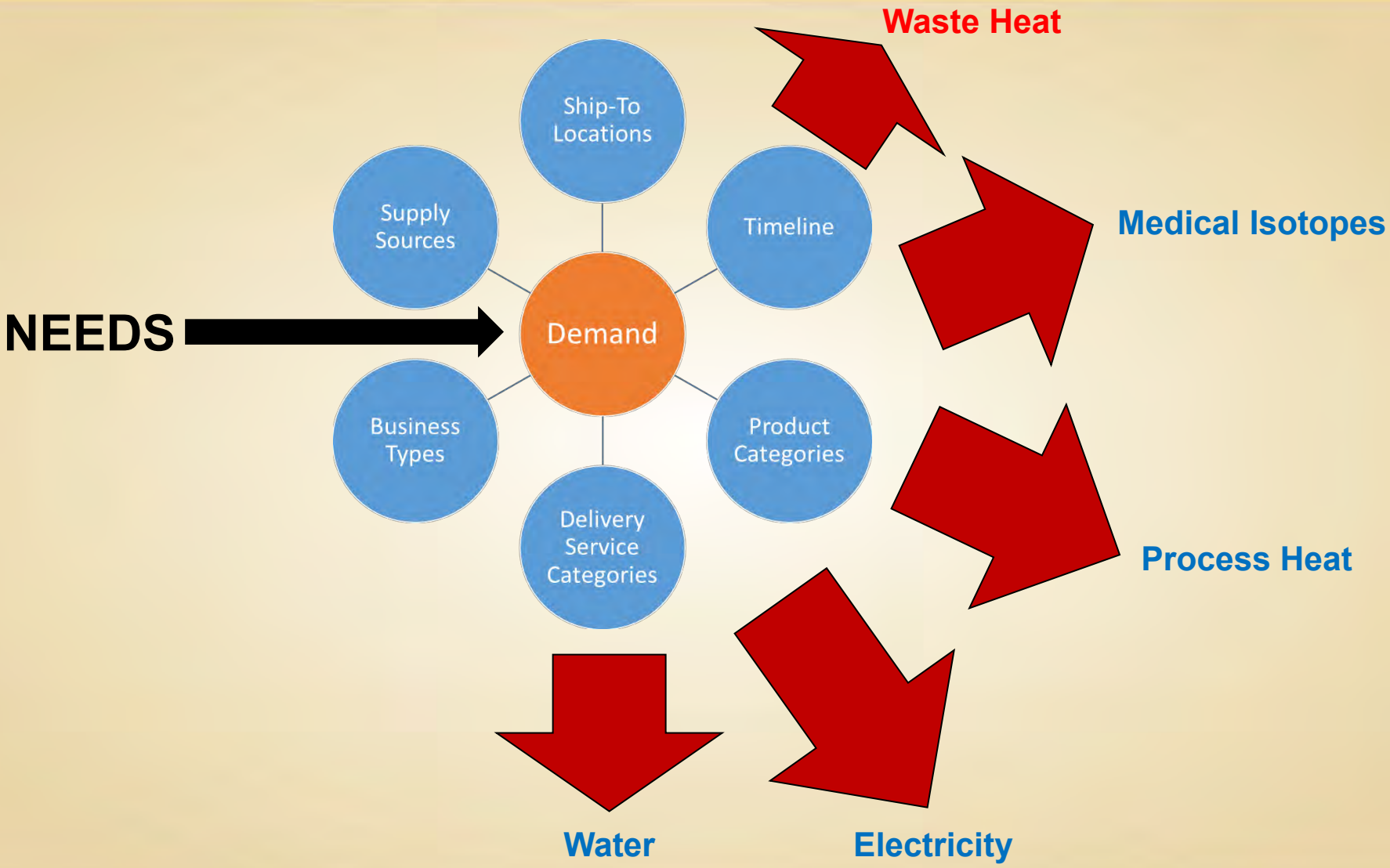


6. Deployment Strategies and Timelines

Energy Supply and Demand

IAEA.org

6. Deployment Strategies and Timelines



6. Deployment Strategies and Timelines

All reactor vendors recognize global energy trends and challenges

6. Deployment Strategies and Timelines

All reactor vendors offer "Full-package solutions"

Package Deal = Power Unit+ Service +New Fuel/Waste Management

The GE Hitachi business

Nuclear Power Plants

- Generation III Advanced Boiling Water Reactor (ABWR)
- Generation III+ Economically Simplified Boiling Water Reactor (ESBWR)
- Power Reactor Innovative Small Modular (PRISM)

Nuclear Services

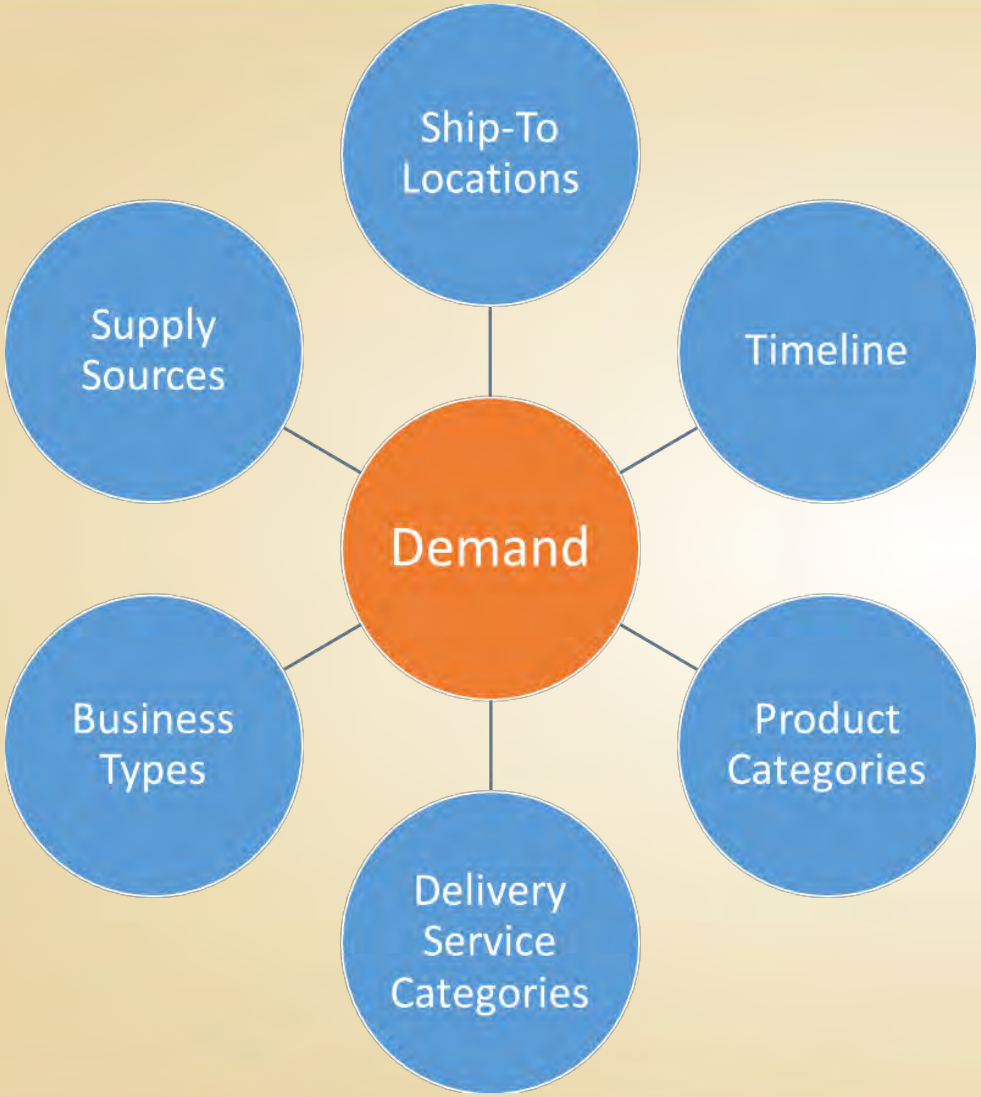
- Reactors & balance of plant
- Life extension
- Power uprates
- Performance services
- Outages and inspections

Fuel Cycle

- Boiling water reactor & mixed oxide fuels
- Candu reactor fuel & handling equipment
- Fuel engineering services
- Nuclear isotopes
- Used nuclear fuel recycling
- Enrichment of natural uranium

HITACHI

6. Deployment Strategies and Timelines



Supply

User (Utility)

- Financial profile and credit capability
- Products
- Prices

Reactor vendor

- Technology Readiness Level (TRL)
- Financial capability
- Supply chain readiness
- Product diversity and competition

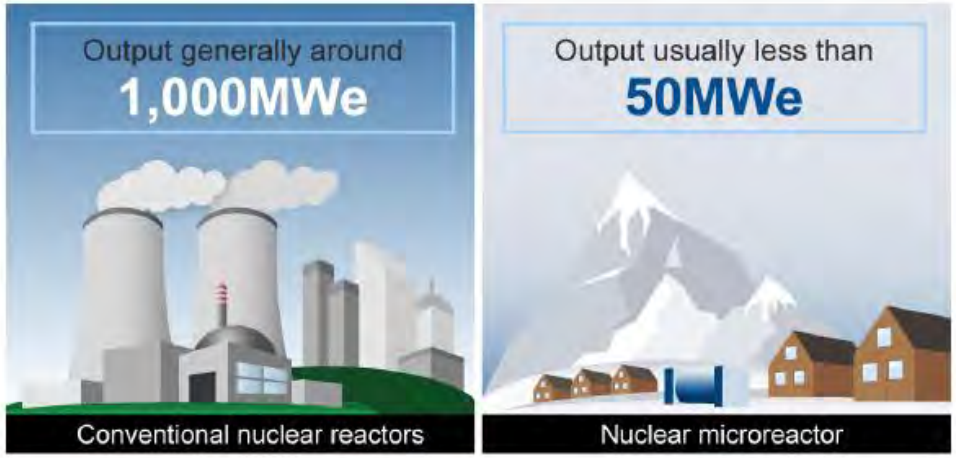
Demand

Customer

- Needs (sufficiency of supply)
- Market: offers and alternatives
- Financial capability

6. Deployment Strategies and Timelines

From Small Modular Reactors to Micro Reactors



Source: GAO. | GAO-20-380SP

Supply Challenges

- Limited fuel supply
- Maintenance
- Security and proliferation risk
- Used unit decommissioning TRL
- Waste stream TRL
- Licensing

Demand Advantages

- Manufacturability (factory assembly line)
- Economics scalability
- Technical scalability
- Adaptability
- Rapid deployment capability
- Higher degree of unit resiliency

Source: GAO. | GAO-20-380SP

6. Deployment Strategies and Timelines

Life Cycle of a Nuclear Power Station

0 10 20 30 40 50 60 70 80 90 100

Pre-Operation (6-10 years)

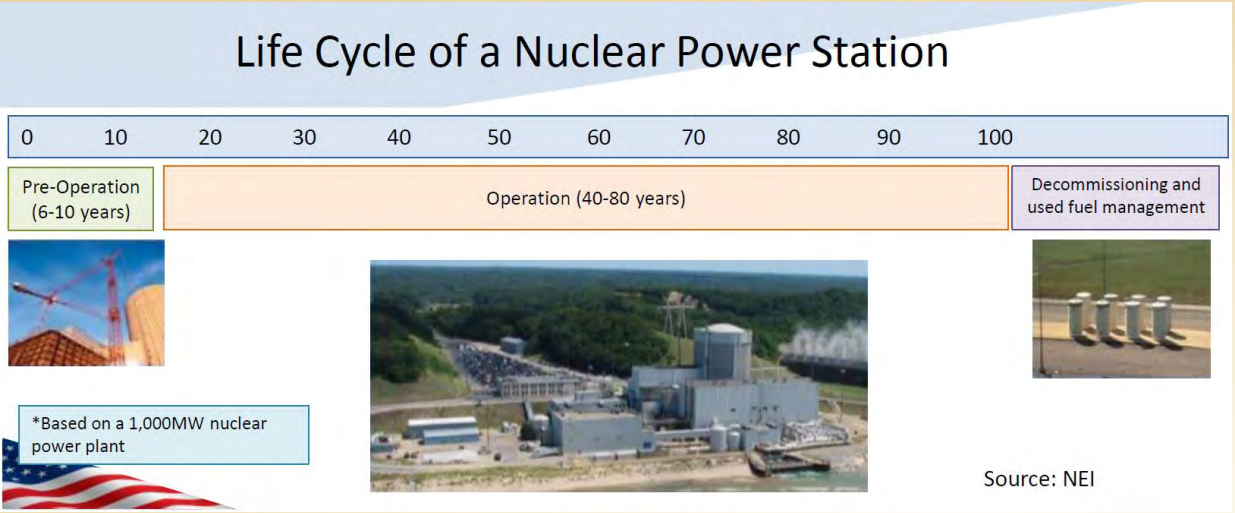
Operation (40-80 years)

Decommissioning and used fuel management

*Based on a 1,000MW nuclear power plant

Source: NEI

6. Deployment Strategies and Timelines

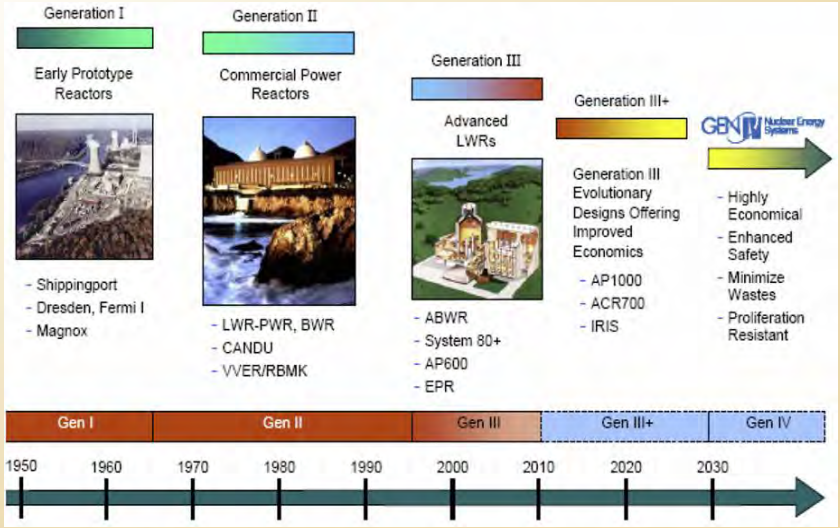


Legacy factor is very significant:

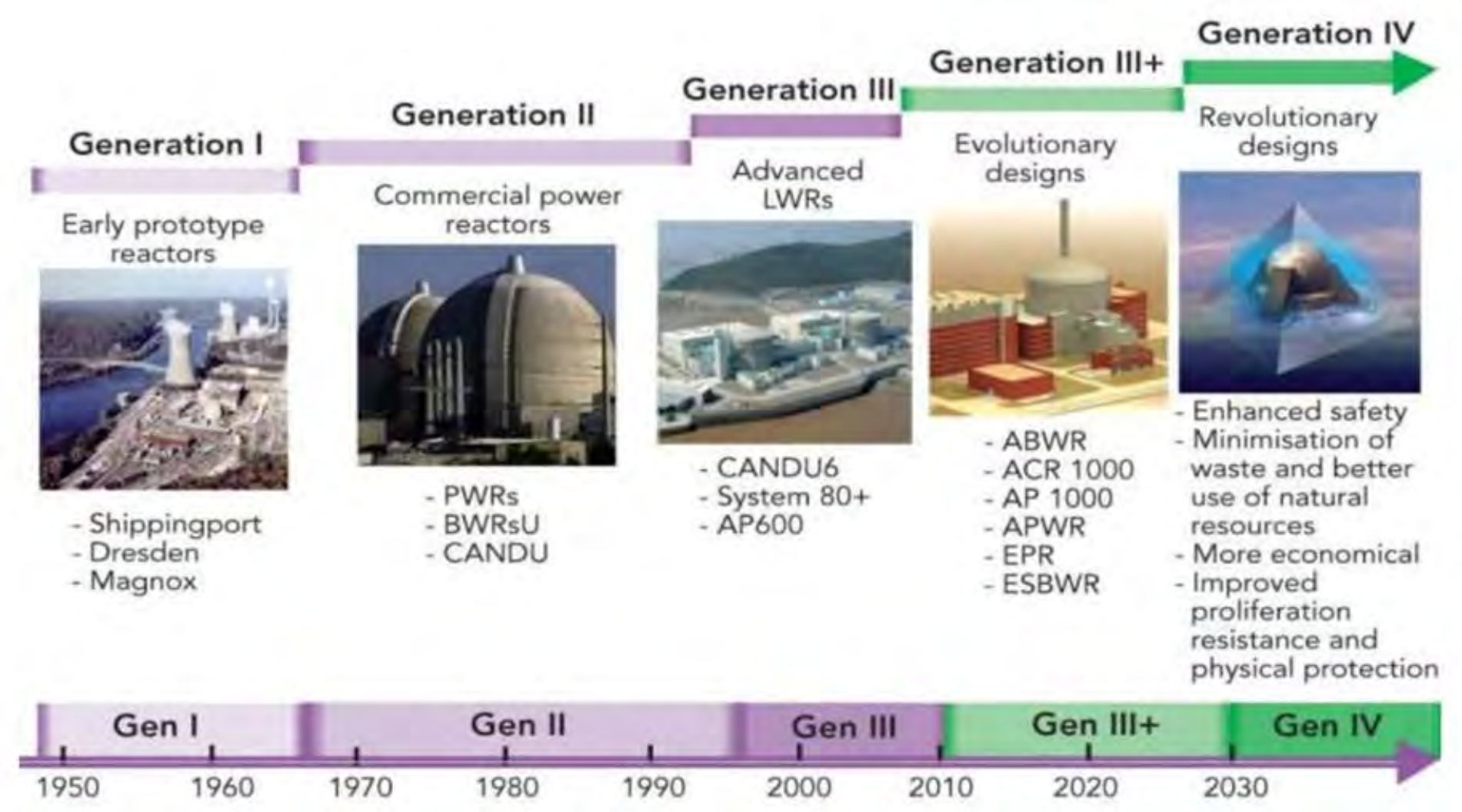
- safety/practice driven
- Economics inertia of infrastructure
- "Business as usual" due to complexity

Legacy factor = technology inertia = challenges to compete

- Other technologies may move ahead
- Slow evolution/stagnation
- Economics of resources



6. Deployment Strategies and Timelines



Reliability Expectations for Industrial Nuclear Desalination Applications

1. References
2. Nuclear Energy
3. Global Nuclear Enterprise – Applications (Market)
4. Reliability in Nuclear: Zero Emissions and Safe
5. Nuclear Desalination
6. Deployment Strategies and Timelines
7. **Reliability Expectations for Nuclear Desalination**
8. Observations and Questions to Ask (Metrics)

7. Reliability Expectations for Nuclear Desalination

Considerations for nuclear power plant construction options:

- Safety and licensing
- Manpower, management, operation
- Site
- Nuclear fuel vs. fossil fuel competition
- Coolant availability
- Supply chain: fuel, infrastructure
- Environment
- Grid
- **Lifecycle – 40 – 100+ years**, availability factor expectation – 95%, high-cost maintenance, high reliability

Desalination stages are not nuclear safety significant. By design, they do not impact nuclear safety unless integrated.

Challenge - combined reliability

Solution 1 (if co-generation) – relative independence of nuclear and co-generation stages

Solution 2 – single purpose plants

Considerations for co-generation options (desalination focus):

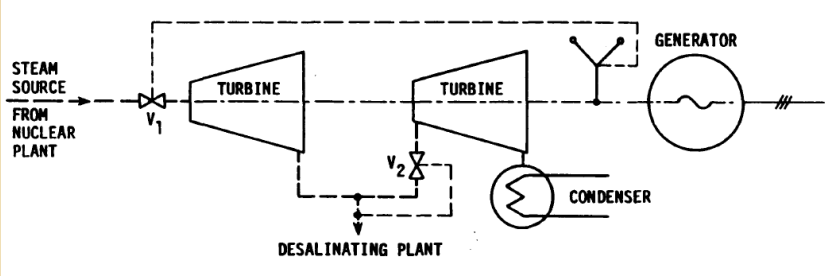
- Manpower, management, operation
- Site
- Availability and reliability of desalination stages
- Integration of desalination and power generation stages
- Non-nuclear safety considerations
- **Lifecycle – 25 years**, low-cost maintenance, low reliability

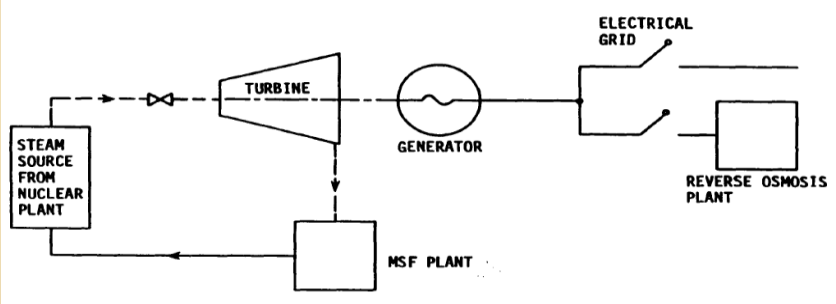
7. Reliability Expectations for Nuclear Desalination

Option 1 – close integration

Advantage: small footprint

Challenge: nuclear safety, access





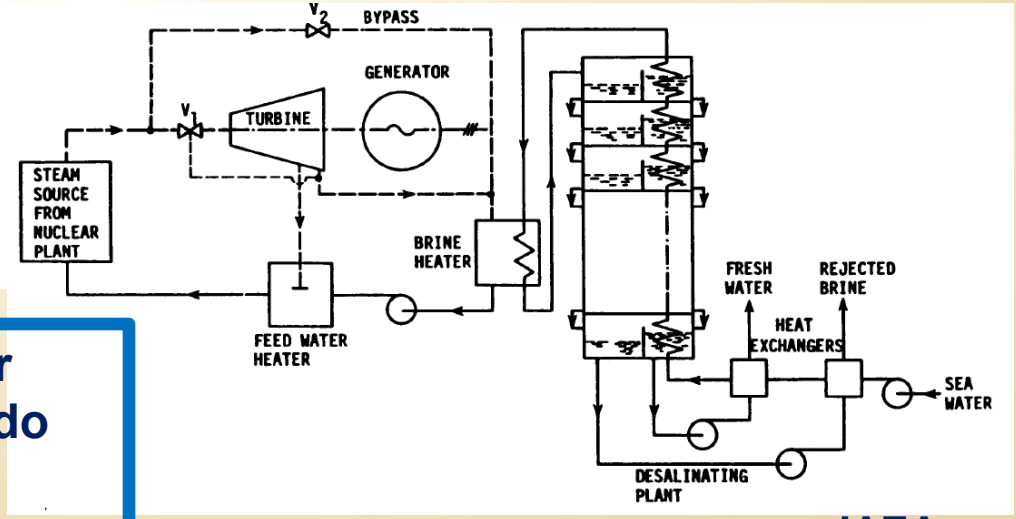
Challenge - combined reliability

Solution – relative independence of nuclear and co-generation stages

Option 2 – component separation

Advantage: non-nuclear safety, access

Challenge: larger footprint, product delivery



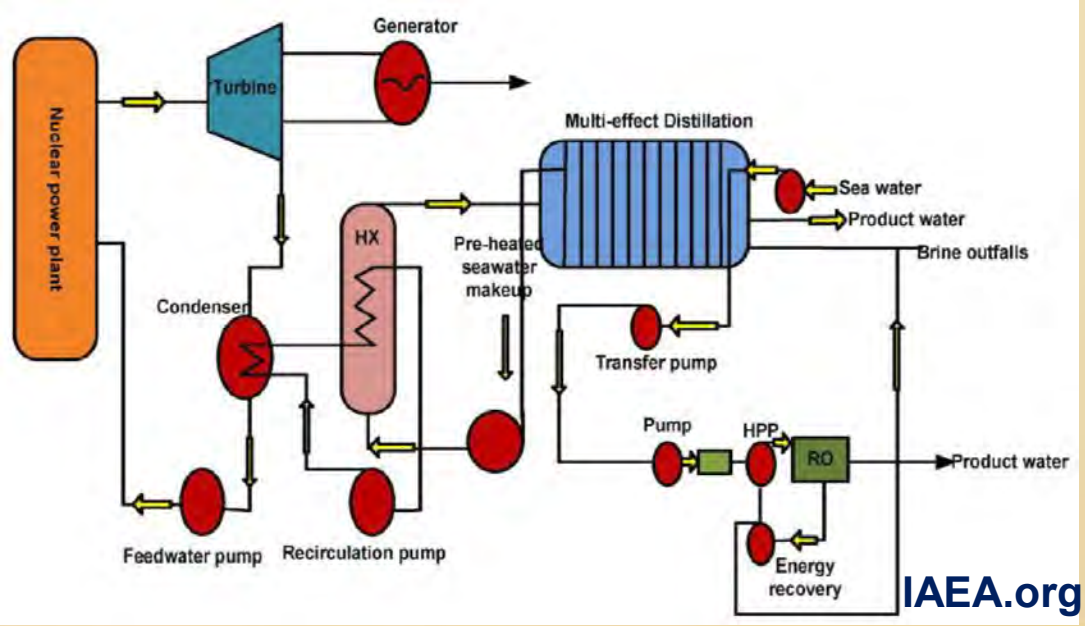
Desalination stages are not nuclear safety significant. By design, they do not impact nuclear safety.

7. Reliability Expectations for Nuclear Desalination

Factors affecting availability of desalination stages (reliability factors):

- Material performance, compatibility
- Mechanical design
- Radiochemistry
- Availability of components and materials
- Manpower availability and qualifications
- Operator and personnel training
- Maintenance practices
- External and environmental conditions and considerations
- Hazards

Reactor Type	Location	Desalination process	Status
PWR	Japan (Ohi, Genaki, Ikata)	MED, MSF, RO	In service for more than 125 years
	Korea and Argentina	MED and RO	Under design
BWR	Japan	MSF	Testing in the 1980s, dismantled in 1999
NHR	China	MED	Under design
LMFR	Kazakhstan	MED, MSF	Was in service till 1999
HTGR	South Africa, France, Netherlands	MED, MSF, RO	Under consideration
PHWR	India, Canada and Pakistan	MED, MSF, RO	Under design



Reliability Expectations for Industrial Nuclear Desalination Applications

1. References
2. Nuclear Energy
3. Global Nuclear Enterprise – Applications (Market)
4. Reliability in Nuclear: Zero Emissions and Safe
5. Nuclear Desalination
6. Deployment Strategies and Timelines
7. Reliability Expectations for Nuclear Desalination
8. **Observations and Questions to Ask (Metrics)**

8. Observations and Questions to Ask (Metrics)

May be not really a competition but deployment adaptability?

Demand Metrics

- Carbon-free energy source
- **Scalable (adaptable) energy source**
- Integration with other energy sources (renewable, gas, etc.)
- Siting options flexibility (adaptability)
- Land sizing adaptability
- **Energy product diversity**
- **Increased resilience**

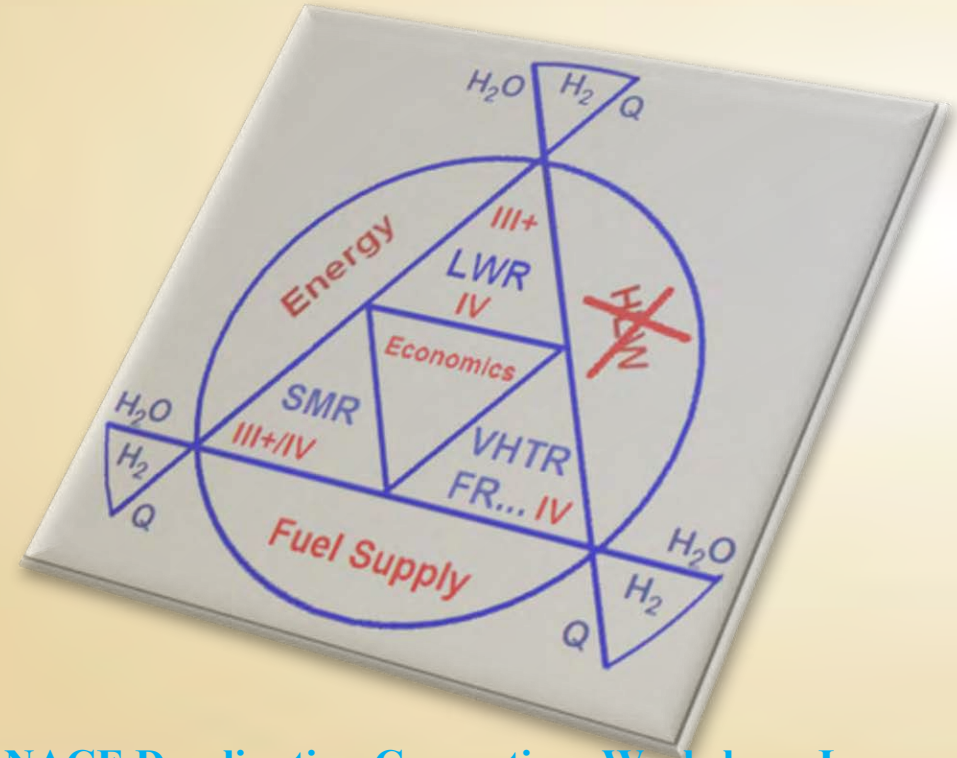
Reliability and sustainability

- Water supply (feed availability)
- Environmental impact: chemicals and heat pollution
- Economics

Supply Metrics

- Fuel availability
- Supply chain
- **Scope and range of deployment vs. deployment economics**
- **Maintenance**
- Security and proliferation risk
- **Licensing**
- Waste management TRL
- Decommissioning TRL

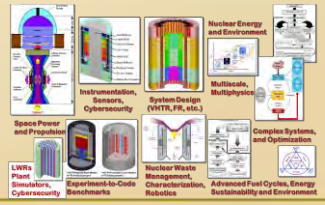
Reliability Expectations for Industrial Nuclear Desalination Applications



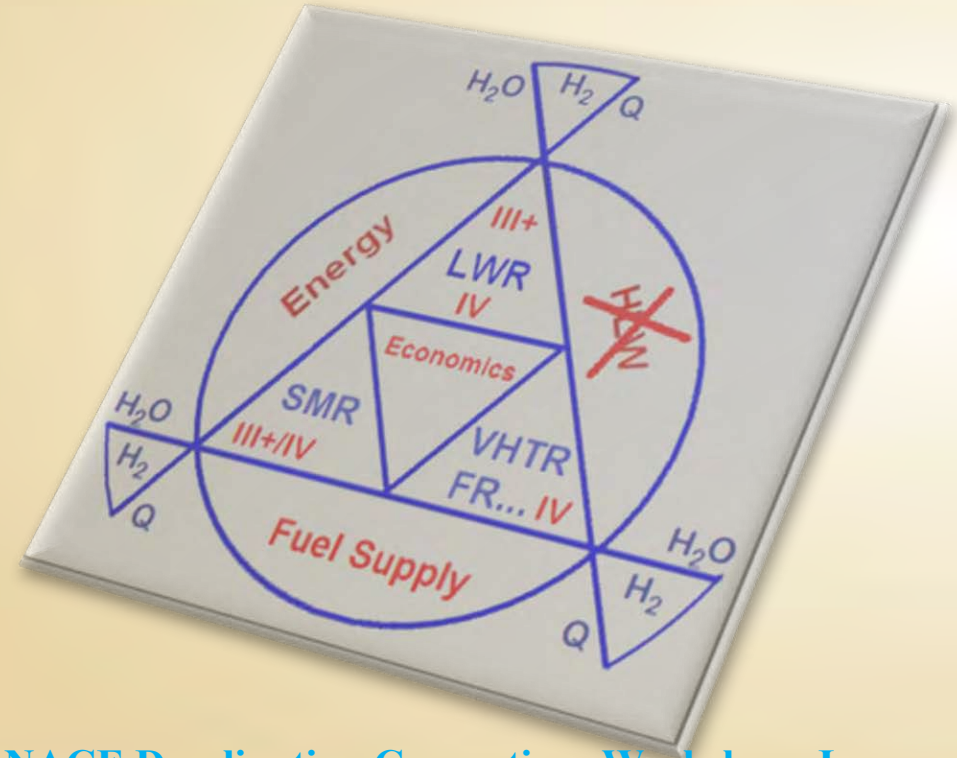
QUESTIONS?

Pavel V. Tsvetkov, tsvetkov@tamu.edu

Advanced Energy Systems Lab



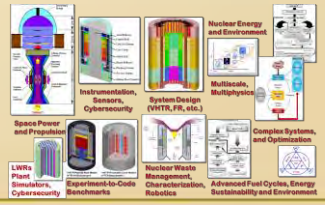
Reliability Expectations for Industrial Nuclear Desalination Applications



THANK YOU?

Pavel V. Tsvetkov, tsvetkov@tamu.edu

Advanced Energy Systems Lab



National Corrosion and Materials Reliability Laboratory (NCMRL)

TEXAS A&M UNIVERSITY

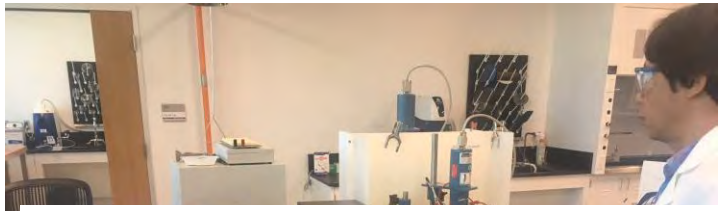
TEES
TEXAS A&M ENGINEERING EXPERIMENT STATION

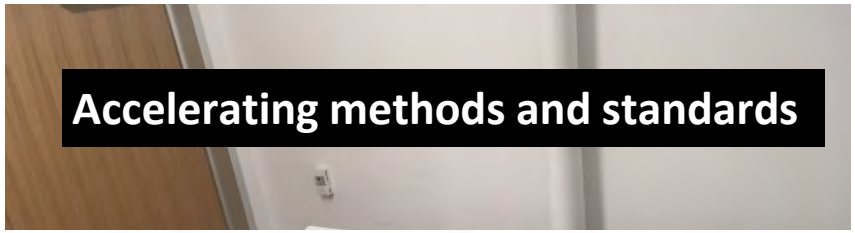
Dr. Homero Castaneda, FNACE
NACE CP Instructor
Associate Professor, Director of NCMRL

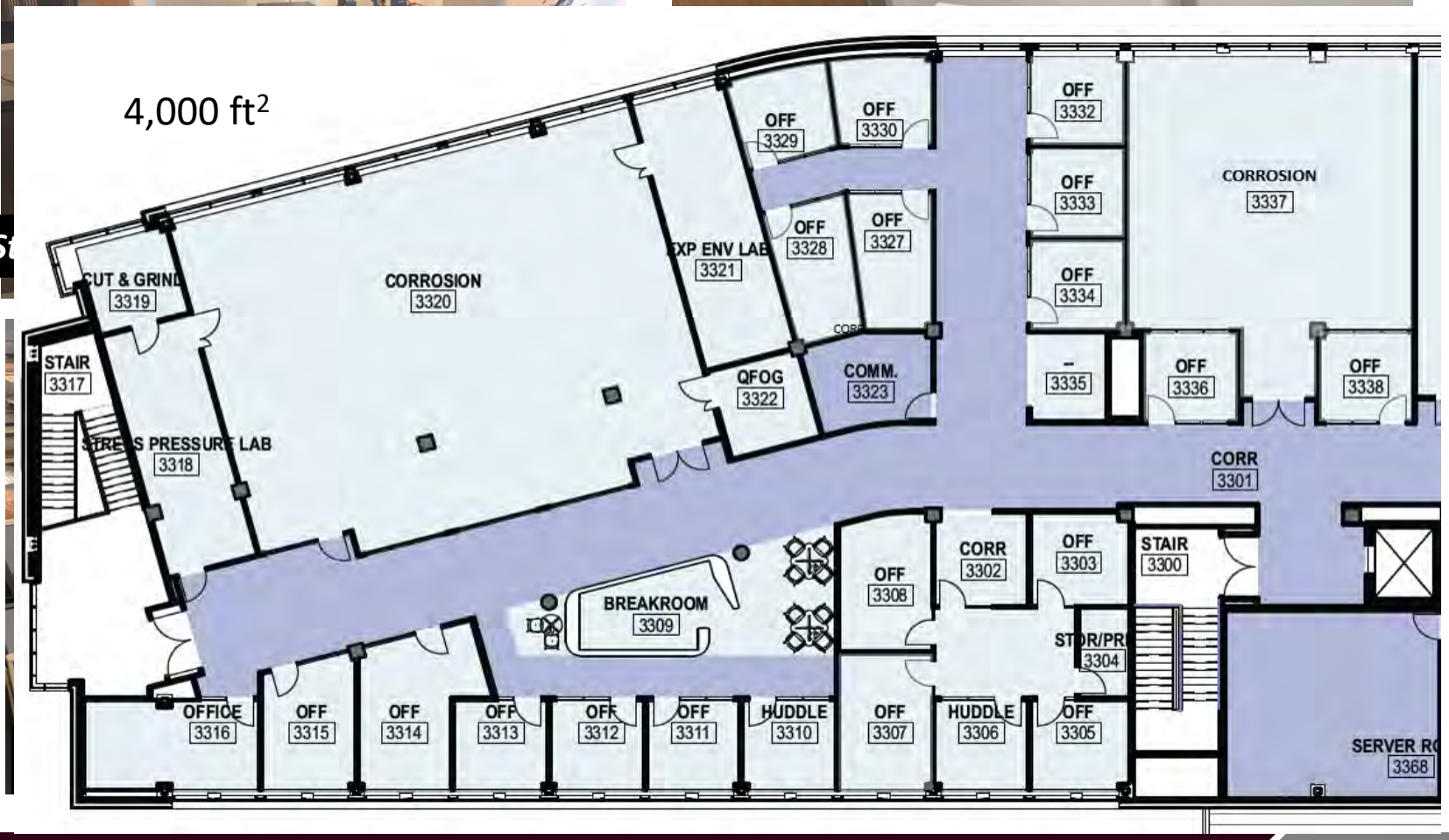
Experimental and modeling techniques tools for corrosion assessment in water management and desalination related processes

NCMRL-Main Laboratory

MATERIALS SCIENCE & ENGINEERING
TEXAS A&M UNIVERSITY







Outlines

MATERIALS SCIENCE & ENGINEERING
TEXAS A&M UNIVERSITY

- Background
- Advance techniques for corrosion in desalination related processes
- Advanced characterization tools for in situ or ex situ monitoring of corrosion mechanisms
- Theoretical tools and computer modeling and lifetime prediction based on corrosion assessment

Background

MATERIALS SCIENCE & ENGINEERING
TEXAS A&M UNIVERSITY

- Desalination technology provide fresh water from salty seawater (off shore) and brackish water (in land) representing the best options to narrow the gap between water supply and demand.
- Due to the high chloride content, high pressure and dissolved oxygen content at saturation, material selection, monitoring and characterizing methods for seawater desalination processes requires special attention.

Ref **Desalination and Water Treatment**
February 2013, Volume 51 (7-9), Pages 1744–1761
http://dx.doi.org/10.1080/19443994.2012.714666

- Brackish water:0,5 à 3 g/l
- Northern Sea close to estuaries :21 g/l
- Atlantic Ocean :35 g/l
- Mediterranean Sea :38 g/l
- Arabian Sea :45 g/l
- Dead Sea :300 g/l

Guangzhou KangYang Seawater Desalination Equipment Co.,Ltd

Desalination and Water Treatment
February 2013, Volume 51 (7-9), Pages 1744–1761
http://dx.doi.org/10.1080/19443994.2012.714666

Material Selection development for MSF plant desalination

MATERIALS SCIENCE & ENGINEERING
TEXAS A&M UNIVERSITY

Component	First generation specification	Second generation specification	Reasons	third generation specification
Vent baffles	Carbon steel	Stainless steel typically AISI 316L sometime 304	Understanding of corrosion induced by high concentration of CO_2, O_2 bromamine and non-condensable gases	Duplex steel DIN 1.4462 or equivalent i.e. SAF 2205
Support plates	Carbon steel	Stainless steel typical AISI 316L sometime 304	Ditto	Duplex steel DIN 1.4462 or equivalent i.e. SAF 2205
De-aerator	Carbon steel + rubber lining	Stainless steel Typical AISI 317 LN	Understanding of corrosion induced by high oxygen and chloramine concentration	Duplex steel DIN 1.4462 or equivalent i.e. SAF 2205
Shell	Carbon steel painted	Stainless steel AISI 316L sometime CS clad	Maintenance reduction cost effect	Duplex steel DIN 1.4462 or equivalent i.e. SAF 2205
Internals	carbon steel Painted	Stainless steel AISI 316L	Ditto	Duplex steel DIN 1.4462 or equivalent i.e. SAF 2205
Make up spray pipe	carbon steel stainless steel	Duplex steel DIN 1.4462	Understanding of the erosion phenomena induced by flashing inside the pipe	Duplex steel DIN 1.4462 or equivalent i.e. SAF 2205

Ref: https://e360.yale.edu/features/as-water-scarcity-increases-desalination-plants-are-on-the-rise

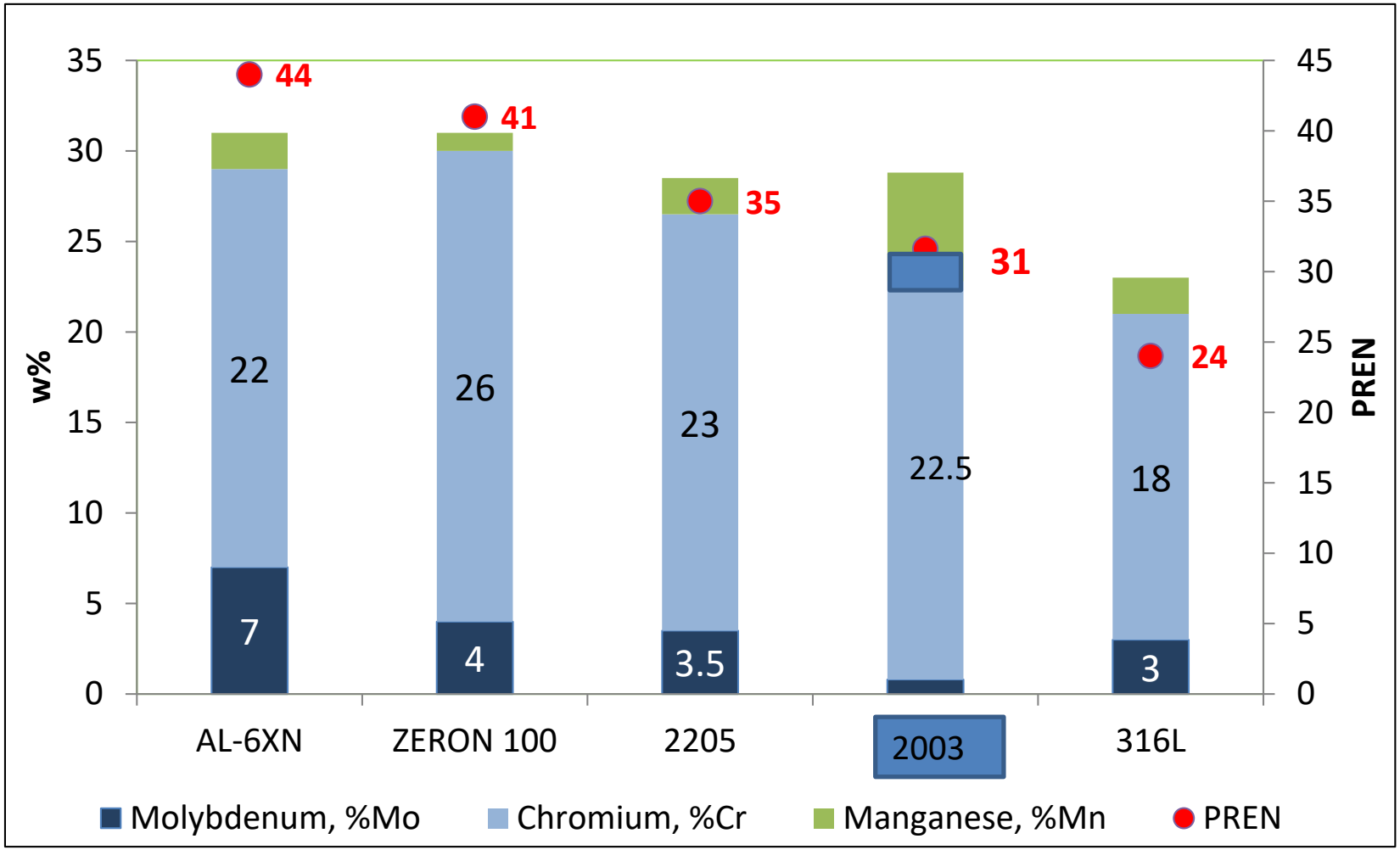
https://www.aquatechtrade.com/news/desalination/worlds-largest-desalination-plants/

MATERIAL SELECTION AND CORROSION - VOL. II - *STAINLESS STEEL FOR DESALINATION PLANTS* - J.O. OLSSON AND S.G.E.

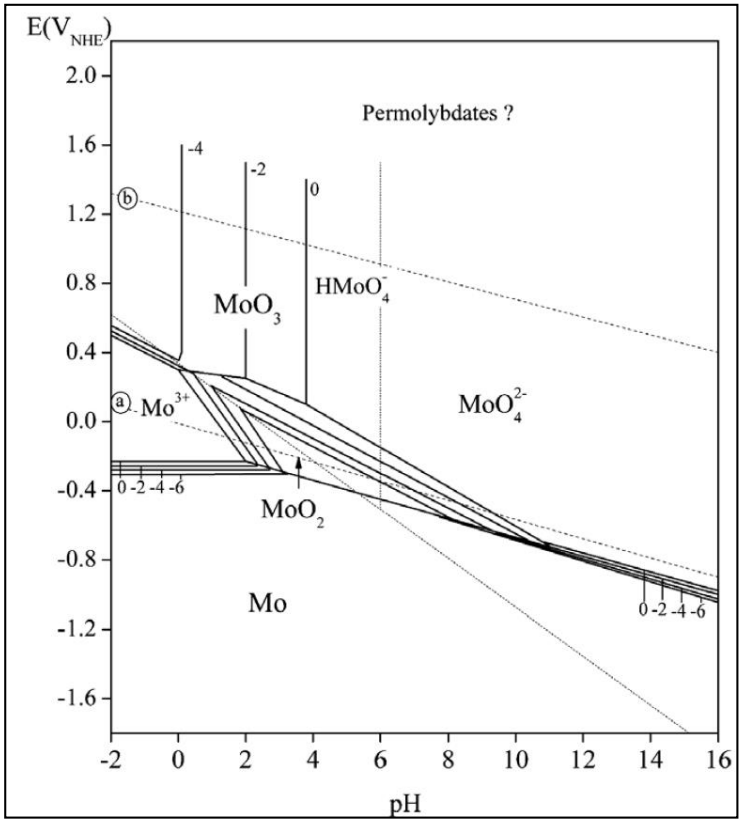
CRA main alloying components

MATERIALS SCIENCE & ENGINEERING
TEXAS A&M UNIVERSITY

PREN = Cr + 3.3 Mo + 16N



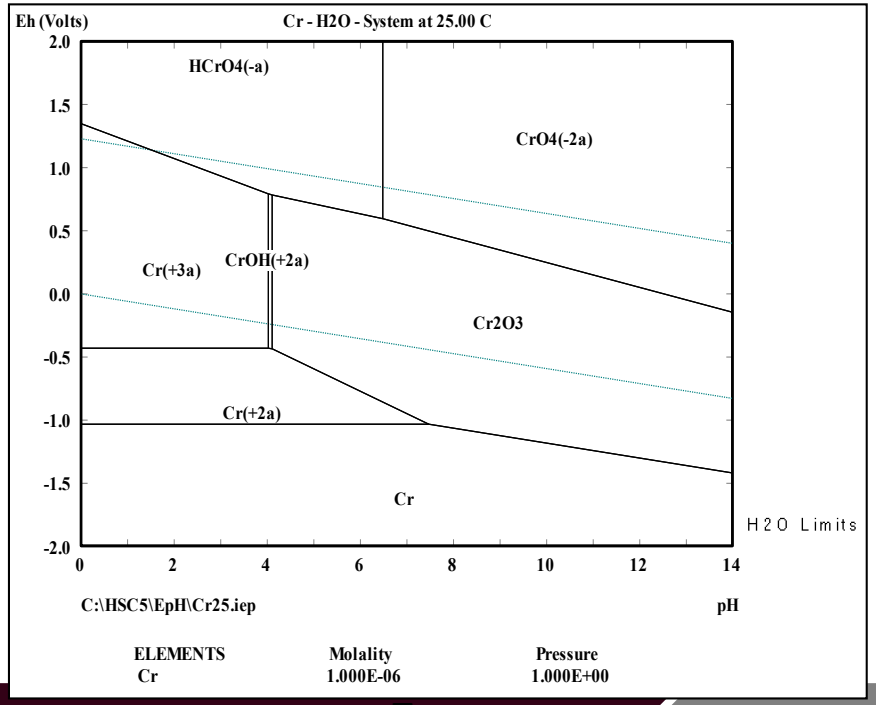
Layer stability- Theoretical tools



C. R. Clayton, (1986) A Bipolar film, **MoO_4^{2-}** and **CrO_4^{2-}** anions are formed in the solid state along with formation of XCr_2O_3, $YCrO_3$ barrier layer.

Combined formation of MoxOy and CrxOy, increase break down passivity to Cl-

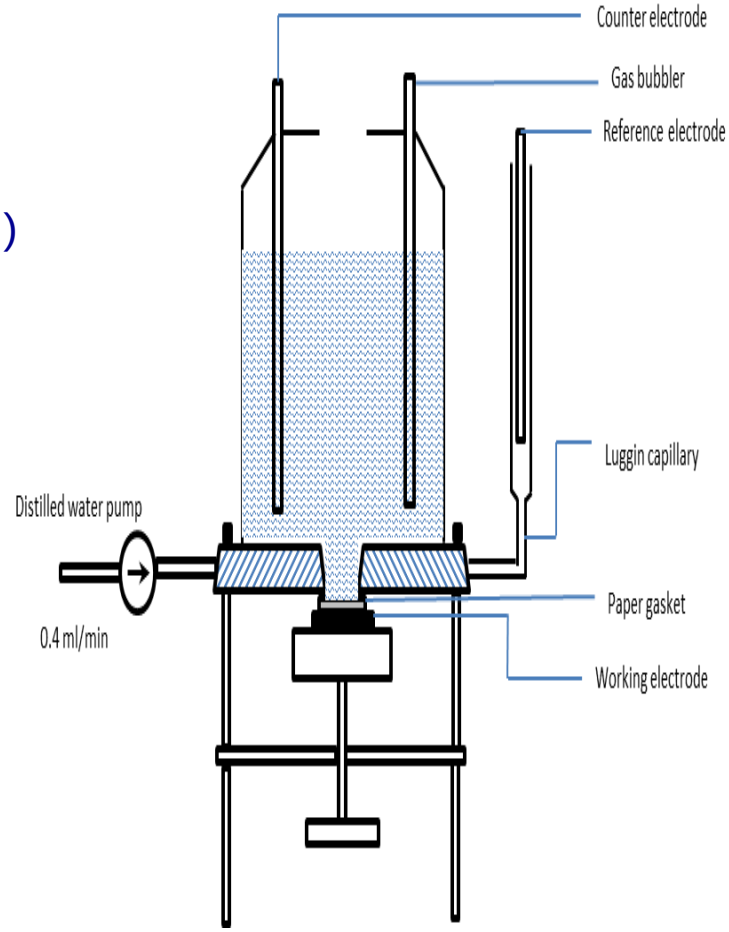
http://www.asia-valve.com/globe-valve/duplex-stainless-steel-special-alloy-globe-valves.html



Experimental tools

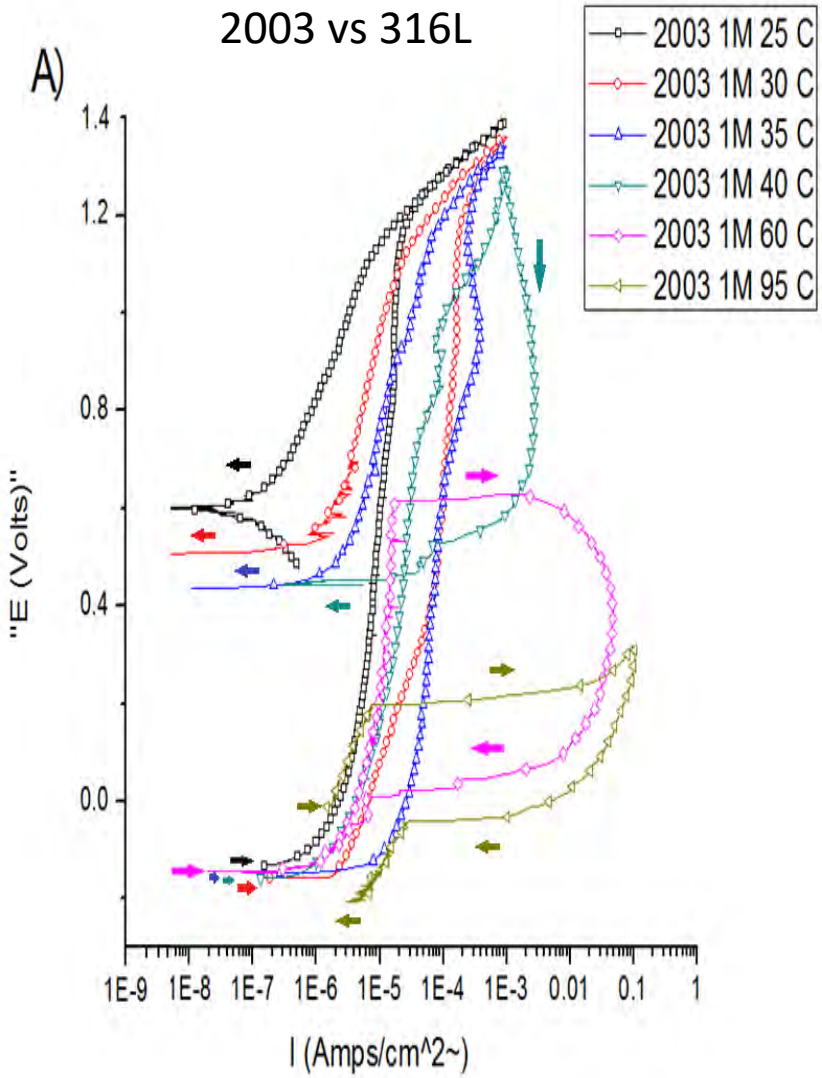
MATERIALS SCIENCE & ENGINEERING
TEXAS A&M UNIVERSITY

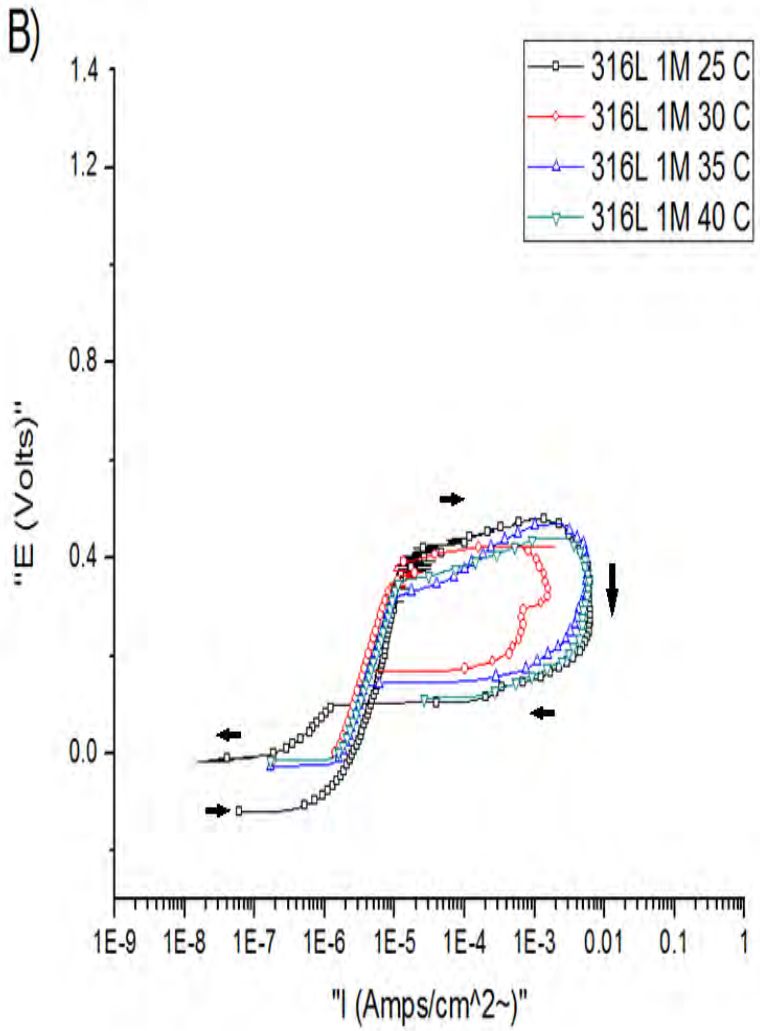
- Materials: N08367, S32003 and S31603
- Reference electrode: SCE ; Counter electrode: Platinum
- Cell design : Avesta cell (crevice-free-cell)
- Polarization test: E_{init}: 0 V (OCP); E_{ver}: 1.2 V (SCE); E_{fin} : -0.2 V (SCE); Scan rate : 0.167 mV/s.
- ASTM G 150 (1999) Standard CPT Testing for Stainless Steels
- EIS at OCP, and bias potential. Frequency range was from 50KHz to 10 mHz with amplitude of 10 mV
- Surface morphology after corrosion tests by digital camera and IFM



Advanced characterization for materials selection

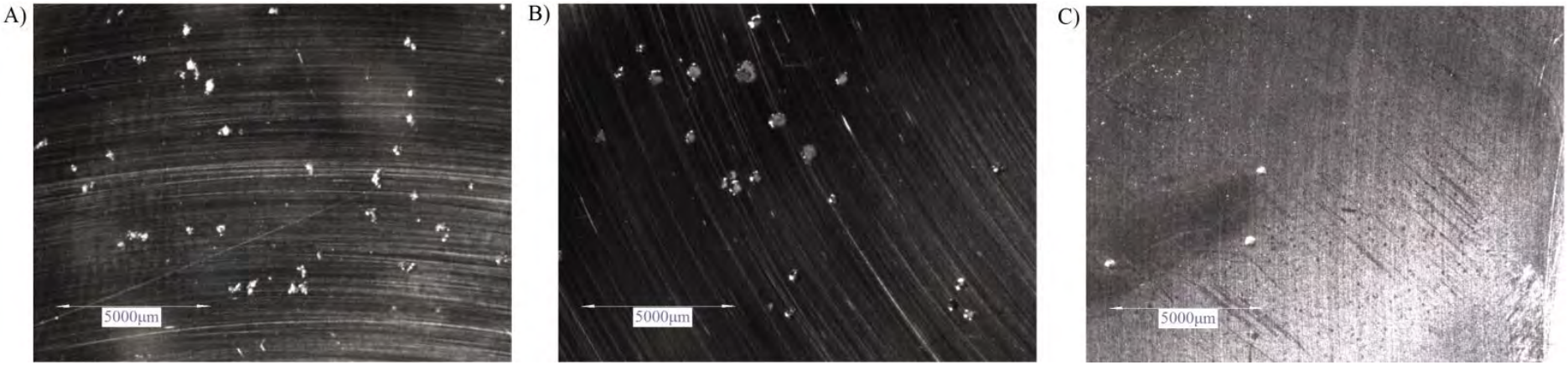
MATERIALS SCIENCE & ENGINEERING
TEXAS A&M UNIVERSITY





Micrographs of the surface of UNS S32003 after CPP tests where pitting corrosion

MATERIALS SCIENCE & ENGINEERING
TEXAS A&M UNIVERSITY



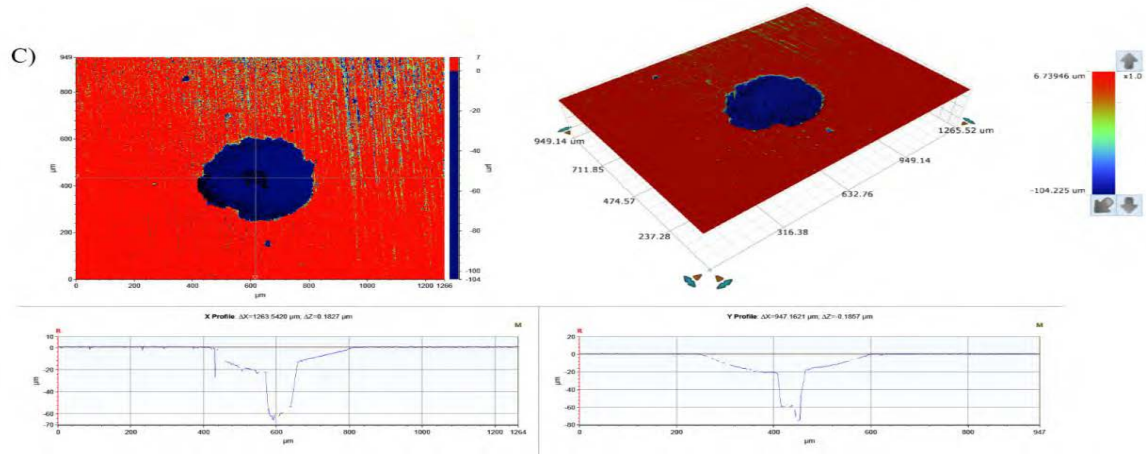
Surface of UNS S32003 samples at different temperatures after CPT. A) 95˚C, B) 60 ˚C, C) 40 ˚C.

Surface of 316L samples at different temperatures CPT. A) 40˚C, B) 30 ˚C, C) 25˚C.

Experimental tools for model validation

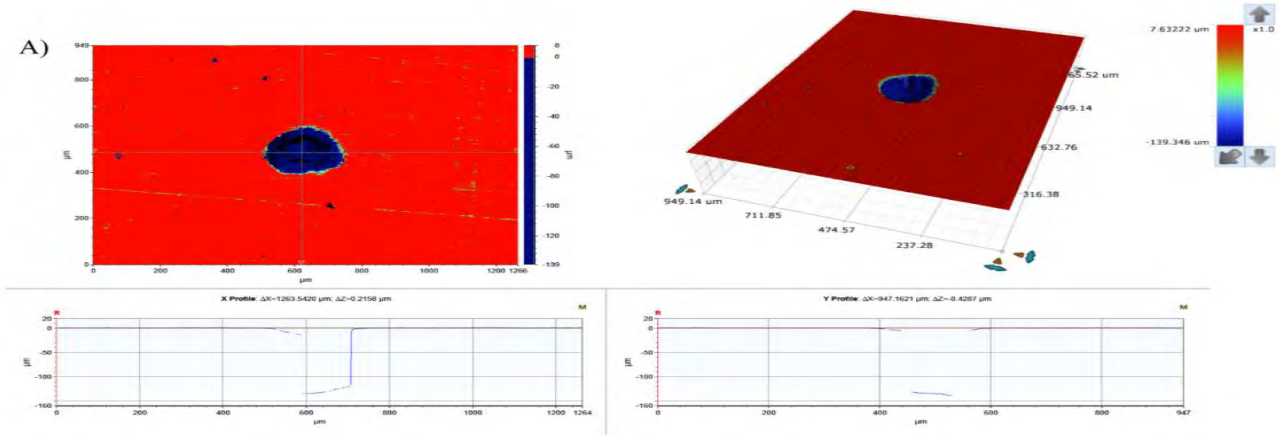
MATERIALS SCIENCE & ENGINEERING
TEXAS A&M UNIVERSITY

2003



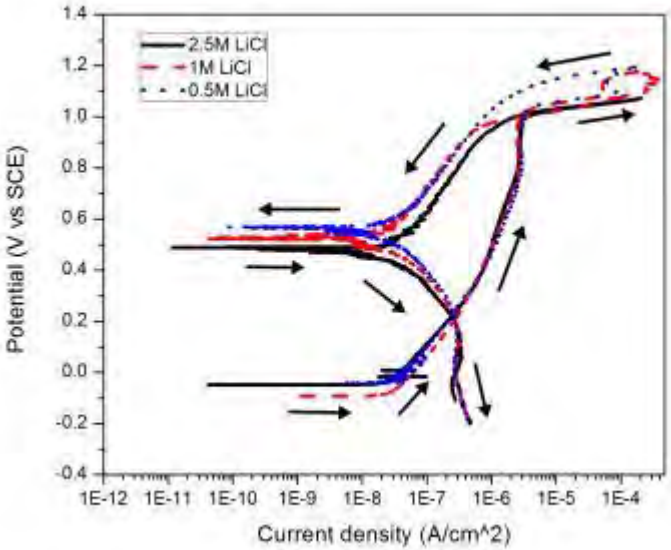
	95 °C	60 °C	40 °C	30 °C	25 °C
2003	120 µm	125 µm	75 µm	-	-
316L	-	-	145 µm	125 µm	45 µm

316L

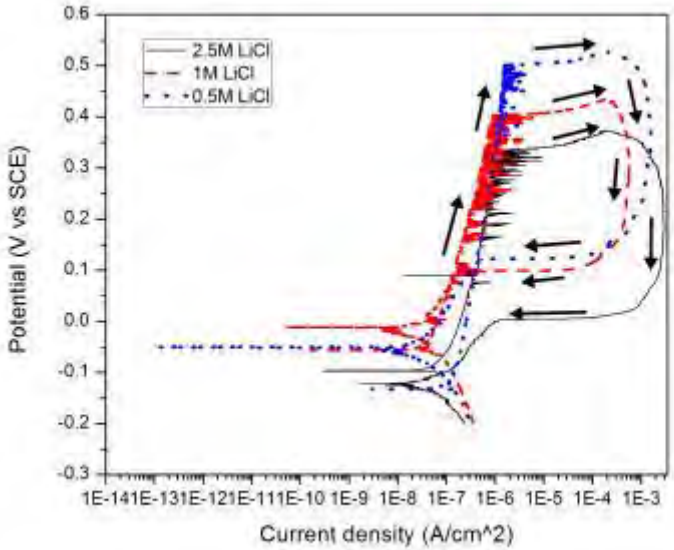


Advanced characterization for materials selection

MATERIALS SCIENCE & ENGINEERING
TEXAS A&M UNIVERSITY



N08367



S31603

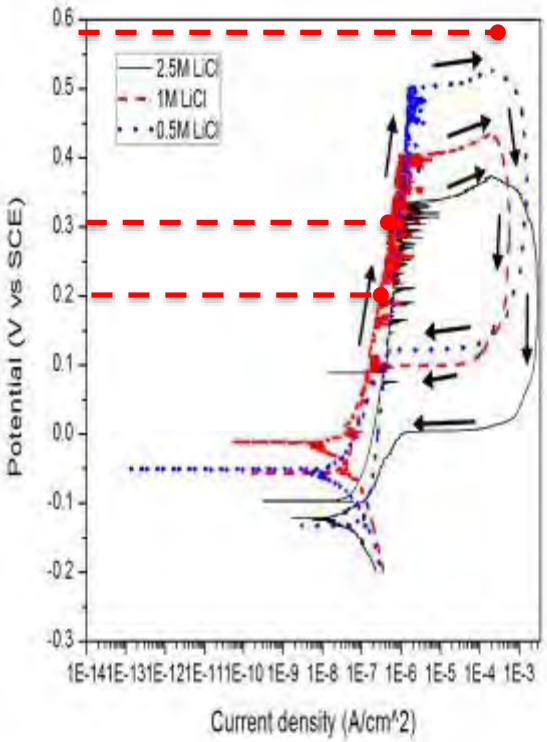
- The negative hysteresis loop found in the cyclic polarization curves of N08367 indicates this alloy is not pitted. In contrast, S31603 reveals the positive hysteresis loop, suggesting this alloy is attacked by pittng corrosion.

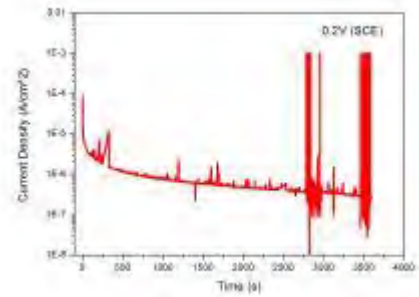
J Solid State Electrochem (2014) 18:3191–3202 DOI 10.1007/s10008-014-2566-0

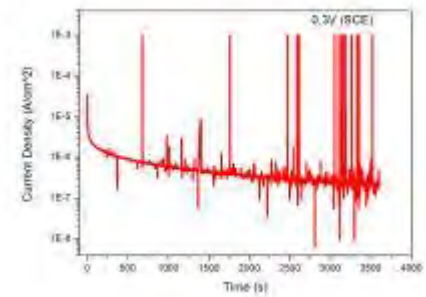
Potentiostatic Test for S31603 in 0.5M LiCl

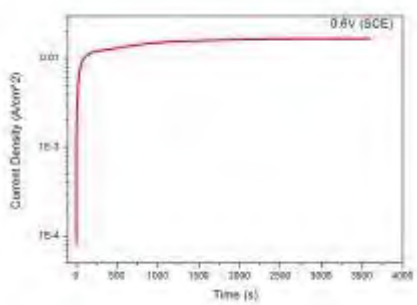
MATERIALS SCIENCE & ENGINEERING
TEXAS A&M UNIVERSITY

- Current transients which were attributed to metastable pits appeared even at the passive region potentials





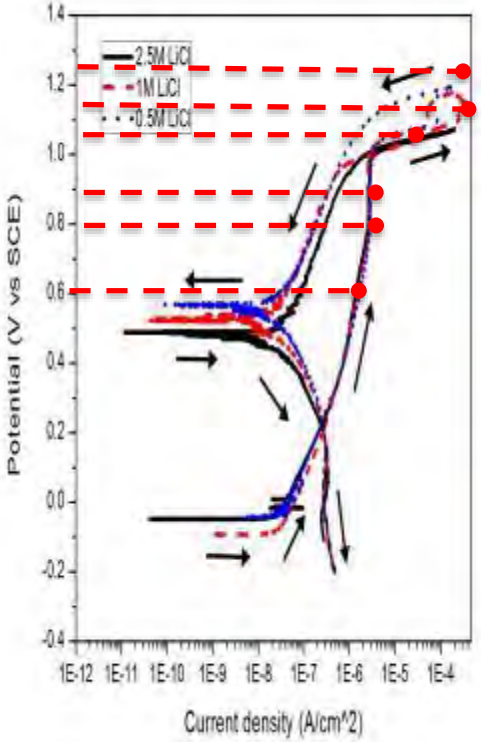


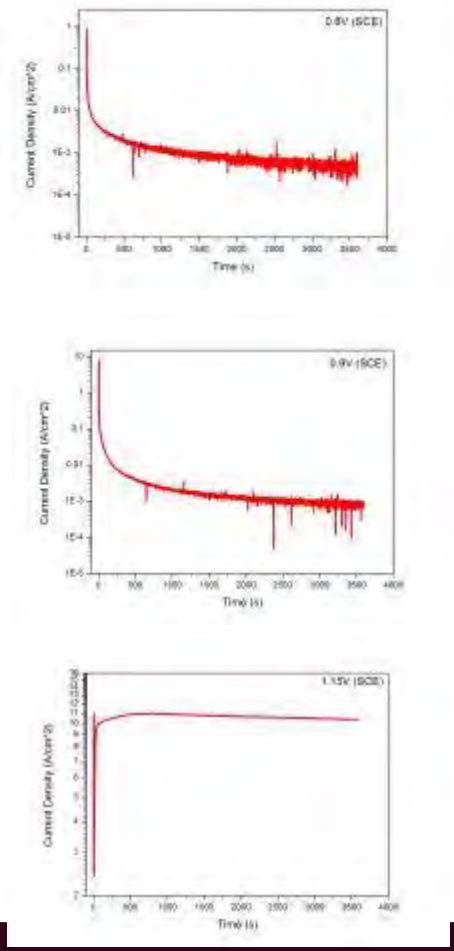


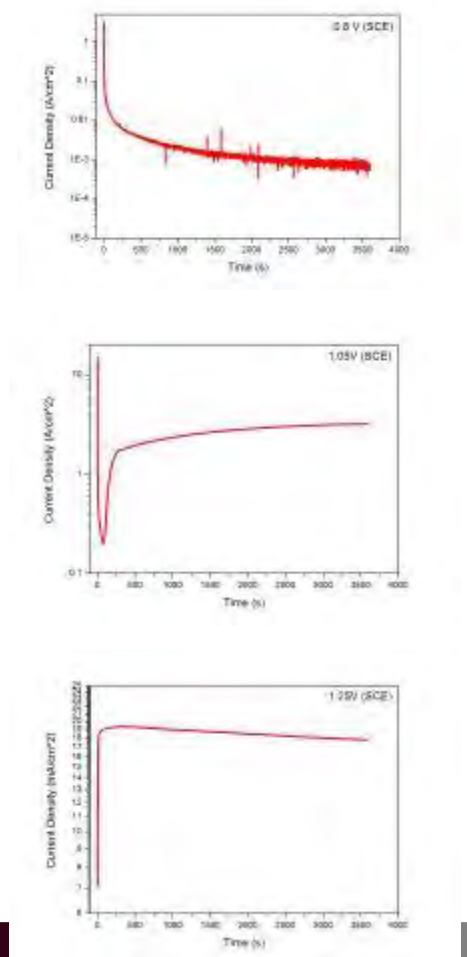
Potentiostatic Test for N08367 in 2.5M LiCl

MATERIALS SCIENCE & ENGINEERING
TEXAS A&M UNIVERSITY

- Passive film transformation was noticed at the transpassive region



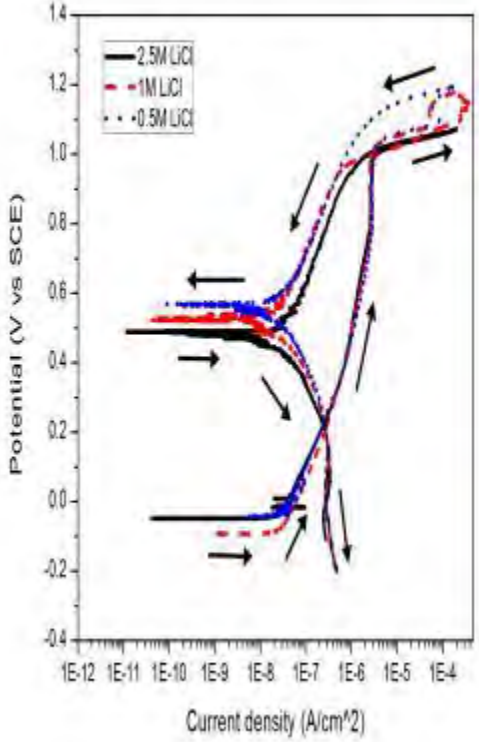


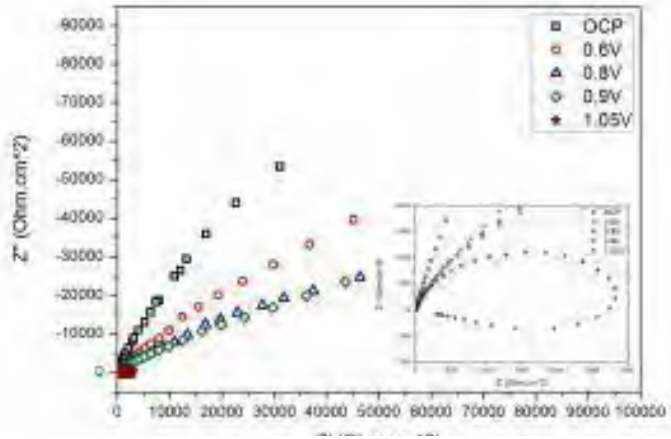


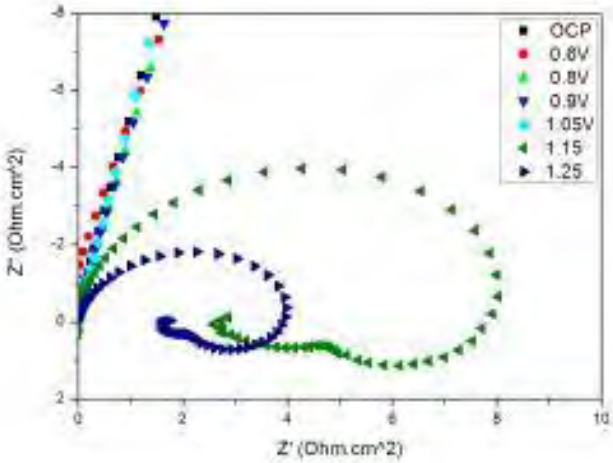
EIS for N08367 in 2.5M LiCl

MATERIALS SCIENCE & ENGINEERING
TEXAS A&M UNIVERSITY

- No noises were observed at the transspassive region potential (1.05 V vs SCE).
- Inductive loop appeared at low frequencies, indicating the formation of adsorbed intermediates at the interface.

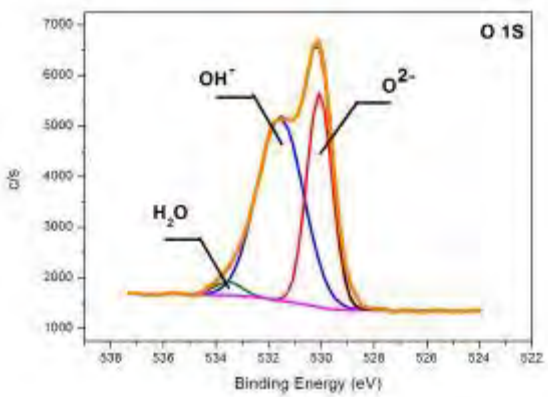


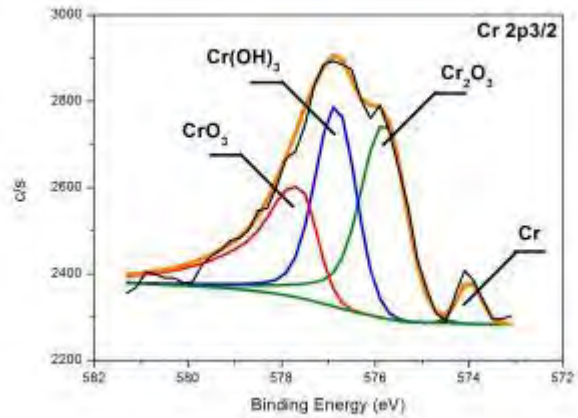


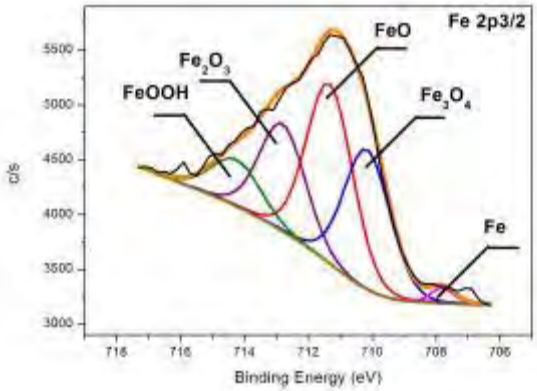


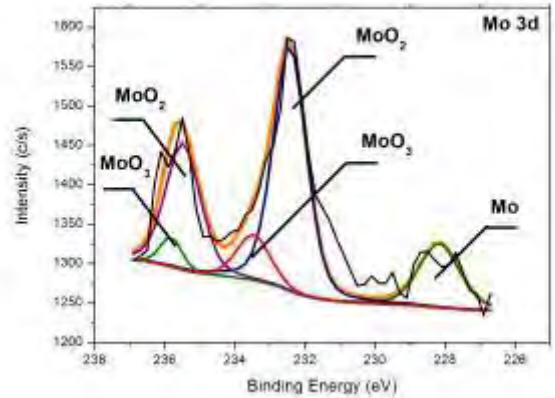
Deconvolution of XPS Spectra of N08367 Surface Polarized at Passive Potential

MATERIALS SCIENCE & ENGINEERING
TEXAS A&M UNIVERSITY

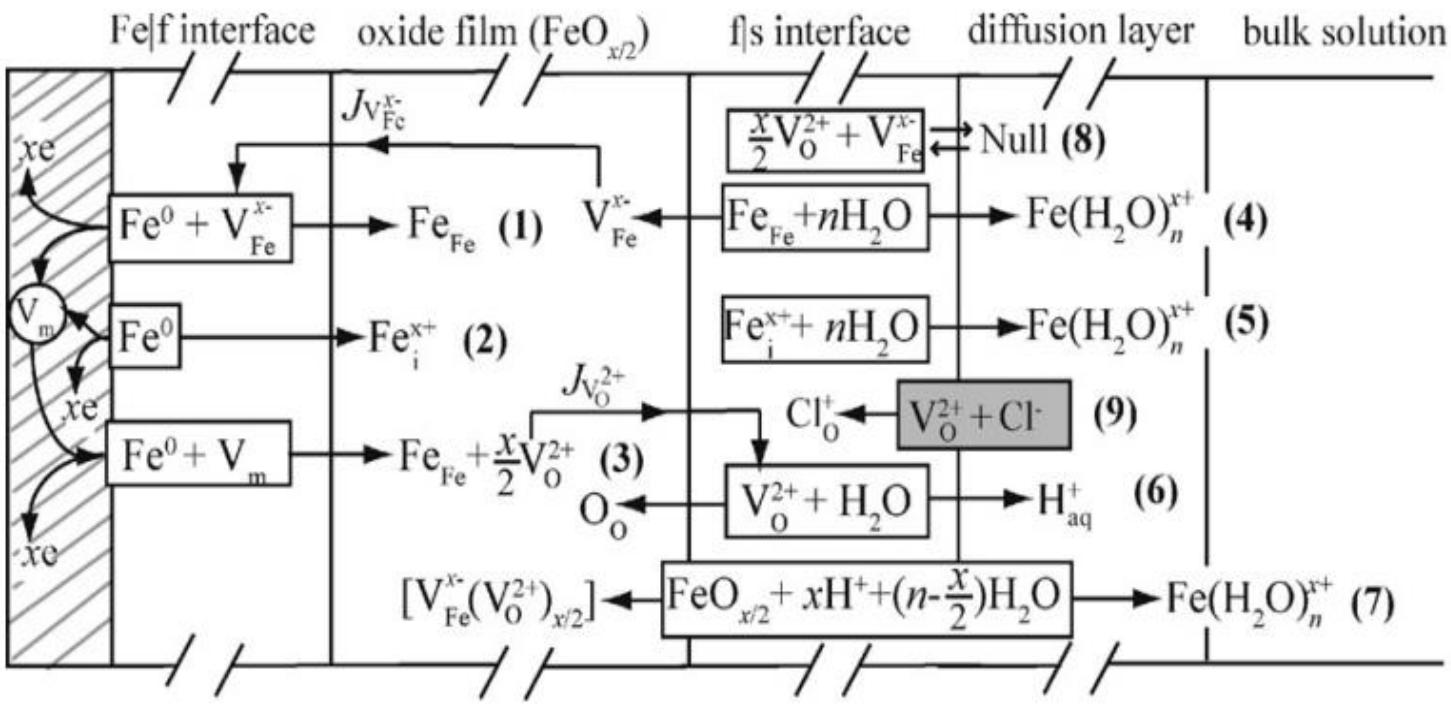








Point defect model



$$Cr \rightarrow Cr_i^{x+} + xe'$$

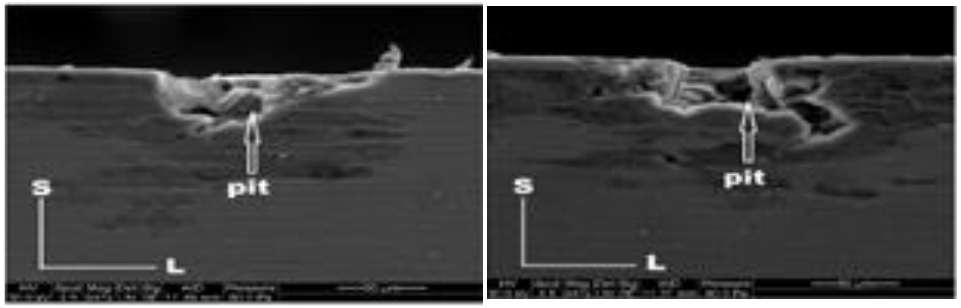
$$Cr \rightarrow Cr_{Cr} + \frac{x}{2}Vo^{\cdot\cdot} + xe'$$

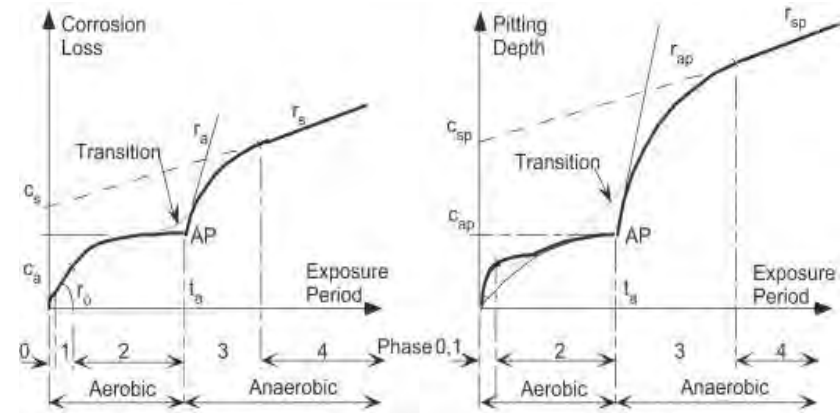
$$Cr_i^{x+} \rightarrow Cr^{\Gamma+} + (\Gamma - x)e'$$

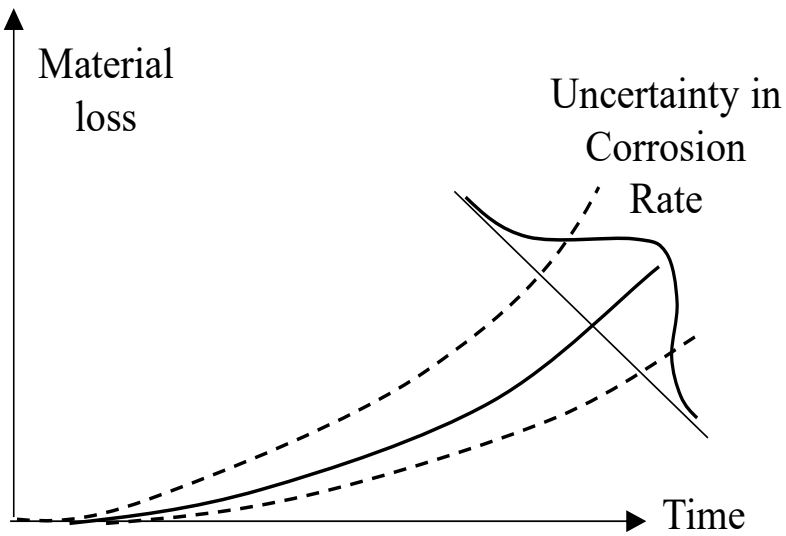
$$Vo^{\cdot\cdot} + H_2O \rightarrow O_o + 2H^+$$

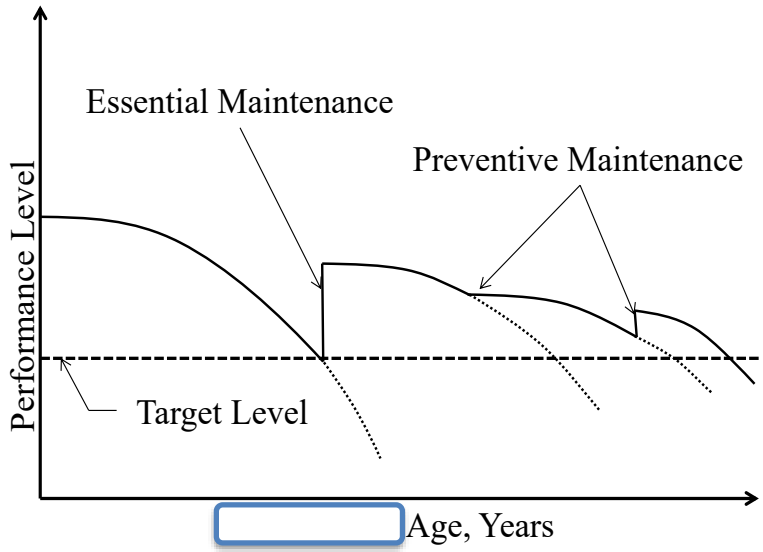
$$CrO_{\frac{x}{2}} + xH^+ \rightarrow Cr^{\Gamma+} + \frac{x}{2}H_2O + (\Gamma - x)e'$$

Reliability Modeling





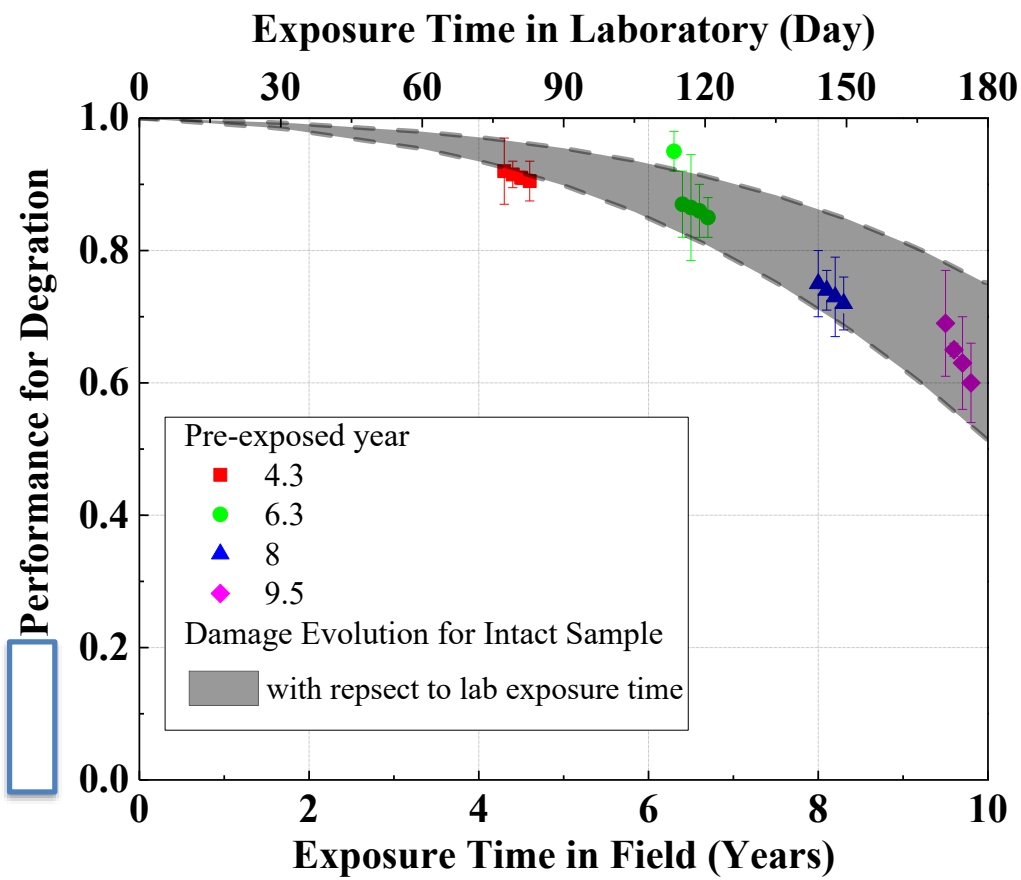




Probabilistic life prediction model

MATERIALS SCIENCE & ENGINEERING
TEXAS A&M UNIVERSITY

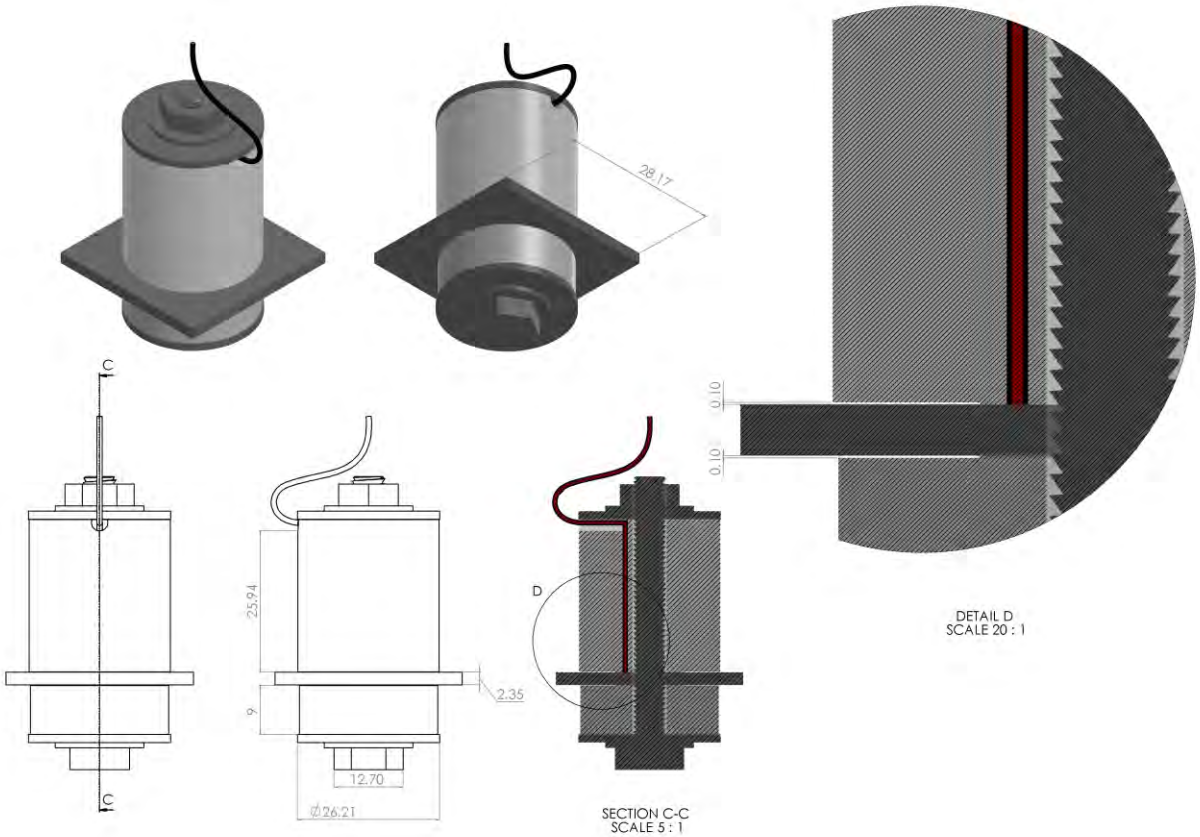
- The probabilistic approach considers the laboratory and field exposure samples correlation.



The image of an anticipated final outcome for probabilistic life prediction

New Experimental tools vs classical Characterization of UNS S32003 Lean Duplex Stainless Steel by using single boss crevice former

Single Boss Crevice Former

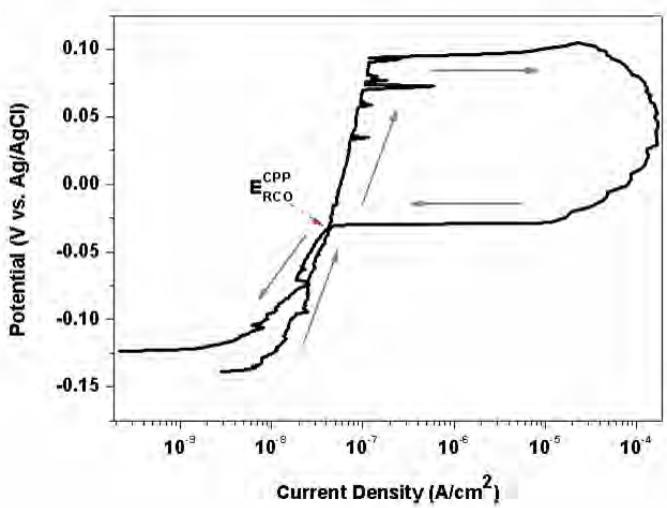


Classic crevice set up

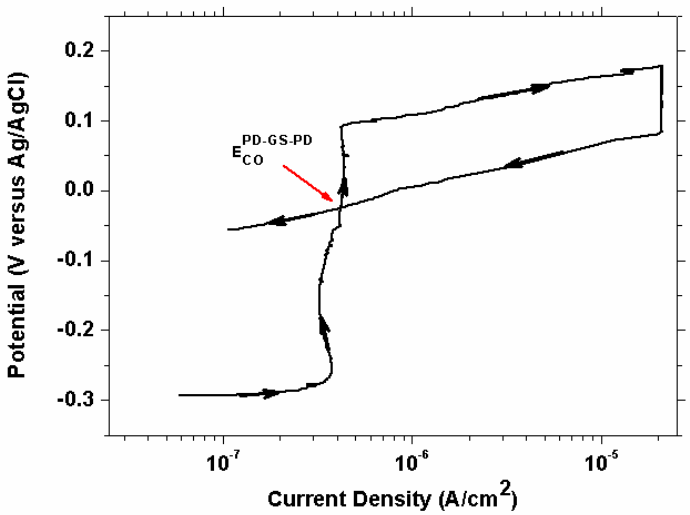
Ref: Single-boss crevice former for studying crevice corrosion of UNS S32003 in chloride-containing solution at high temperature Journal of Alloys and Compounds, Volume 619, 15 January 2015, Pages 544-552

Electrochemical Techniques Comparison UNS S32003

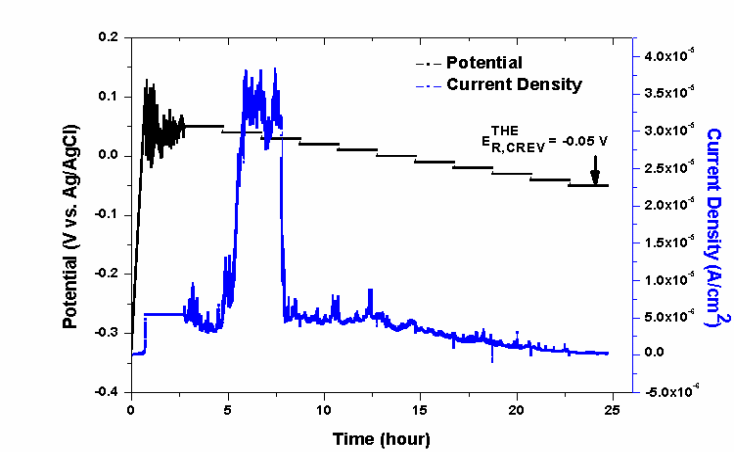
MATERIALS SCIENCE & ENGINEERING
TEXAS A&M UNIVERSITY



Cyclic Potentiodynamic Polarization (CPP).



Potentiodynamic-Galvanostatic-Potentiodynamic (PD-GS-PD) Polarization.



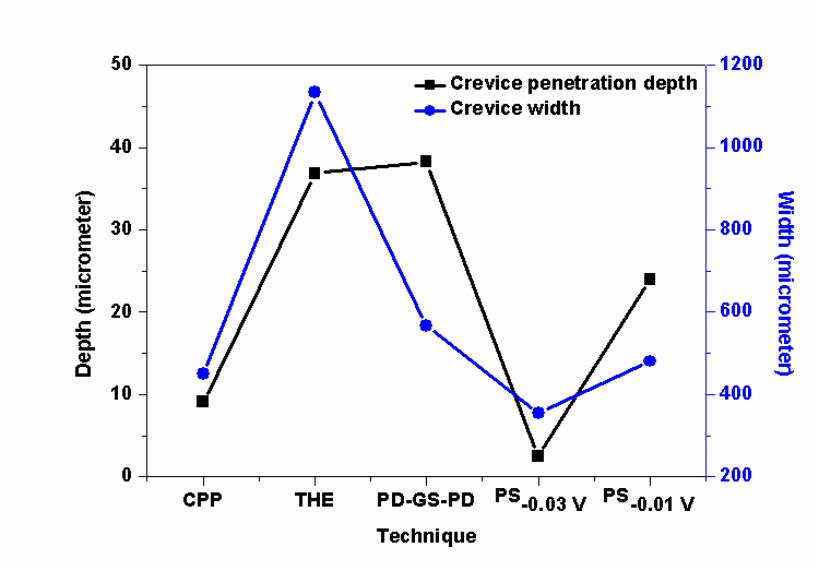
Ref: Single-boss crevice former for studying crevice corrosion of UNS S32003 in chloride-containing solution at high temperature Journal of Alloys and Compounds, Volume 619, 15 January 2015, Pages 544-552

Tsujikawa-Hisamatsu Electrochemical (THE) Method.

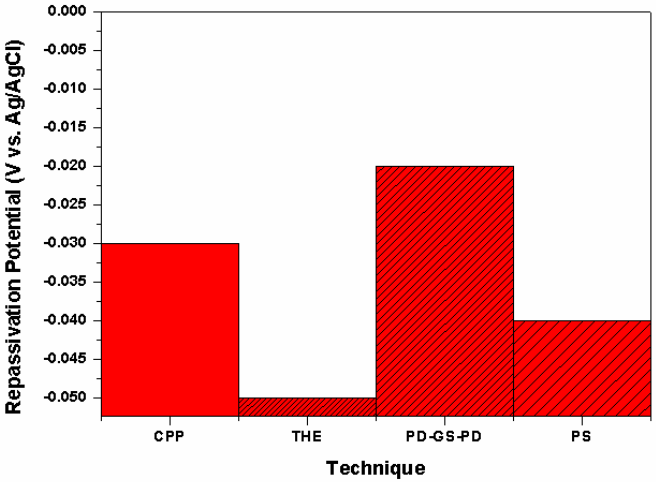
Analysis per electrochemical technique

MATERIALS SCIENCE & ENGINEERING
TEXAS A&M UNIVERSITY

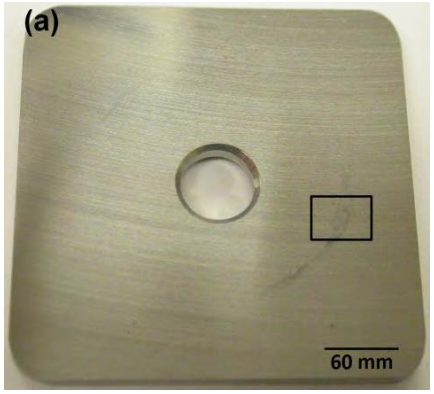
https://doi.org/10.1016/j.jallcom.2014.09.060



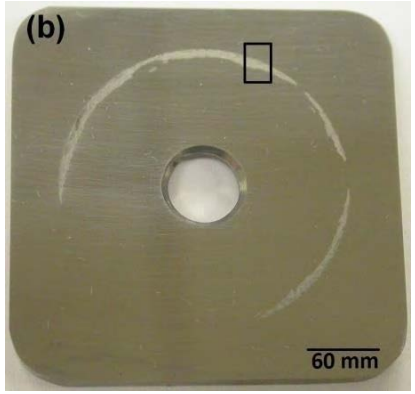
Crevice morphology



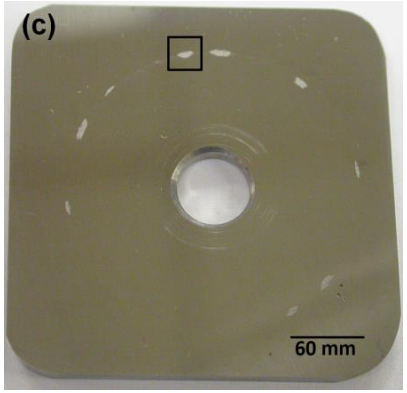
Comparison of critical potential obtained between techniques



CPP



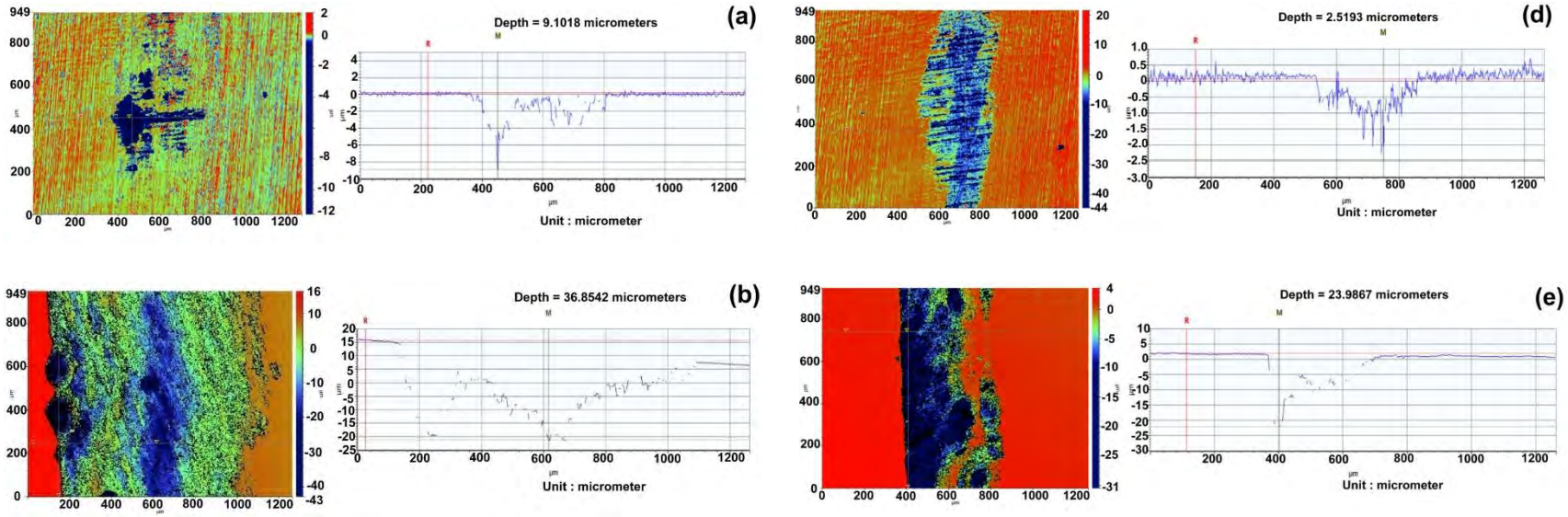
THE



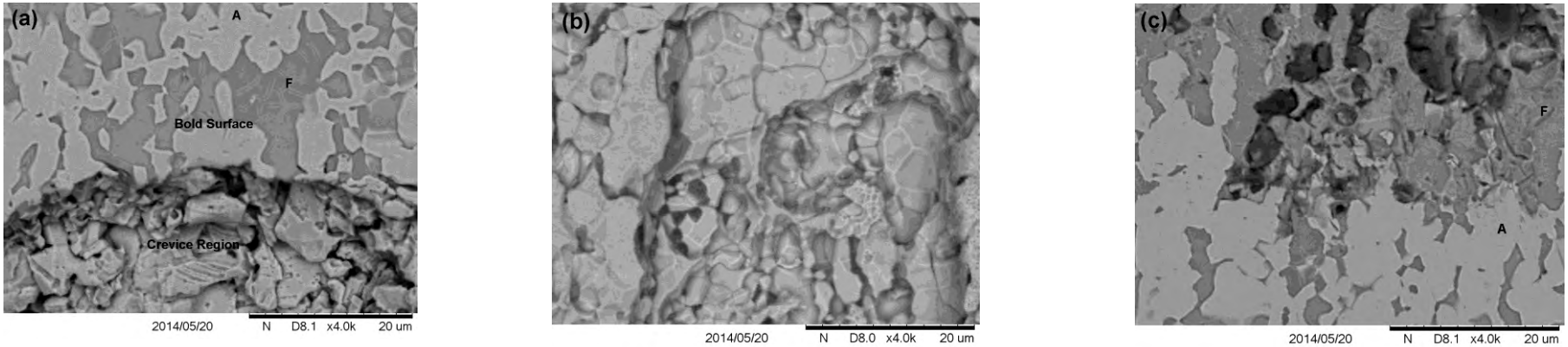
PD-GS-PD

3D Microscope and SEM techniques

MATERIALS SCIENCE & ENGINEERING
TEXAS A&M UNIVERSITY

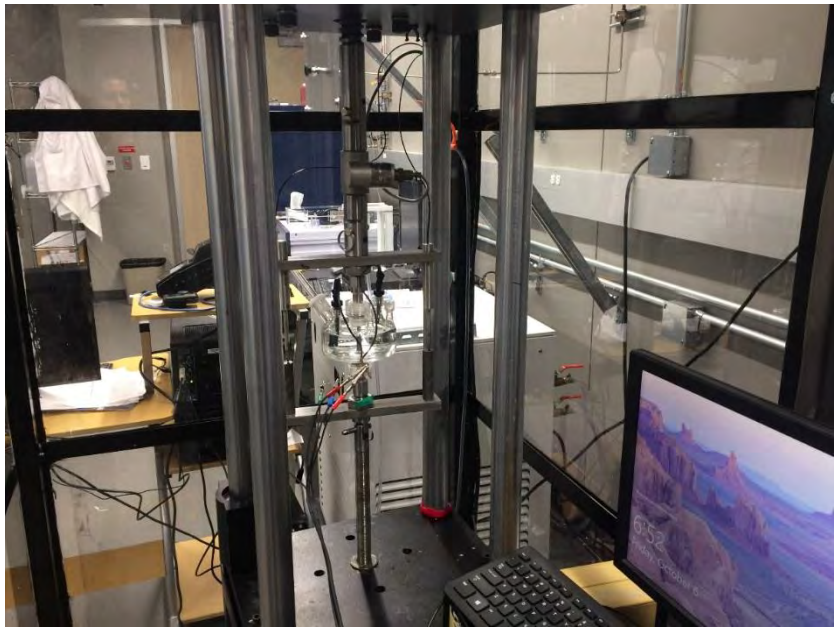


Localized Corrosion appears to start at the Crevice Mouth.



Metastable pits are preferentially formed in the ferrite phase (dark phase). Localized corrosion can be found on the crevice region near the mouth where some areas show integranular attack in ferrite grain boundaries

Mechanical Assisted Machine with corrosion environment and HPHT conditions



- Corrosion specimens are held in a 1/2-liter autoclave vessel, which is made from Hastelloy© C-276 with excellent corrosion resistance.
- This vessel system is designed for a MAWP of 350 bar (about 5000 psi), and it can withstand a maximum working temperature of 300°C (Note: 200°C for the electrochemical measurement).

Kinetics of Stress corrosion cracking crack growth

MATERIALS SCIENCE & ENGINEERING
TEXAS A&M UNIVERSITY

❖ ***Fracture/Damage Mechanics Driven Crack Growth***

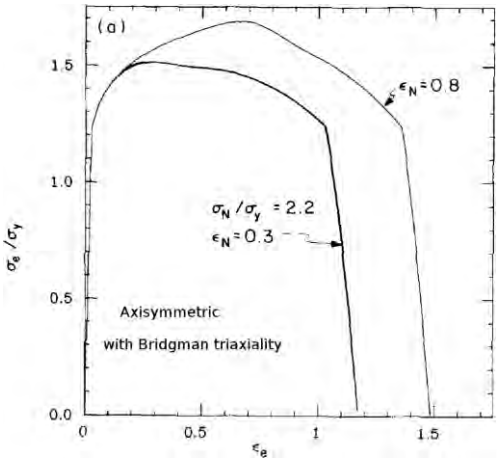
Evolution of damage:

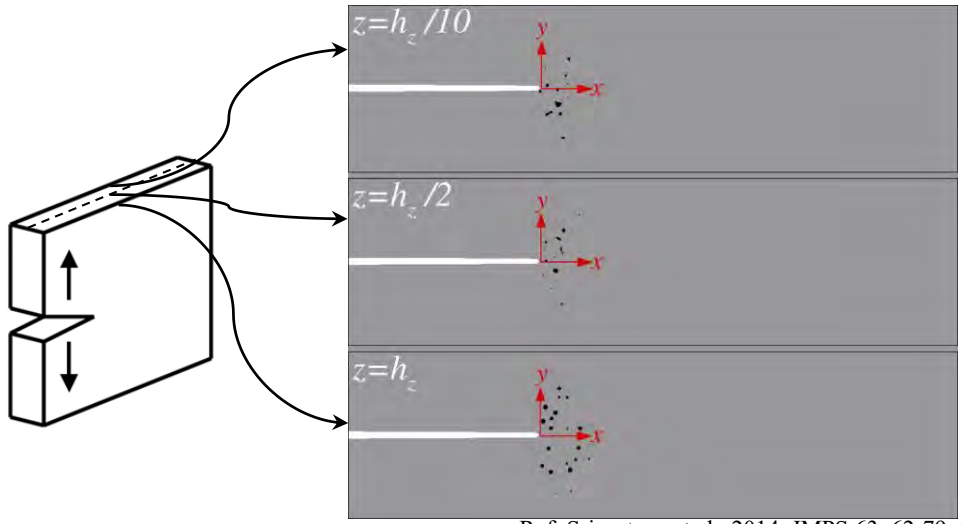
$$\dot{f} = (1-f)\mathbf{d}^p : \mathbf{I} + \dot{f}_{nucl}$$

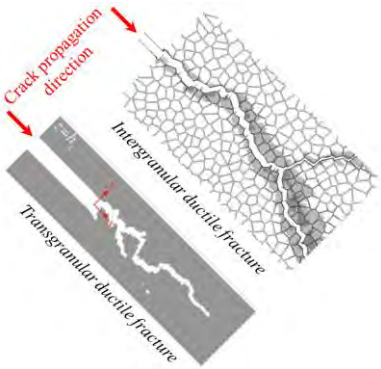
Flow potential:

$$\Phi(\sigma_{ij}, \bar{\sigma}, f) = \frac{\sigma_e^2}{\bar{\sigma}^2} + 2q_1 f^* \cosh\left(\frac{q_2 \sigma_{kk}}{2\bar{\sigma}}\right) - 1 - (q_1 f^*)^2 = 0$$

❑ The stress carrying capacity vanishes when $f^*=1/q_1$ which is when $f=f_f$ (the surface $\Phi = 0$ shrinks to a point) and new free surface is created.



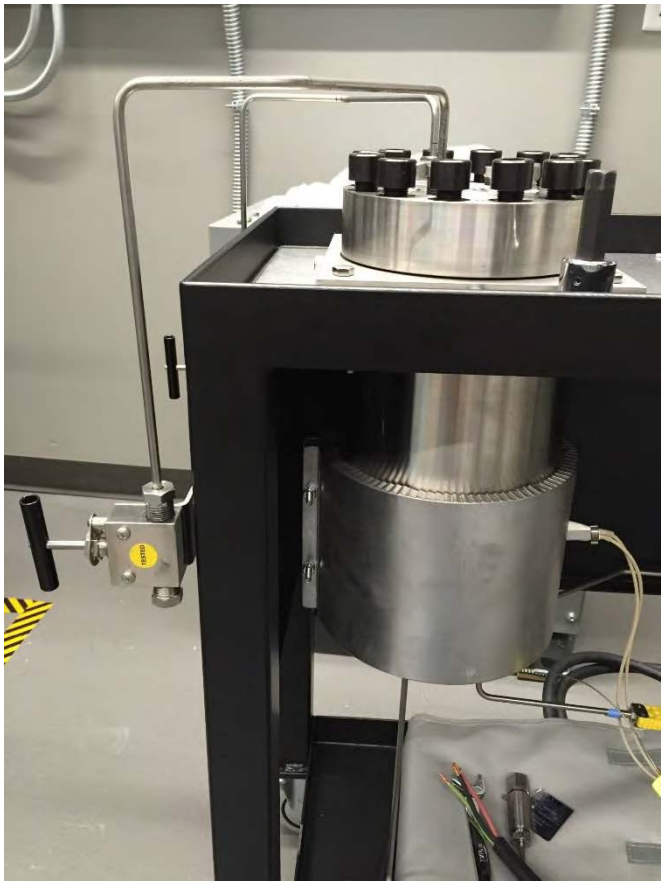




Ref: Srivastava et al., 2014, JMPS 63, 62-79; Osovski et al., 2015, Acta Mat. 82, 167-178.

Testing capabilities for High Temperature and High pressure for materials

MATERIALS SCIENCE & ENGINEERING
TEXAS A&M UNIVERSITY



Cortest Autoclave system: This autoclave system includes a high pressure autoclave, a control panel, a heater, pressure gauges, valves, ancillary equipment, and all the required connections.

Corrosion specimens are held in a 4-liter autoclave vessel, which is made from Hastelloy© C-276 with excellent corrosion resistance.

This autoclave system is designed for a MAWP of 350 bar (about 5000 psi), and it can withstand a maximum working temperature of 300°C (Note: 200°C for the electrochemical measurement).

The autoclave is designed with the capacity of performing electrochemical testing at high pressures and temperatures.

Also it can be fitted to perform DCB tests according NACE TM0177-2016

CO_2 Booster Pump: This pump is equipped to the autoclave system in order to create a high pressure condition for corrosion experiments in the autoclave vessel. This pump is capable of delivering CO_2 from a CO_2 cylinder (nominally 835 psi at room temperature) to a pressure of 10,000 psi.

Mobile Desalination Monitoring

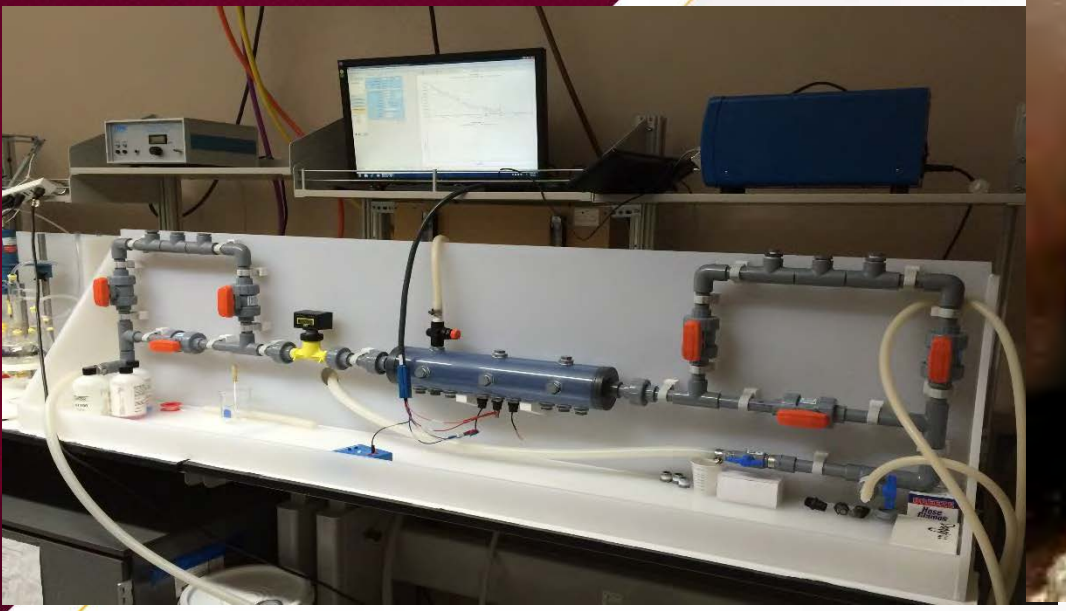
MATERIALS SCIENCE & ENGINEERING

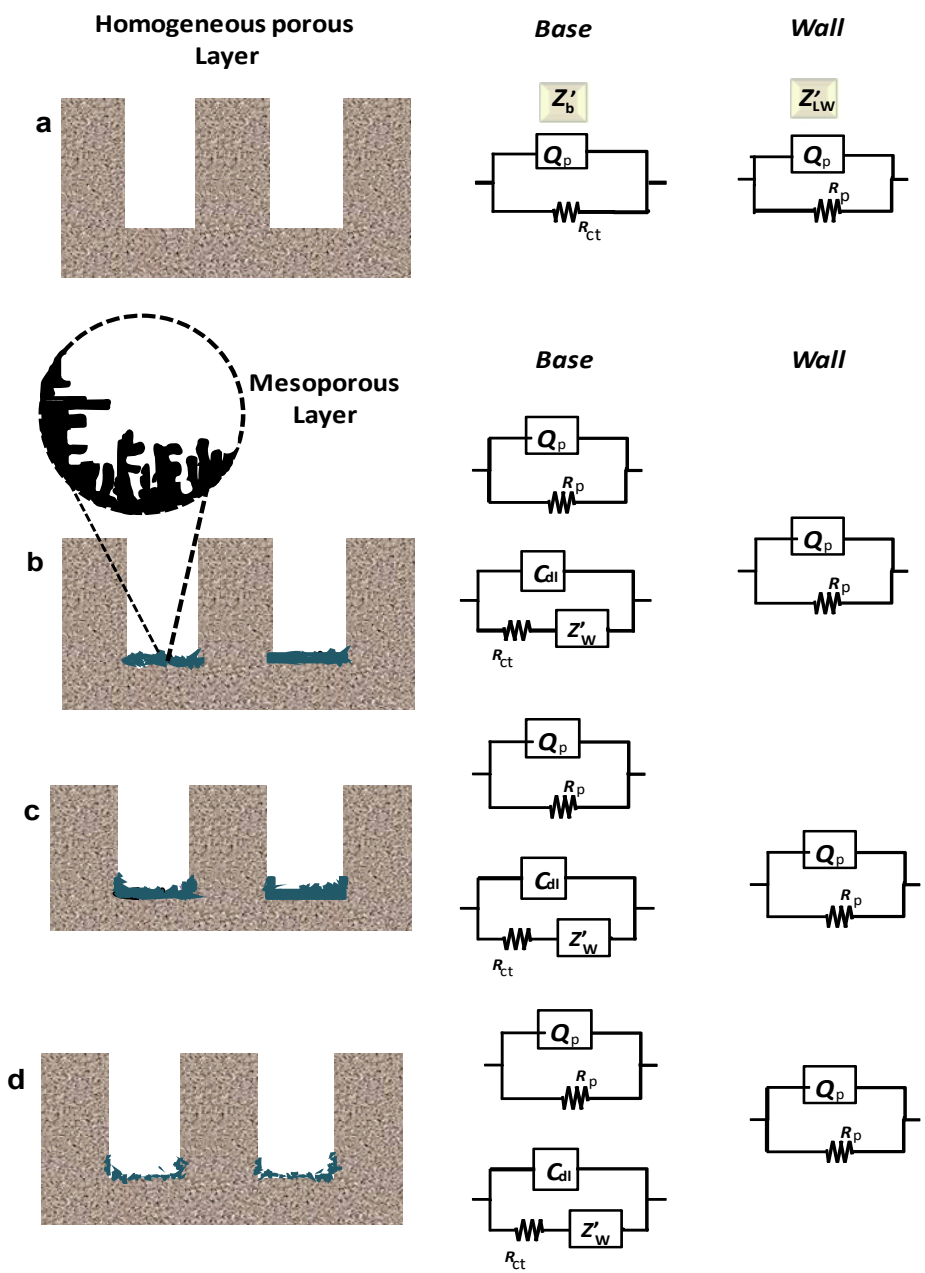
TEXAS A&M UNIVERSITY

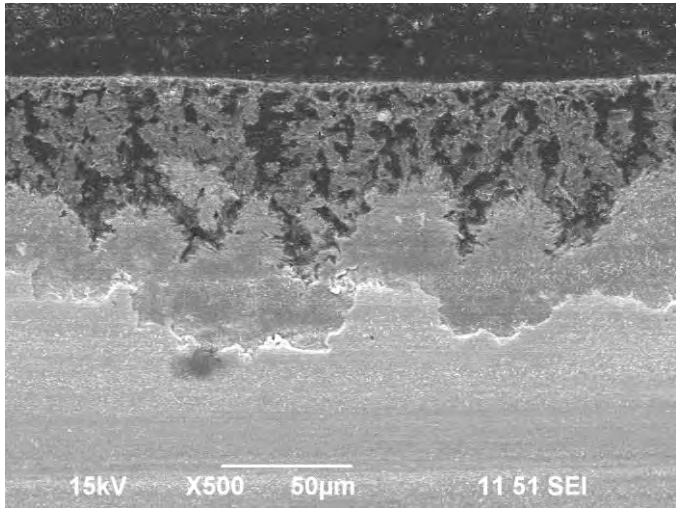
TEES

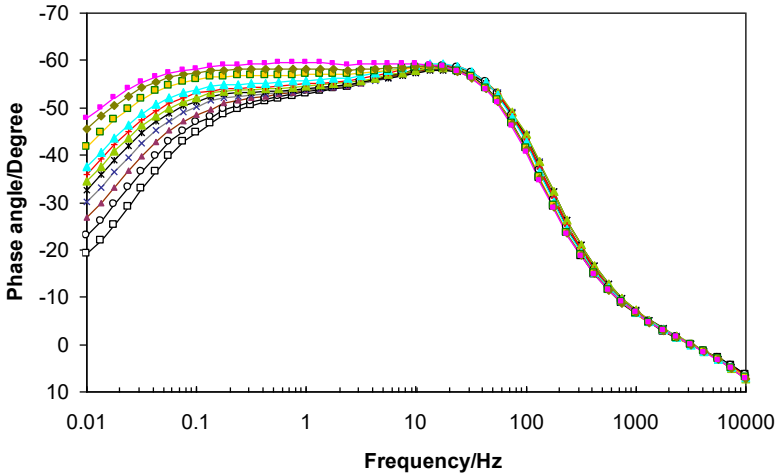
TEXAS A&M ENGINEERING EXPERIMENT STATION

Internal corrosion in pipelines
Scaling and monitoring







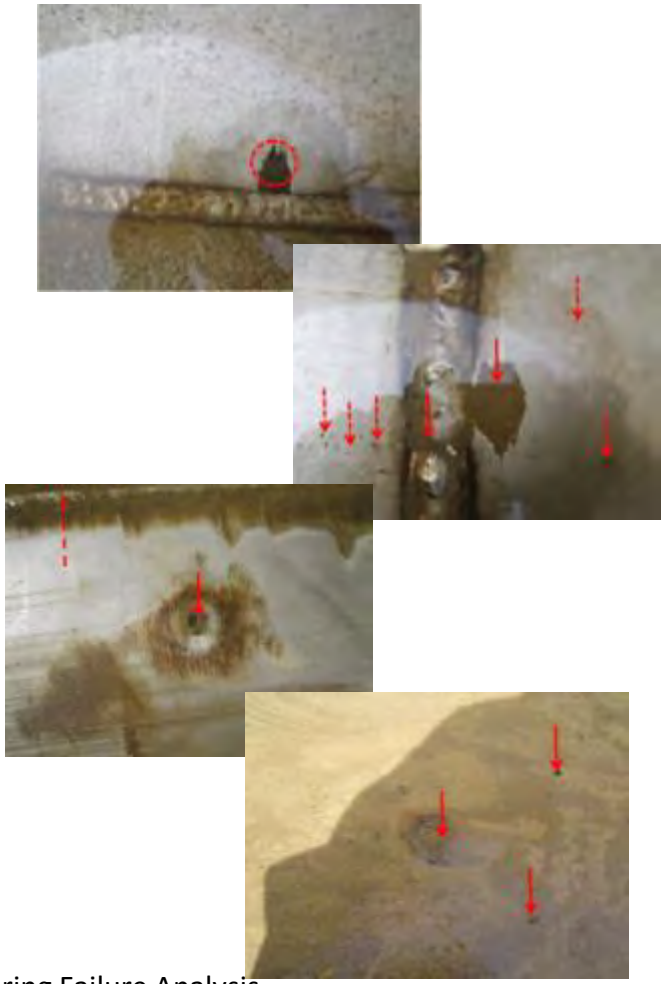


F.Farelas*, M.Galicia, B.Brown, S.Nesic, **H. Castaneda**, *Corrosion Science* 52, pp. 509–517. (2010).
H. Castaneda, M. Galicia, *J. of Solid State Electrochemistry*, Volume 16, Issue 9 (2012), Page 3045-3058

Corrosion Failure of Metallic storage tanks

MATERIALS SCIENCE & ENGINEERING
TEXAS A&M UNIVERSITY

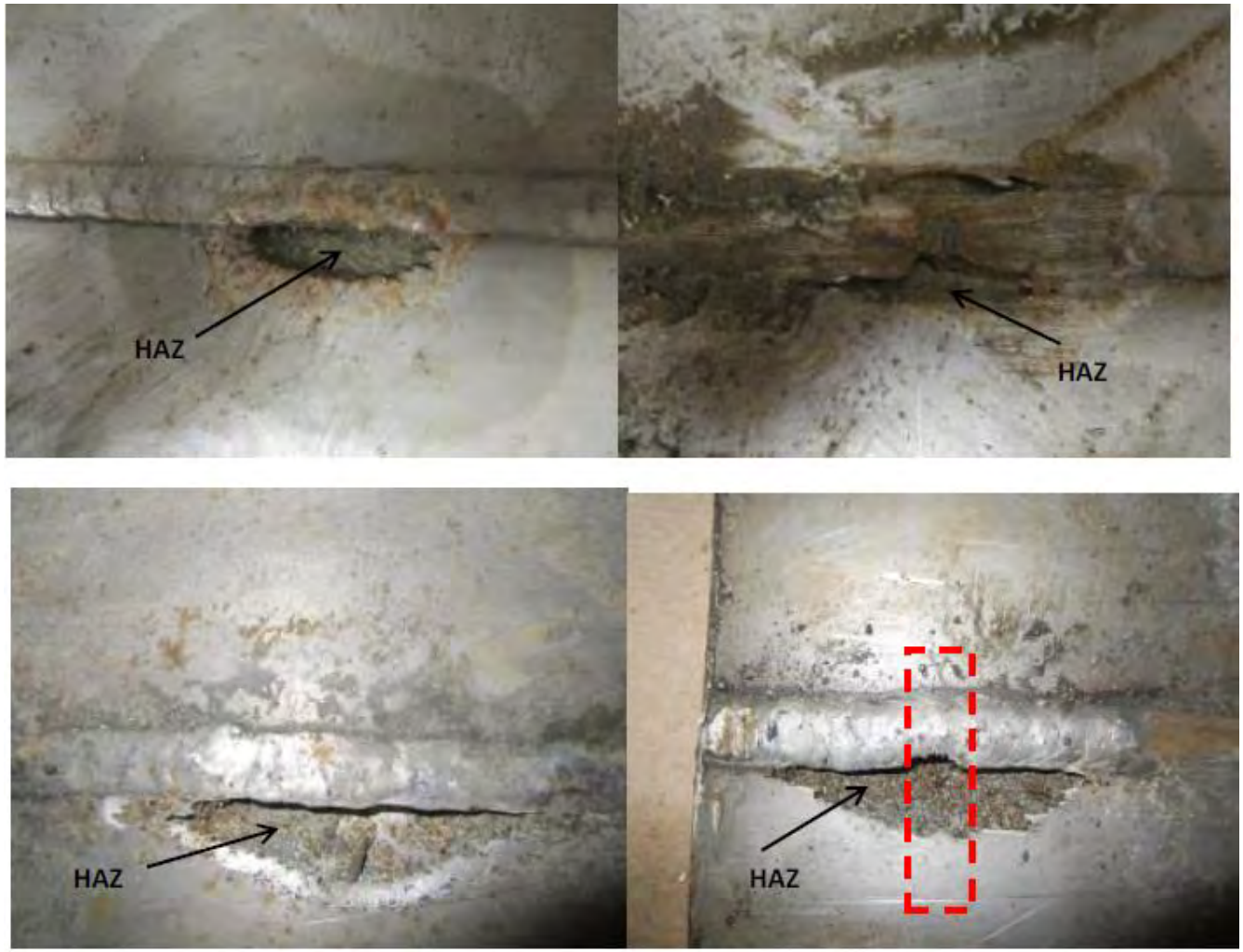
The failure was characterized by localized corrosion along the weld/HAZ



Reference: Engineering Failure Analysis
Volume 44, September 2014, Pages 351-362

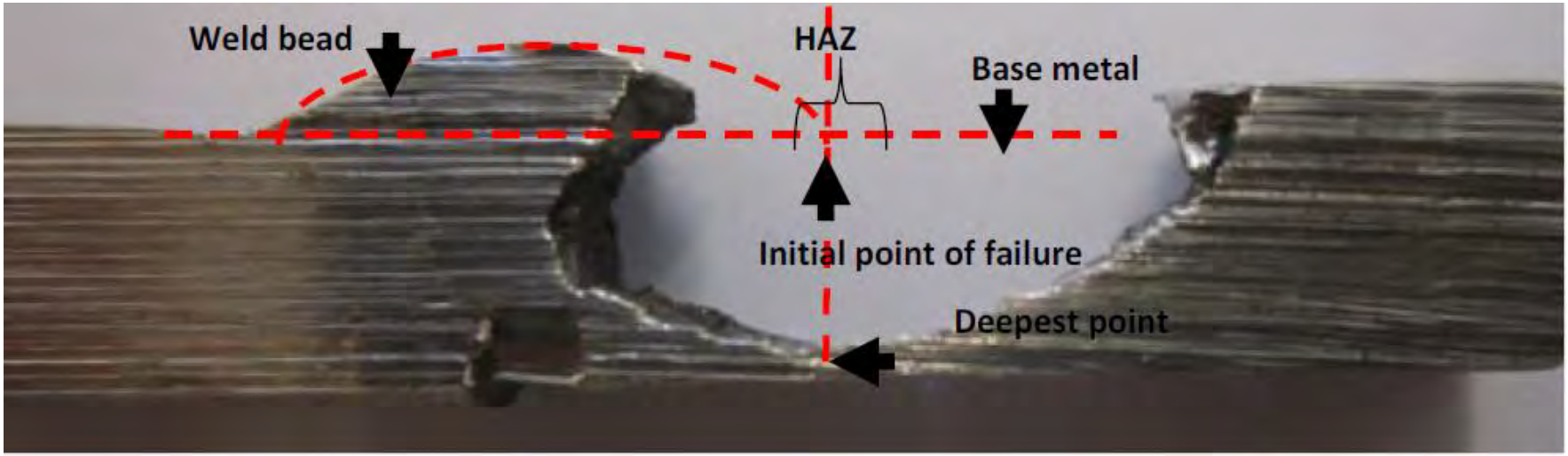
So, Where Did Corrosion Start? Base Metal? HAZ? or Weld Bead?

MATERIALS SCIENCE & ENGINEERING
TEXAS A&M UNIVERSITY



Reference: Engineering Failure Analysis Volume 44, September 2014, Pages 351-362

Reconstruction of Initial Point of Failure



Corrosion started on the heat affected zone (HAZ)

Thanks to our corrosion group
Questions??

MATERIALS SCIENCE & ENGINEERING
TEXAS A&M UNIVERSITY

CONSULEX®
Corrosion Professionals

Corrosion Management

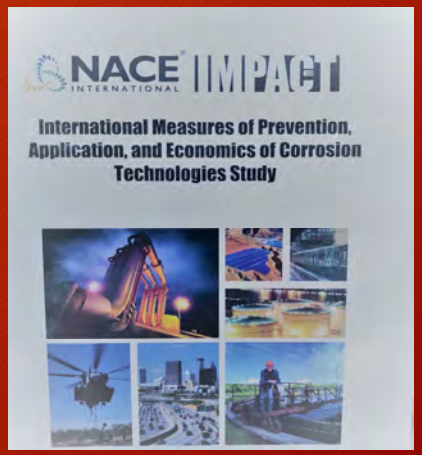
Texas A&M and NACE International's Desalination Corrosion Consortia

D. Terry Greenfield

IMPACT Study Launched October 2014

The IMPACT study:

- Updates the global cost of corrosion
- Assesses corrosion management practices
- Corrosion management templates
- Financial tools
- Benchmarking



Most Critical Findings of NACE International IMPACT Study

- A change in how decisions are made is required
- Continue investment in technology for corrosion control
- Corrosion Management System Framework
- Justify corrosion control actions by business impact

Corrosion Control Programs

Do you have one? Which one?

- Asset Integrity Management System (AIMS)
- Integrity Management System
- Corrosion Control Program
- Corrosion Control System
- Corrosion Engineering
- Corrosion Management

Corrosion Engineering

"Combating corrosion through proper materials selection, environmental control, and design"

An Introduction to Asset Corrosion Management in the Oil & Gas Industry
by Dr. Ali Morshed

Corrosion Management

- A Synonym for Corrosion Engineering?
- Corrosion control through corrosion engineering?
- *Definition: "The process of reviewing the existing Integrity Management measures, regular monitoring of their performances, and assessment of their effectiveness post-commissioning."*

An Introduction to Asset Corrosion Management in the Oil & Gas Industry
by Dr. Ali Morshed

Corrosion Management

- Should include Corrosion Engineering and Corrosion control efforts comprised of policies, processes and procedures that address corrosion across the complete lifecycle of the asset, from design to decommissioning.
- A Corrosion Management Program must include an accepted philosphy within the organization and ingrained into the that corporate culture.

Corrosion Management Program

- Asset Integrity Management
- Overarching and encompassing all aspects of corrosion control including the use of coatings
- Methods can be widely varied
- Corrosion Engineering vs. Corrosion Management
- NACE International IMPACT Study and IMPACT Plus Tool
- Sustainability

Corrosion Control Program Benefits

- Corrosion Control Program Benefits
- Satisfy regulatory requirements
- Ensure safe operation of assets
- An effective Corrosion Control Program requires a relatively small investment compared to the potential return on that investment
- Sustainability

Current Industry Mindset?

Corrosion Management

Program Elements Identification of Corrosion Threats

- Life-Cycle Cost Analysis
- Corrosion Control Strategies
- Corrosion Monitoring and Inspection
- Program Performance Review and Management

Corrosion Prevention Systems

- Protective Coatings
- Materials Selection
- Cathodic Protection

1- MATERIALS PERFORMANCE MAGAZINE
Essential Elements of a Successful Corrosion Management Program
By *Ben DuBose* on 6/30/2016 – a summary of S. Ghalsasi, B. Fultz, R. Colwell, "Primary Constituents of a Successful Corrosion Management Program," NACE Corrosion Risk Management Conference, paper no. RISK16-8734 (Houston, TX: NACE International, 2016).

NACE International IMPACT PLUS Corrosion Management Maturity Model

And it's Role in the Asset Integrity Management of a Corrosion Control Program

Corrosion Management Maturity Model

Was developed with the lessons learned from the IMPACT Study and a panel of Industry Corrosion Professionals. It provides a structured model of corrosion management maturity characteristics

Key Features:

- 10 management system domains (Areas of business practice)
- 5 maturity levels (Defined sets of characteristics)
- Characteristics (Capabilities you would expect to see at each stage of maturity)

Corrosion Management System Domains

1) **POLICY**
   Policies, associated strategies, and objectives to address business needs (including regulatory, legal, environmental, and societal).

2) **ACCOUNTABILITY**
   Roles, responsibilities, and resource allocation.

3) **COMMUNICATION**
   Awareness, knowledge management, and lessons learned.

4) **STAKEHOLDER INTEGRATION**
   Alignment to stakeholder needs, performance monitoring, and compliance,

5) **RESOURCES**
   Competencies, training and development, and formalization of job and work requirements,

Corrosion Management System Domains

6) **CM PRACTICE INTEGRATION**
   Integration into work processes, alignment to quality and other disciplines, and incident tracking/resolution

7) **PERFORMANCE MEASURES**
   Quantifiable indication, such as Key Performance Indicators (KPIs) to assess and to measure how well an organization or individual is achieving desired goals

8) **ORGANIZATION**
   Structure, interaction model and internal/external engagement (vendors/suppliers)

9) **CULTURE & KNOWLEDGE MANAGEMENT**
   Knowledge capture and transfer, lessons learned, content management, sharing culture

10) **CONTINUOUS IMPROVEMENT**
    Improvement identification, prioritization, selection, and change management

Five Levels of Maturity for Each Domain

(Defined sets of characteristics)

5 Innovative & Leading	• Highly engaged and driving the state-of-the art of corrosion management • Anticipatory, agile, and embedded in the flow of the work	Progressive; Inclusive
4 Optimized & Proactive	• Corrosion management program implemented; • Lessons learned activities built into CM processes to capture and apply learnings to improve CM processes • May have some anticipatory capabilities	Visible; Improving
3 Managed & Integrated	• Corrosion management is well-structured management approach • Aligned end-to-end across the enterprise	Comprehensive; Enterprise-wide
2 Defined & Compliant	• Corrosion management defined but only compliant with the standard or bare minimum • Some CM processes defined, but may still be isolated and not part of integrated management approach	Locally Consistent
1 Reactive	• Need for corrosion management identified, but no strategic focus • Corrosion management activities occur on as-needed basis but no systematic plan in place to address more consistently	Basic; Individual

The VALUE Proposition…

- Integrated platform for corrosion management professionals who desire to move their company to higher levels of performance
- A common language and structure needed to ensure communication throughout all levels of an organization
- Easy way for organizations to identify gaps in processes that could lead to the reduced lifecycle of assets
- The CMMM creates a roadmap of strategies, investments and best practices that lead to higher performance

THANK YOU

- D. Terry Greenfield
- Principal Consultant
- +1 (321) 213-2170
- Terry.greenfield@consulex.com

- www.consulex.com

?