

Thermo-Electric Design of a 400 kA Cell Using Mathematical Models: A Tutorial

Marc Dupuis

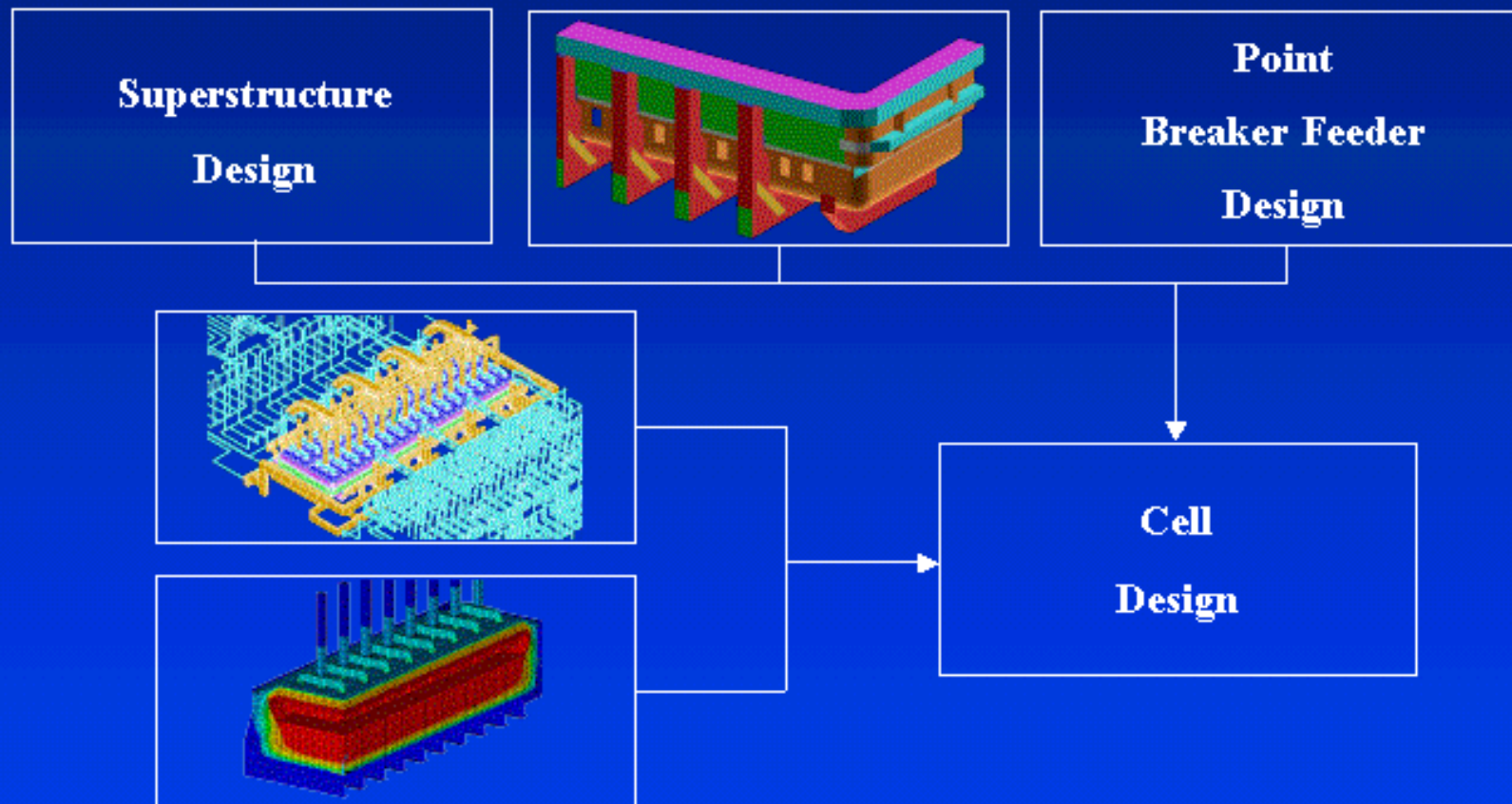
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Plan of the Presentation

- **Modeling the Hall-Héroult Cell**
- **Thermo-Electric Steady State Models**
 - Full 3D finite element cell slice model
 - Full 2D+ finite element cell slice model
 - 1D lump parameters process model
- **Validation of the Base Case Models**
 - *Current* design operating at 300 kA
- **Step-by-Step Retrofit Study**
 - Increasing amperage to 350 kA
- **Greenfield Study**
 - Increasing amperage to 400 kA
 - Monte Carlo risk assessment study
 - *Ease of operation* dynamic study
- **Conclusions**

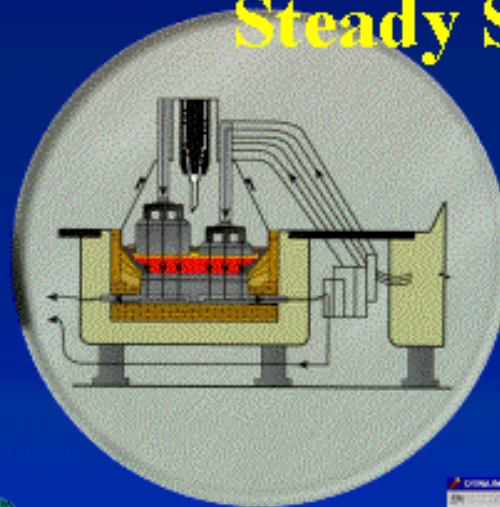
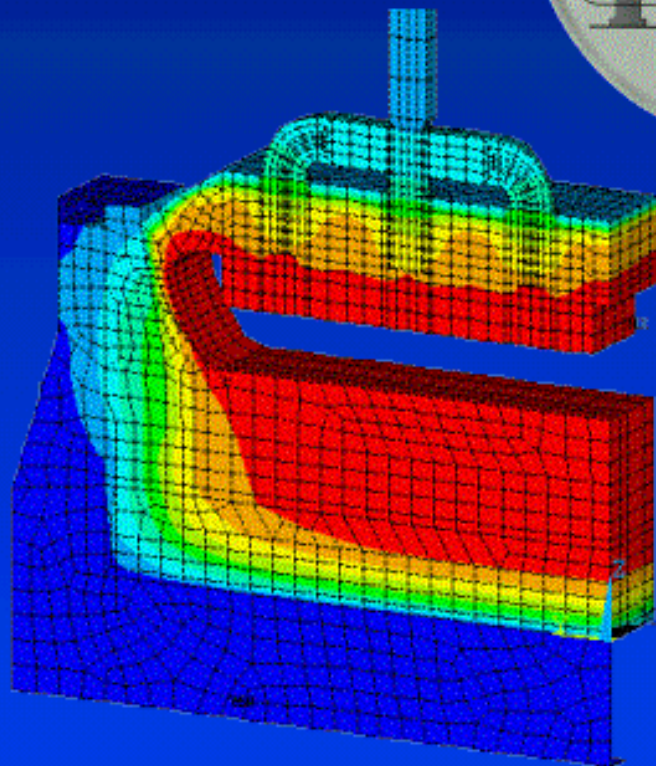
Modeling the Hall-Hérault Cell



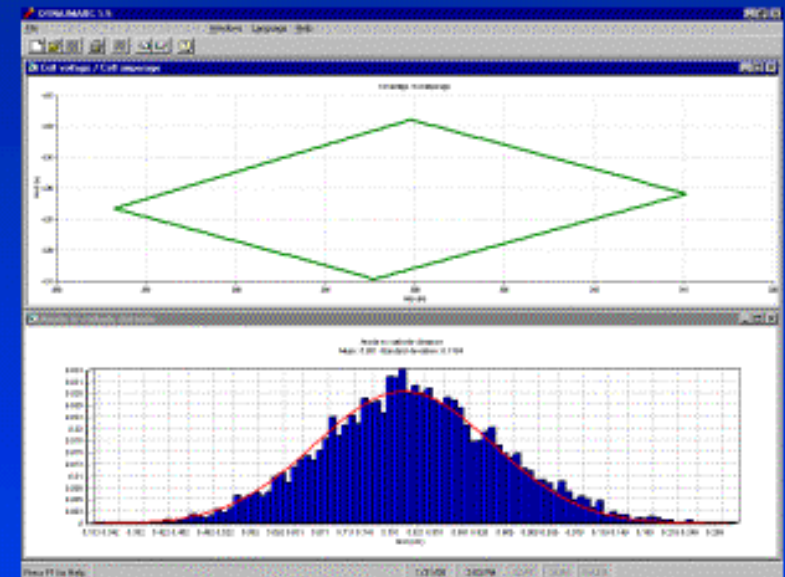
Thermo-Electric

Steady State Models

3D and 2D+
Finite Element Models

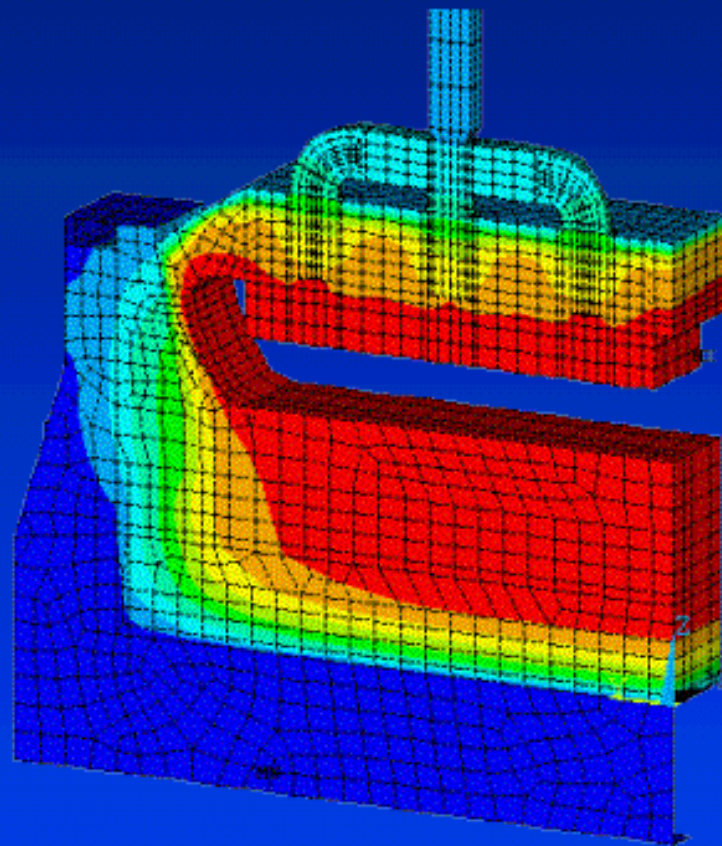


1D Lump Parameters
Process Model



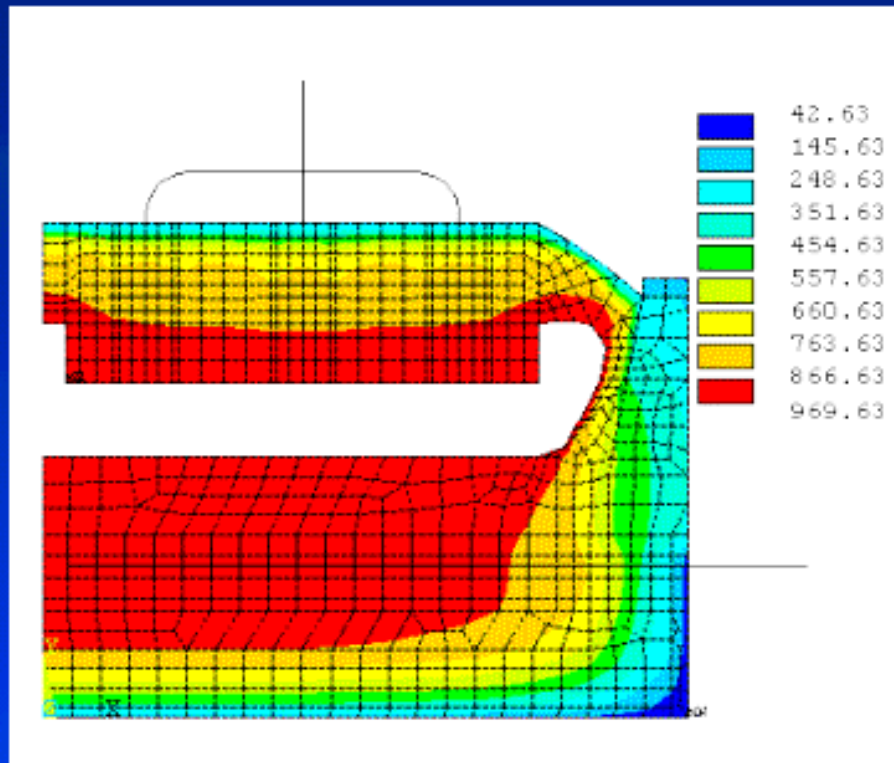
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Full 3D Finite Element Cell Slice Model



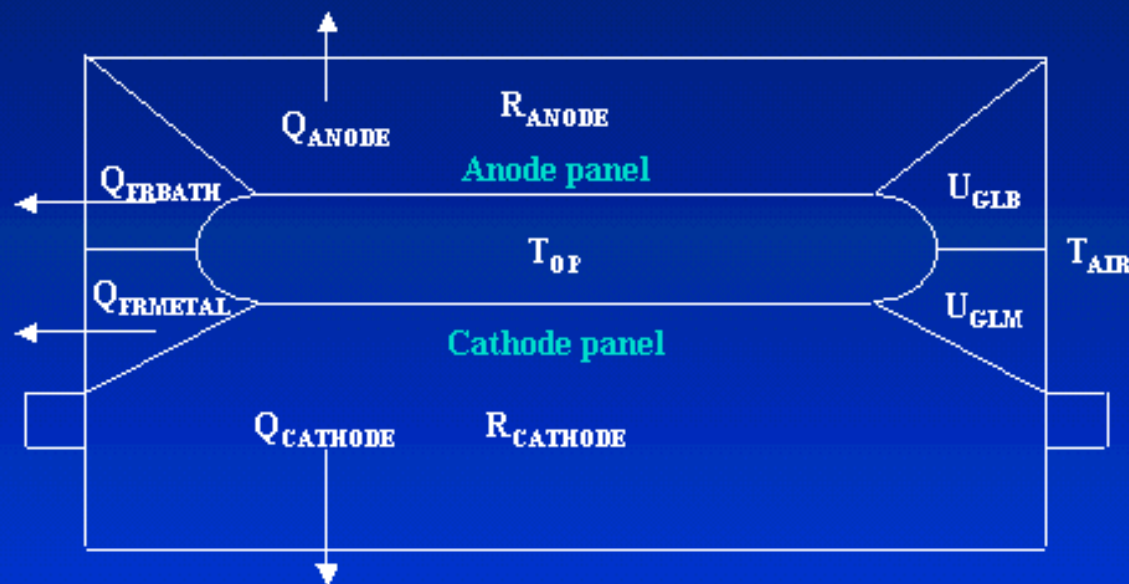
- Most accurate cell slice model available
- Require around 30 min. CPU to converge solution on a Pentium II 266 MHz PC

Full 2D+ Finite Element Cell Slice Model



- Fastest cell slice model available
- Require less than 5 min. CPU to converge solution on a Pentium II 266 MHz PC

1D Lump Parameters Process Model



- Very simplified thermal sub-model
- Can compute thousands of solutions in a few sec. CPU

$$Q_{ANODE} = R_{ANODE} * (T_{OP} - T_{AIR})$$

$$Q_{CATHODE} = R_{CATHODE} * (T_{OP} - T_{AIR})$$

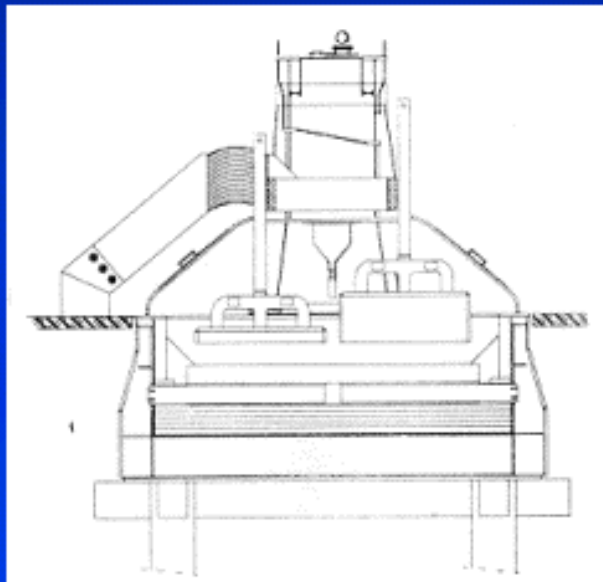
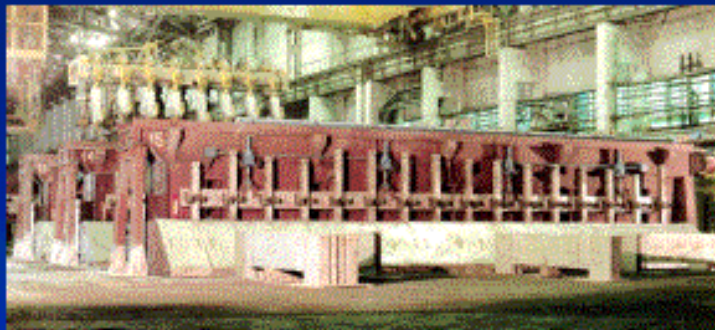
$$Q_{FRBATH} = h_{FRB} * A_{BATHLEGE} * (T_{OP} - T_{MIT}) = U_{GLB} * A_{BATHLEGE} * (T_{OP} - T_{AIR})$$

$$Q_{FRMETAL} = h_{FRM} * A_{METALEGE} * (T_{OP} - T_{MIT}) = U_{GLM} * A_{METALEGE} * (T_{OP} - T_{AIR})$$

$$U_{GLB} = \frac{1}{\left(\frac{1}{U_{FIXB}} + \frac{1}{U_{FRB}} \right)}$$

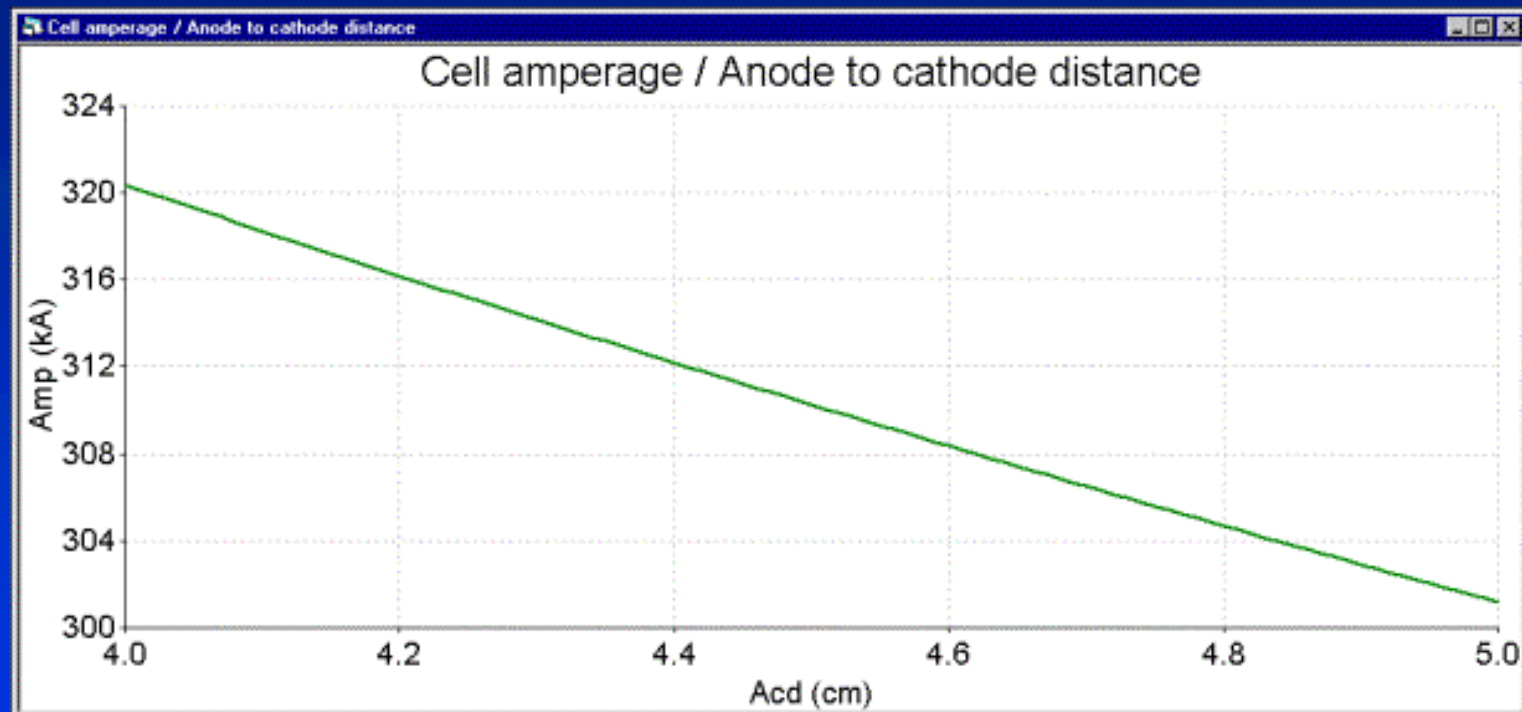
$$U_{GLM} = \frac{1}{\left(\frac{1}{U_{FIXM}} + \frac{1}{U_{FRM}} \right)}$$

Validation of the Base Case Model



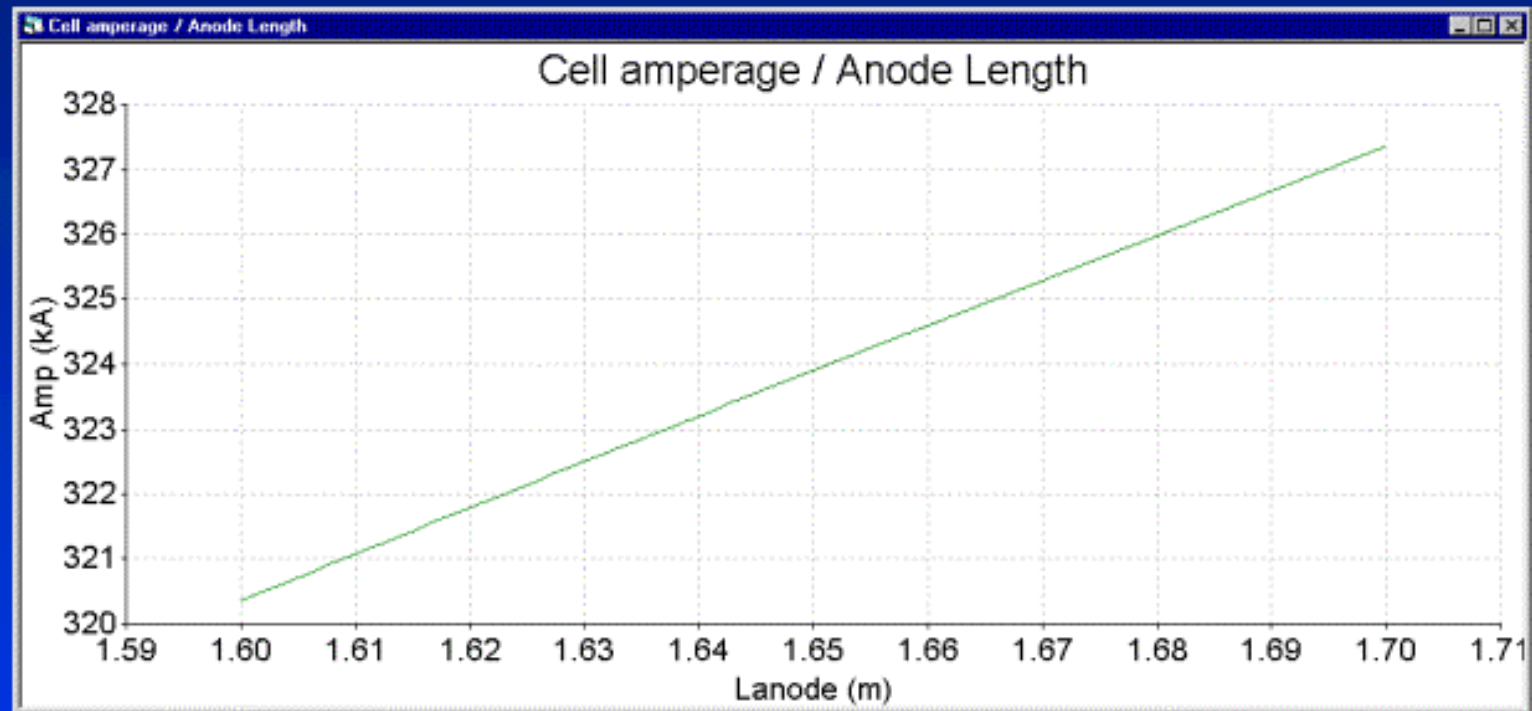
| | |
|-----------------------|-----------------|
| Amperage | 300 kA |
| Nb. of anodes | 32 |
| Anode size | 1.6 m X 0.8 m |
| Nb. of anode studs | 3 per anode |
| Anode stud diameter | 18 cm |
| Anode cover thickness | 16 cm |
| Nb. of cathode blocks | 18 |
| Cathode block length | 3.47 m |
| Type of cathode block | 30 % graphitic |
| Type of side block | 30 % graphitic |
| Side block thickness | 15 cm + |
| ASD and AED | 35 cm |
| Inside potshell size | 14.4 m X 4.35 m |
| ACD | 5 cm |
| Excess AlF_3 | 10.9 % |
| Operating temperature | 973.3 °C |
| Liquidus superheat | 6.8 °C |
| Current efficiency | 94.0 % |
| Internal heat | 628 kW |
| Energy consumption | 13.75 kWh/kg |

Step-by-Step Retrofit Study



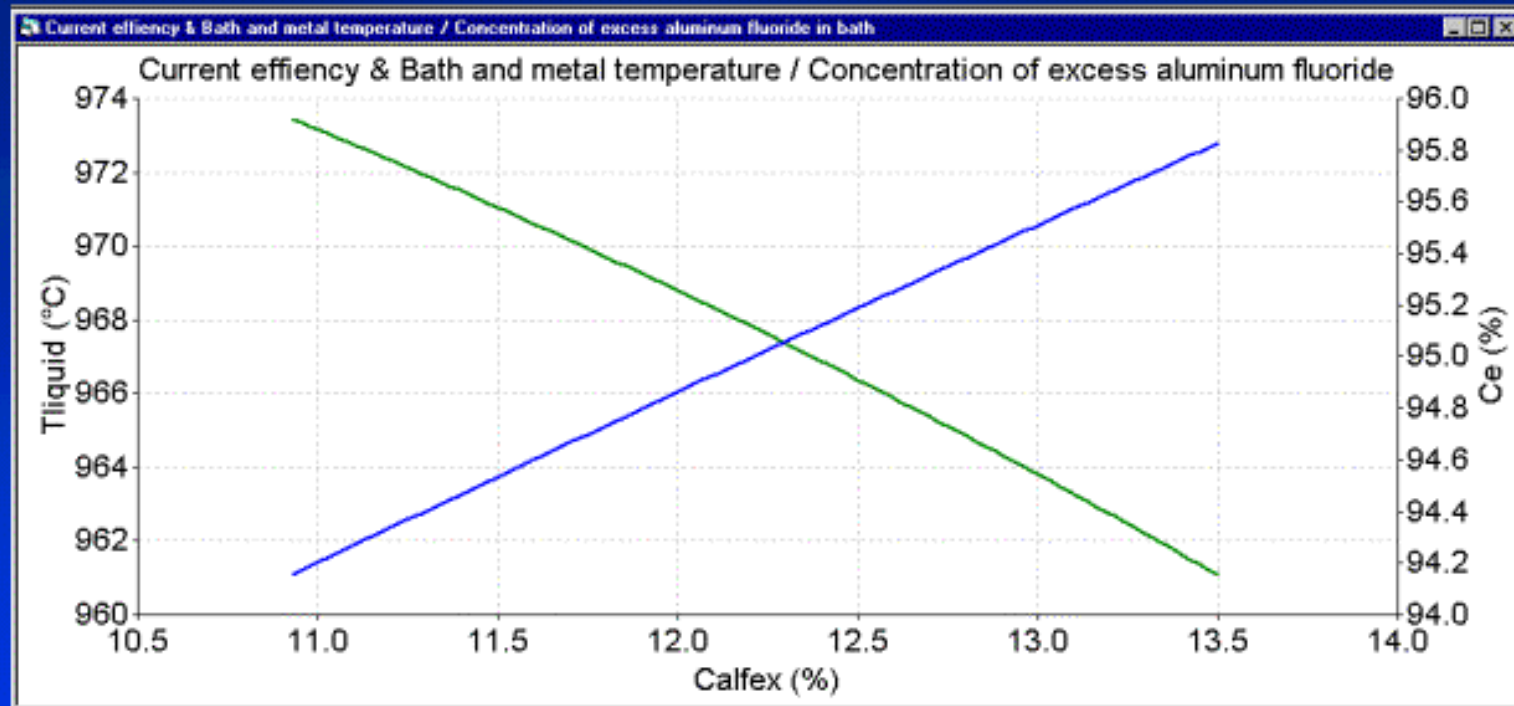
- Process model's trend analysis: Exchanging ACD for amperage

Step-by-Step Retrofit Study



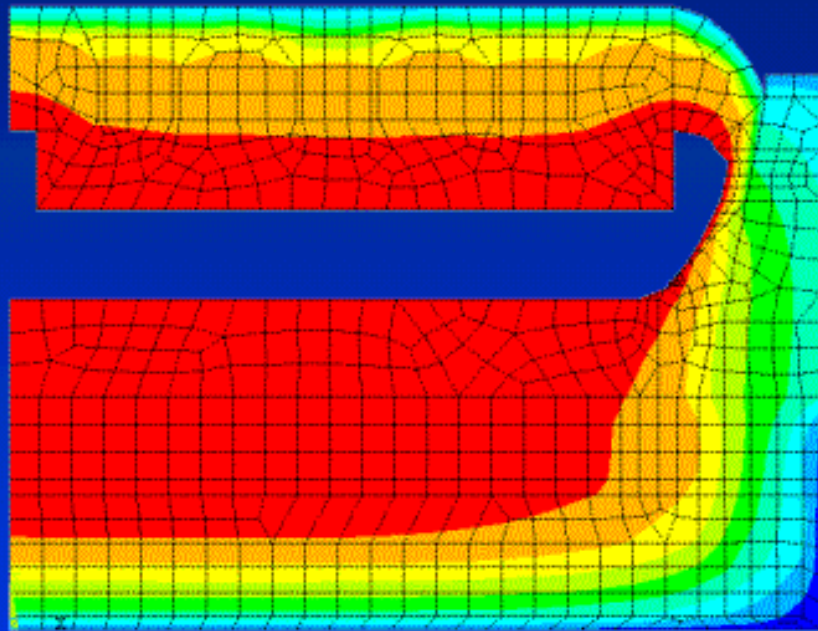
- Trend analysis: More amperage using longer anodes

Step-by-Step Retrofit Study



- Trend analysis: Effect of adding excess AlF_3 on CE

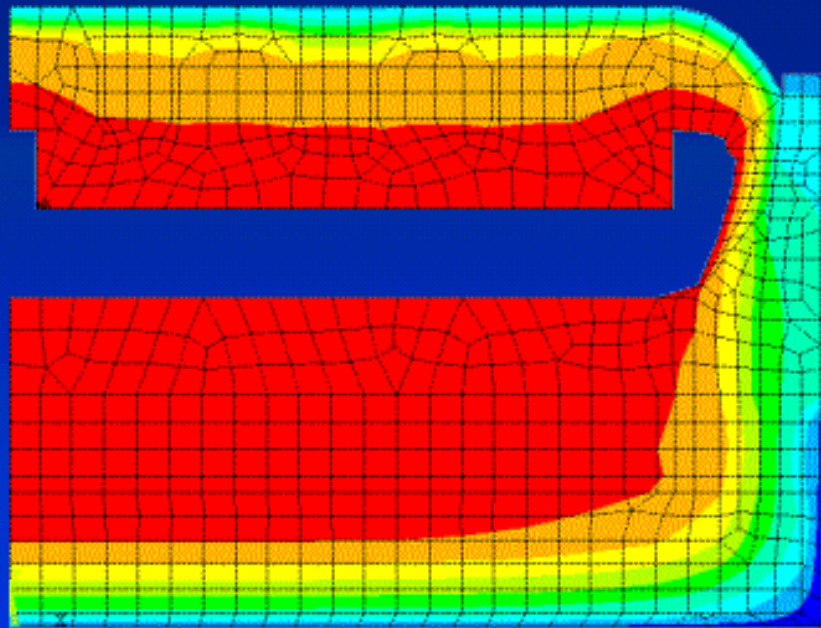
Step-by-Step Retrofit Study



- Confirmation of results using 2D+ model

| | |
|-----------------------|-----------------|
| Amperage | 327 kA |
| Nb. of anodes | 32 |
| Anode size | 1.7 m X 0.8 m |
| Nb. of anode studs | 3 per anode |
| Anode stud diameter | 18 cm |
| Anode cover thickness | 16 cm |
| Nb. of cathode blocks | 18 |
| Cathode block length | 3.47 m |
| Type of cathode block | 30 % graphitic |
| Type of side block | 30 % graphitic |
| Side block thickness | 15 cm + |
| ASD | 25 cm |
| Inside potshell size | 14.4 m X 4.35 m |
| ACD | 4 cm |
| Excess AlF_3 | 13.5 % |
| Operating temperature | 960.8 °C |
| Liquidus superheat | 7.1 °C |
| Current efficiency | 95.8 % |
| Internal heat | 639 kW |
| Energy consumption | 13.09 kWh/kg |

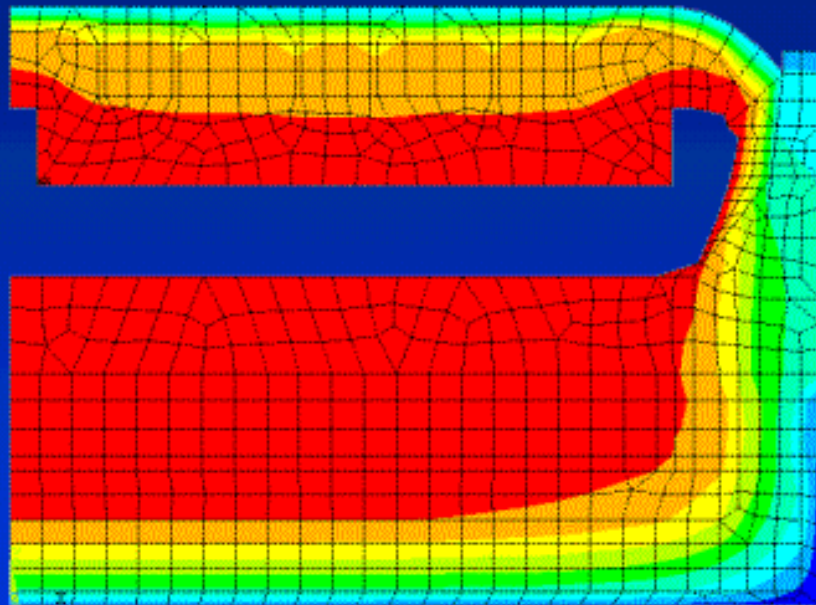
Step-by-Step Retrofit Study



- **Modifying cathode and side wall blocks**

| | |
|-----------------------|-------------------|
| Amperage | 327 kA |
| Nb. of anodes | 32 |
| Anode size | 1.7 m X 0.8 m |
| Nb. of anode studs | 3 per anode |
| Anode stud diameter | 18 cm |
| Anode cover thickness | 16 cm |
| Nb. of cathode blocks | 18 |
| Cathode block length | 3.67 m |
| Type of cathode block | 100 % graphitized |
| Type of side block | Silicon carbide |
| Side block thickness | 10 cm + |
| ASD | 30 cm |
| Inside potshell size | 14.4 m X 4.35 m |
| ACD | 4 cm |
| Excess AlF_3 | 13.5 % |
| Operating temperature | 958.9 °C |
| Liquidus superheat | 5.2 °C |
| Current efficiency | 96.0 % |
| Internal heat | 624 kW |
| Energy consumption | 12.95 kWh/kg |

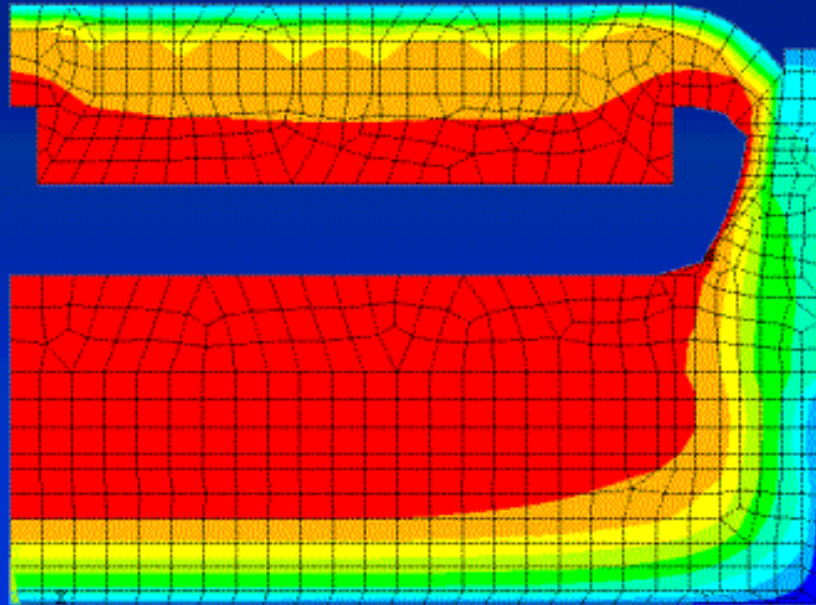
Step-by-Step Retrofit Study



- Decreasing anode cover to 10 cm and increasing amperage to 335 kA

| | |
|-----------------------|-------------------|
| Amperage | 335 kA |
| Nb. of anodes | 32 |
| Anode size | 1.7 m X 0.8 m |
| Nb. of anode studs | 3 per anode |
| Anode stud diameter | 18 cm |
| Anode cover thickness | 10 cm |
| Nb. of cathode blocks | 18 |
| Cathode block length | 3.67 m |
| Type of cathode block | 100 % graphitized |
| Type of side block | Silicon carbide |
| Side block thickness | 10 cm + |
| ASD | 30 cm |
| Inside potshell size | 14.4 m X 4.35 m |
| ACD | 4 cm |
| Excess AlF_3 | 13.5 % |
| Operating temperature | 959.2 °C |
| Liquidus superheat | 5.5 °C |
| Current efficiency | 96.0 % |
| Internal heat | 657 kW |
| Energy consumption | 13.2 kWh/kg |

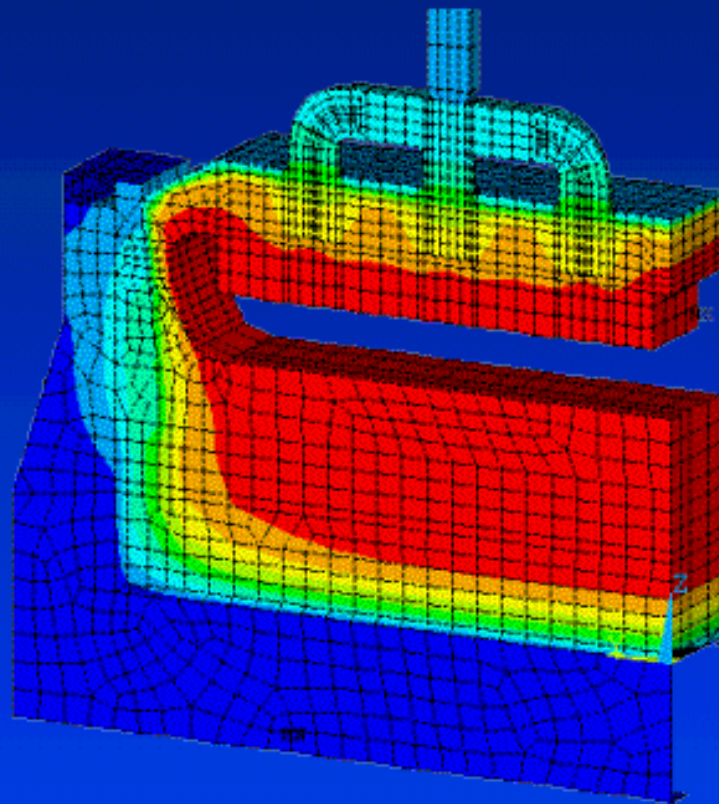
Step-by-Step Retrofit Study



- Increasing stud diameter to 19 cm and increasing amperage to 345 kA

| | |
|-----------------------|-------------------|
| Amperage | 345 kA |
| Nb. of anodes | 32 |
| Anode size | 1.7 m X 0.8 m |
| Nb. of anode studs | 3 per anode |
| Anode stud diameter | 19 cm |
| Anode cover thickness | 10 cm |
| Nb. of cathode blocks | 18 |
| Cathode block length | 3.67 m |
| Type of cathode block | 100 % graphitized |
| Type of side block | Silicon carbide |
| Side block thickness | 10 cm + |
| ASD | 30 cm |
| Inside potshell size | 14.4 m X 4.35 m |
| ACD | 4 cm |
| Excess AlF_3 | 13.5 % |
| Operating temperature | 960.3 °C |
| Liquidus superheat | 6.6 °C |
| Current efficiency | 96.0 % |
| Internal heat | 695 kW |
| Energy consumption | 13.35 kWh/kg |

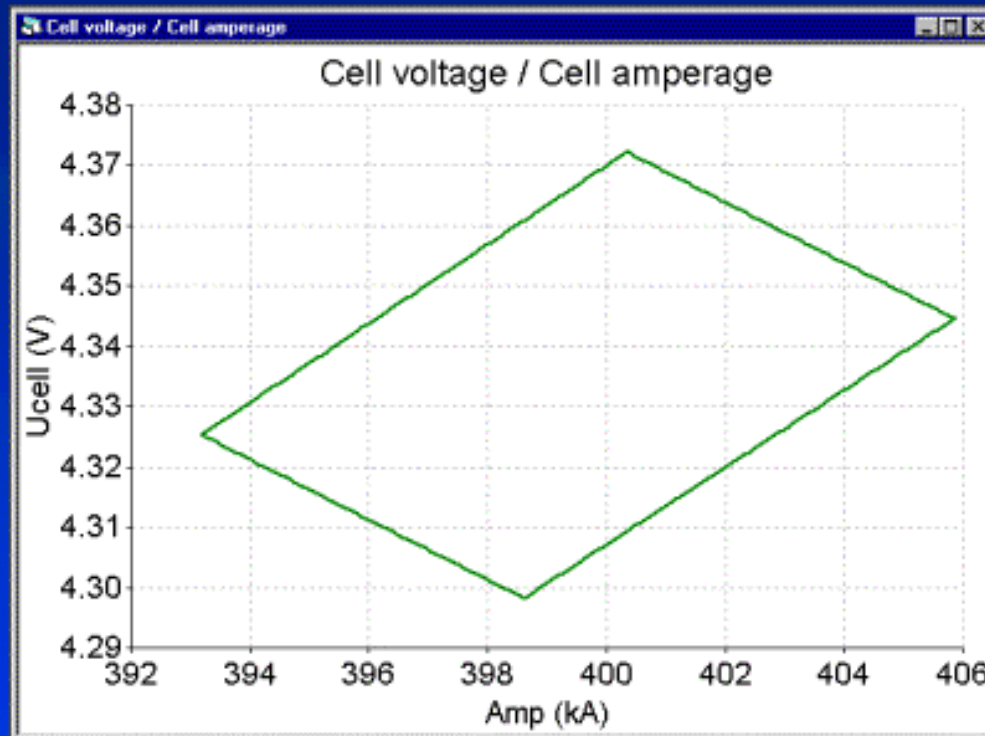
Step-by-Step Retrofit Study



| | |
|-----------------------|-------------------|
| Amperage | 350 kA |
| Nb. of anodes | 32 |
| Anode size | 1.7 m X 0.8 m |
| Nb. of anode studs | 3 per anode |
| Anode stud diameter | 19 cm |
| Anode cover thickness | 10 cm |
| Nb. of cathode blocks | 18 |
| Cathode block length | 3.67 m |
| Type of cathode block | 100 % graphitized |
| Type of side block | Silicon carbide |
| Side block thickness | 10 cm + |
| ASD | 30 cm |
| Inside potshell size | 14.4 m X 4.35 m |
| ACD | 4 cm |
| Excess AlF_3 | 13.5 % |
| Operating temperature | 960.4 °C |
| Liquidus superheat | 6.7 °C |
| Current efficiency | 96.1 % |
| Internal heat | 713 kW |
| Energy consumption | 13.4 kWh/kg |

- Increasing amperage to 350 kA

Greenfield Study

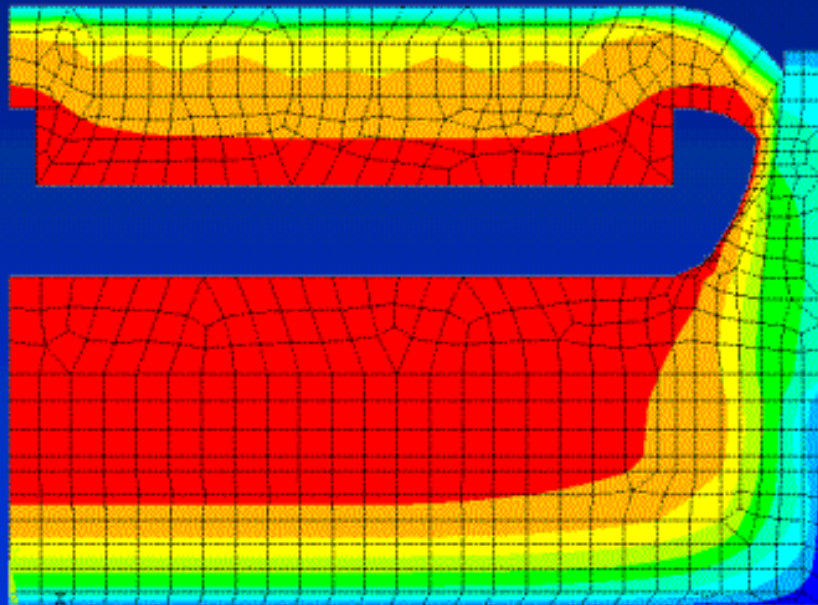


- Initial design using the lump parameters process model

| | |
|-----------------------|-------------------|
| Amperage | 400 kA |
| Nb. of anodes | 36 |
| Anode size | 1.6 m X 0.8 m |
| Nb. of anode studs | 3 per anode |
| Anode stud diameter | 19 cm |
| Anode cover thickness | 10 cm |
| Nb. of cathode blocks | 20 |
| Cathode block length | 3.67 m |
| Type of cathode block | 100 % graphitized |
| Type of side block | Silicon carbide |
| Side block thickness | 10 cm + |
| ASD and AED | 30 cm |
| Inside potshell size | 16.1 m X 4.35 m |
| ACD | 4 cm |
| Excess AlF_3 | 13.5 % |
| Operating temperature | 962.2 °C |
| Liquidus superheat | 8.5 °C |
| Current efficiency | 96.0 % |
| Internal heat | 821 kW |
| Energy consumption | 13.5 kWh/kg |

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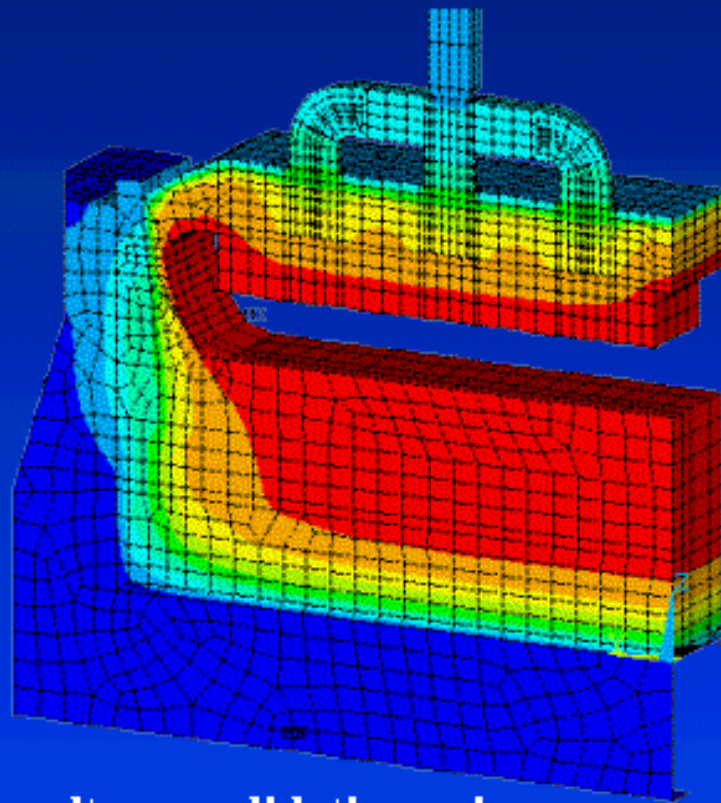
Greenfield Study



- **Results consolidation using 2D+ model**

| | |
|-----------------------|-------------------|
| Amperage | 400 kA |
| Nb. of anodes | 36 |
| Anode size | 1.6 m X 0.8 m |
| Nb. of anode studs | 3 per anode |
| Anode stud diameter | 19 cm |
| Anode cover thickness | 10 cm |
| Nb. of cathode blocks | 20 |
| Cathode block length | 3.67 m |
| Type of cathode block | 100 % graphitized |
| Type of side block | Silicon carbide |
| Side block thickness | 10 cm + |
| ASD and AED | 30 cm |
| Inside potshell size | 16.1 m X 4.35 m |
| ACD | 4 cm |
| Excess AlF_3 | 13.5 % |
| Operating temperature | 962.4 °C |
| Liquidus superheat | 8.7 °C |
| Current efficiency | 96.0 % |
| Internal heat | 834 kW |
| Energy consumption | 13.6 kWh/kg |

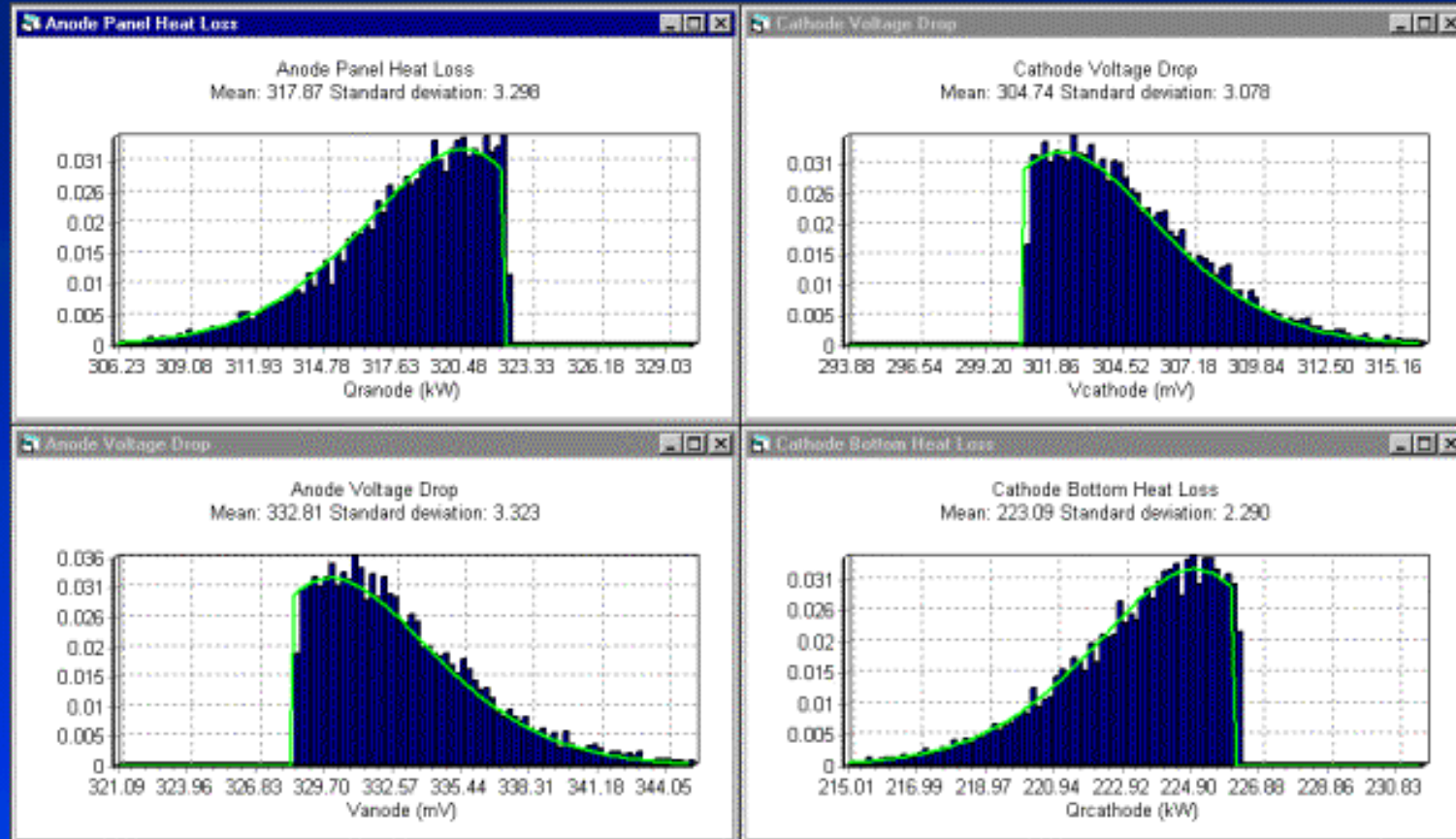
Greenfield Study



- Results consolidation using the 3D model

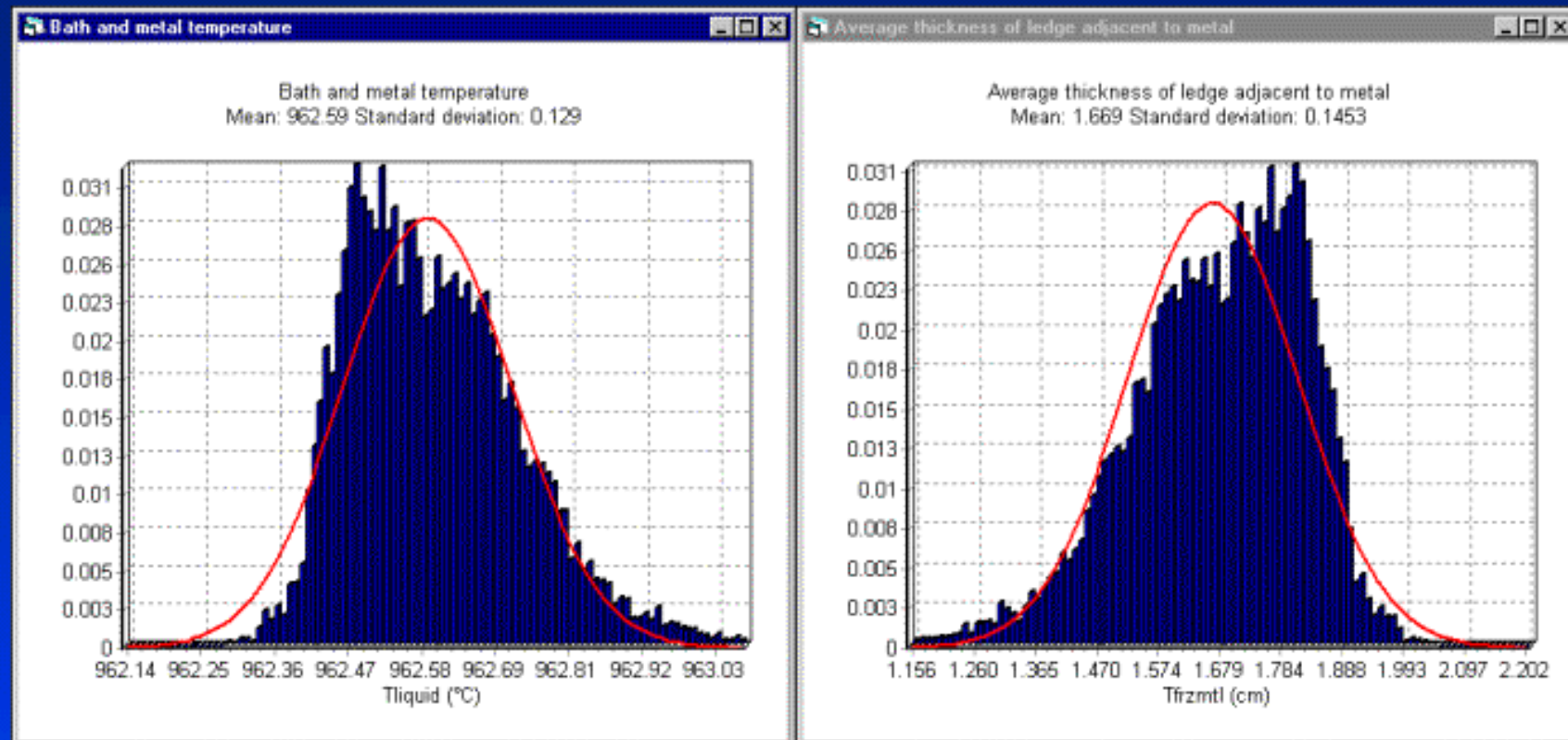
| | |
|-----------------------|-------------------|
| Amperage | 400 kA |
| Nb. of anodes | 36 |
| Anode size | 1.6 m X 0.8 m |
| Nb. of anode studs | 3 per anode |
| Anode stud diameter | 19 cm |
| Anode cover thickness | 10 cm |
| Nb. of cathode blocks | 20 |
| Cathode block length | 3.67 m |
| Type of cathode block | 100 % graphitized |
| Type of side block | Silicon carbide |
| Side block thickness | 10 cm + |
| ASD and AED | 30 cm |
| Inside potshell size | 16.1 m X 4.35 m |
| ACD | 4 cm |
| Excess AlF_3 | 13.5 % |
| Operating temperature | 962.4 °C |
| Liquidus superheat | 8.7 °C |
| Current efficiency | 96.0 % |
| Internal heat | 834 kW |
| Energy consumption | 13.6 kWh/kg |

Greenfield Study



- Monte Carlo risk assessment study: Input distributions

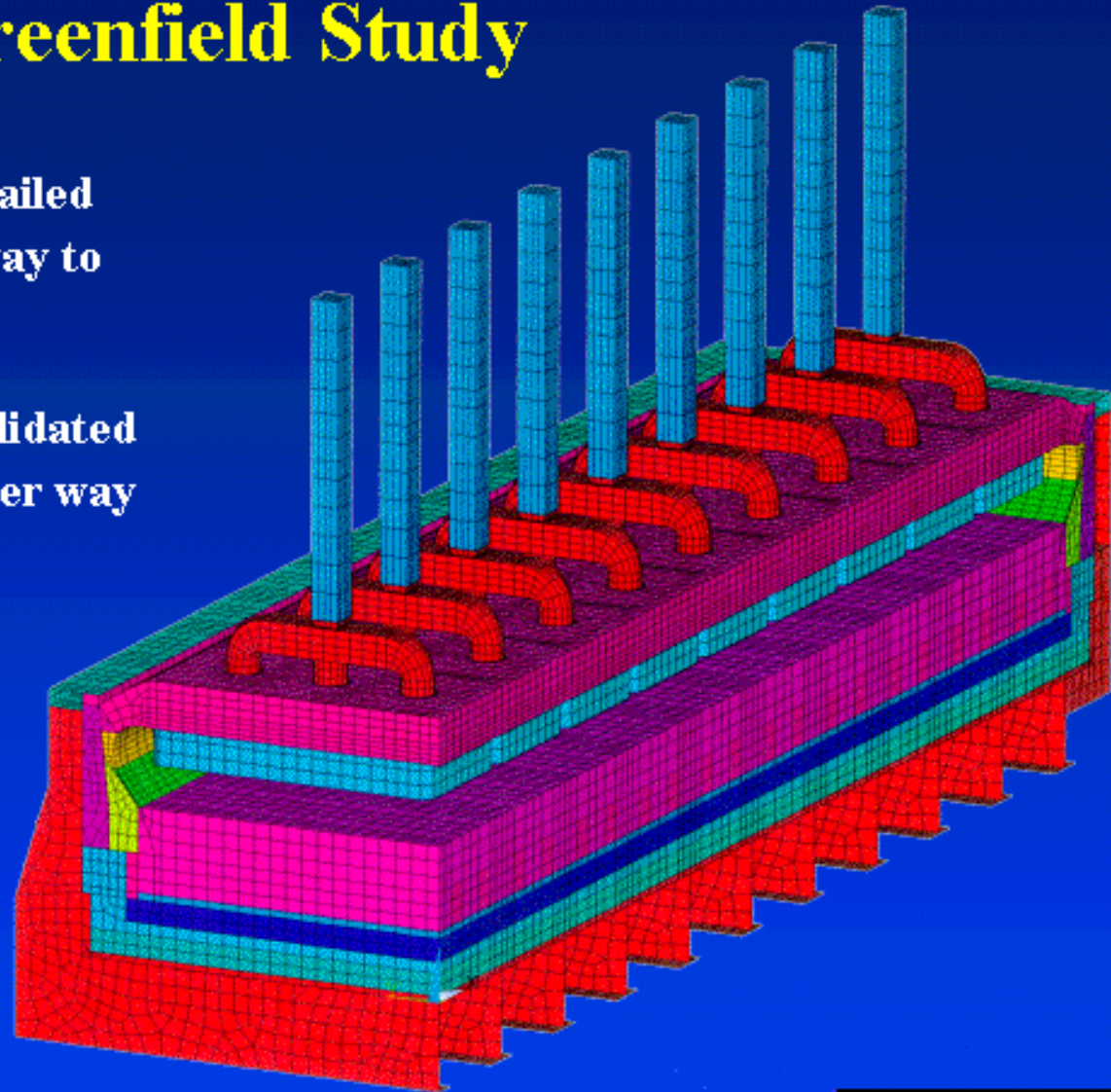
Greenfield Study



- Monte Carlo risk assessment study: Output distributions

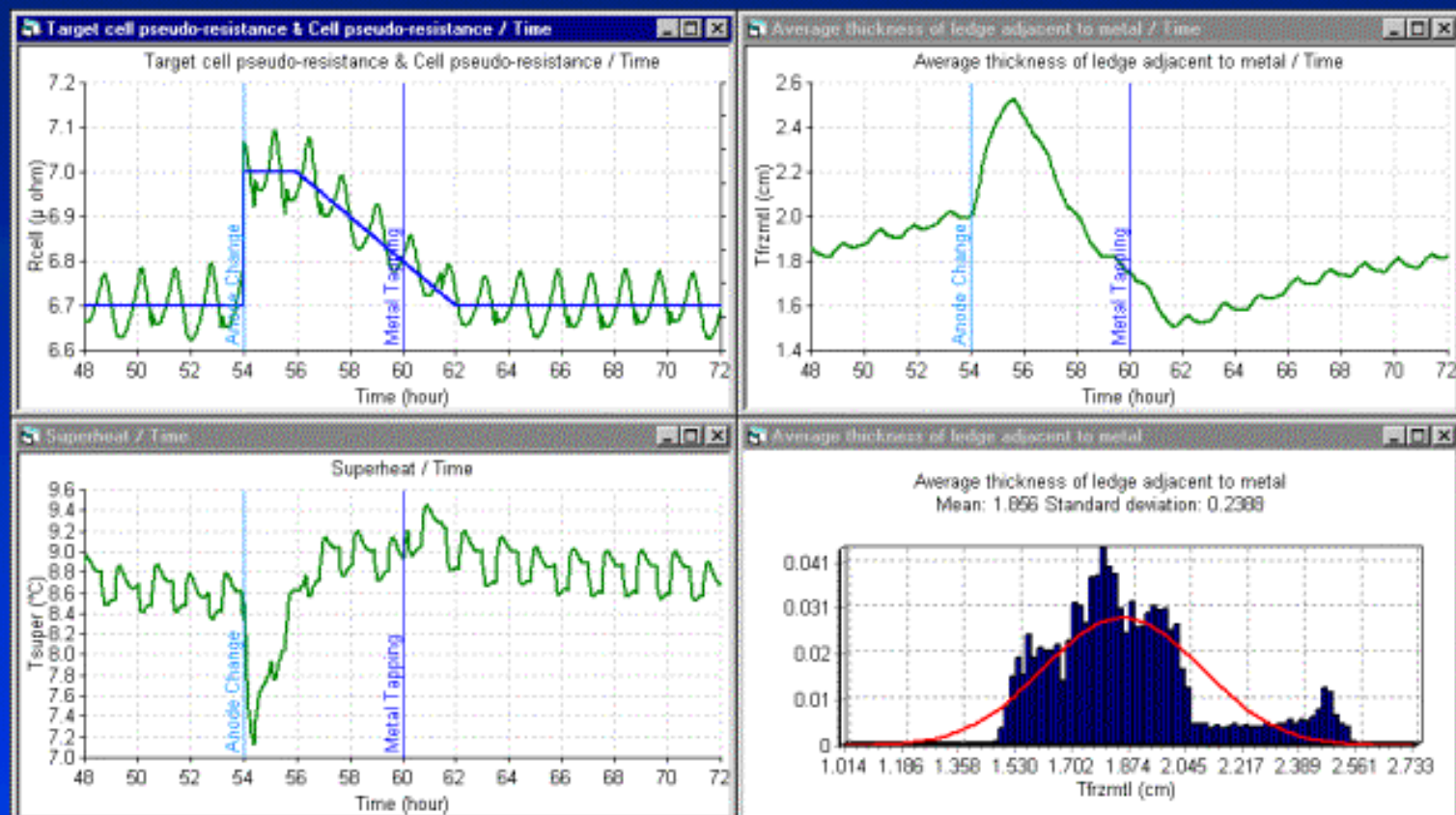
Greenfield Study

- Using more detailed models is one way to reduce the risk
- Using better validated models is another way



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Greenfield Study



- *Ease of operation dynamic study*

Conclusions

- In only a few straightforward steps, a 300 kA cell design was retrofitted into a 350 kA cell design.
- In only one extra step, the 350 kA cell design was extended into a 16 m long 400 kA cell design simply by adding 4 anodes.
- Designing a properly balanced cell lining at 400 kA does not pose a serious challenge to an experienced cell designer using the proper numerical tools.