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Protecting People and the Environment

Status of Fukushima Daiichi

David Skeen
Japan Lessons Learned Project Directorate
U.S. Nuclear Regulatory Commission

November 5, 2013

Japan Lessons Learned

EA/4

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Agenda

- Overall status
- Water Issues
- US Government Agency Involvement
- Path Forward

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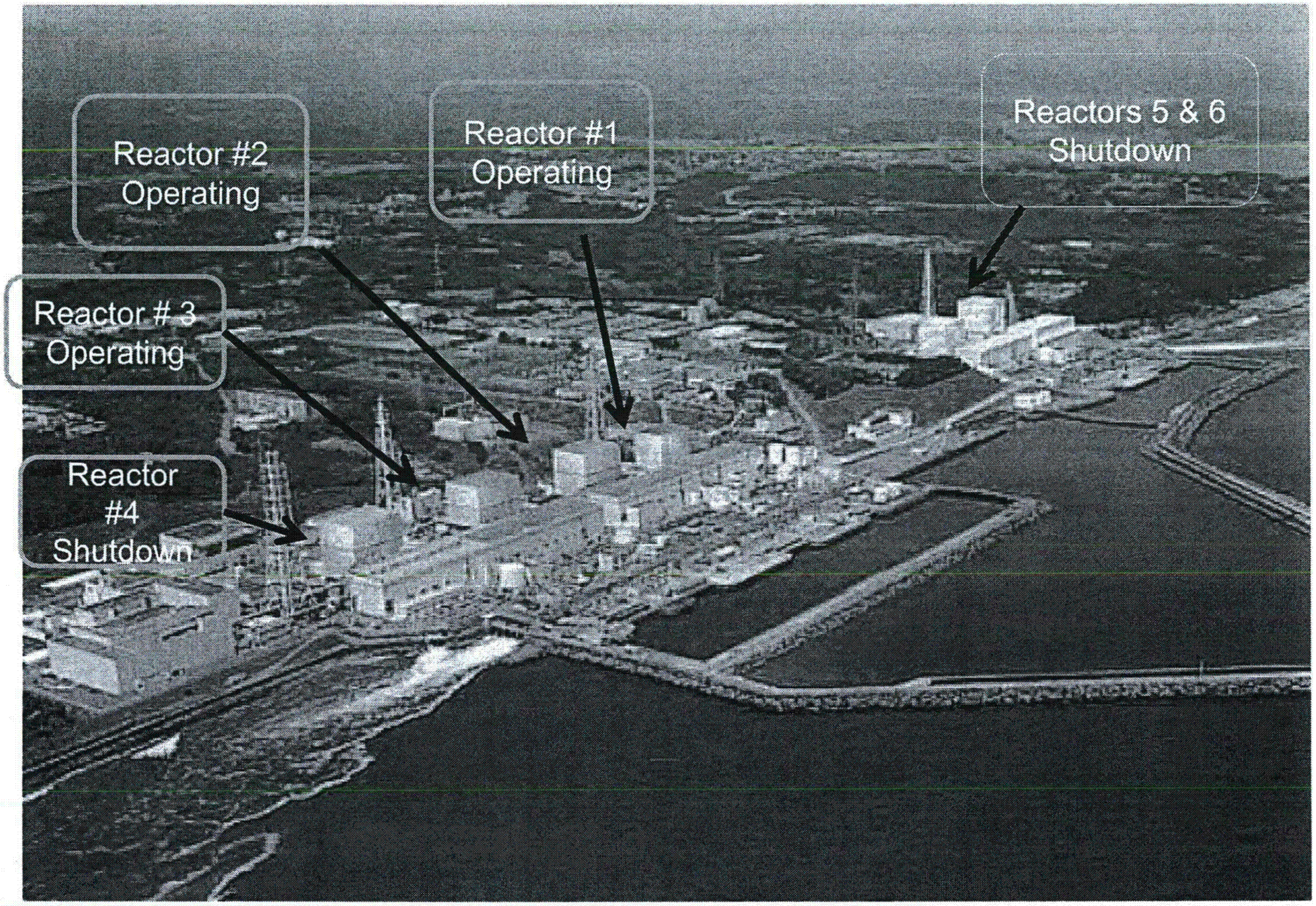
Fukushima Dai-ichi Site Before the Event



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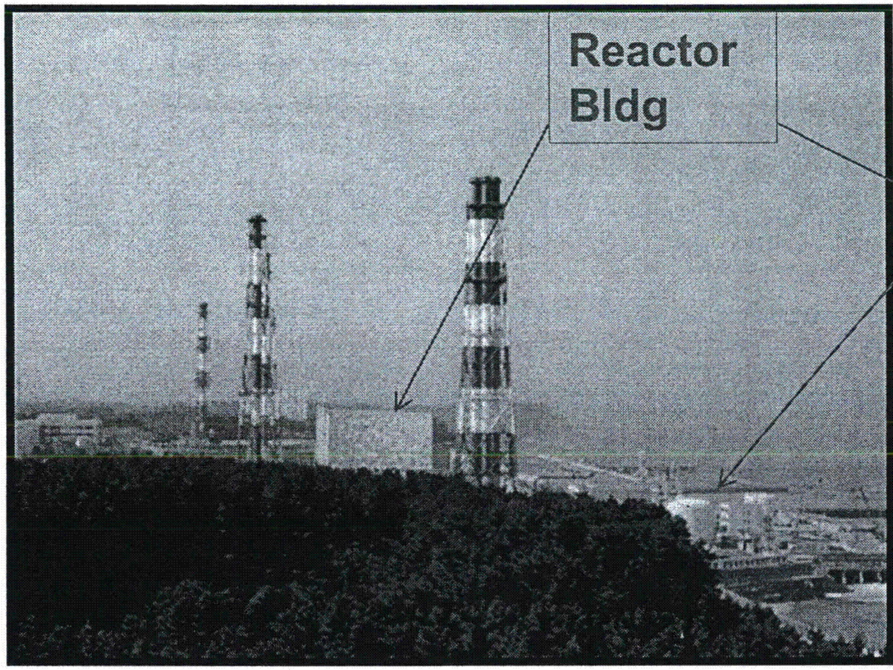
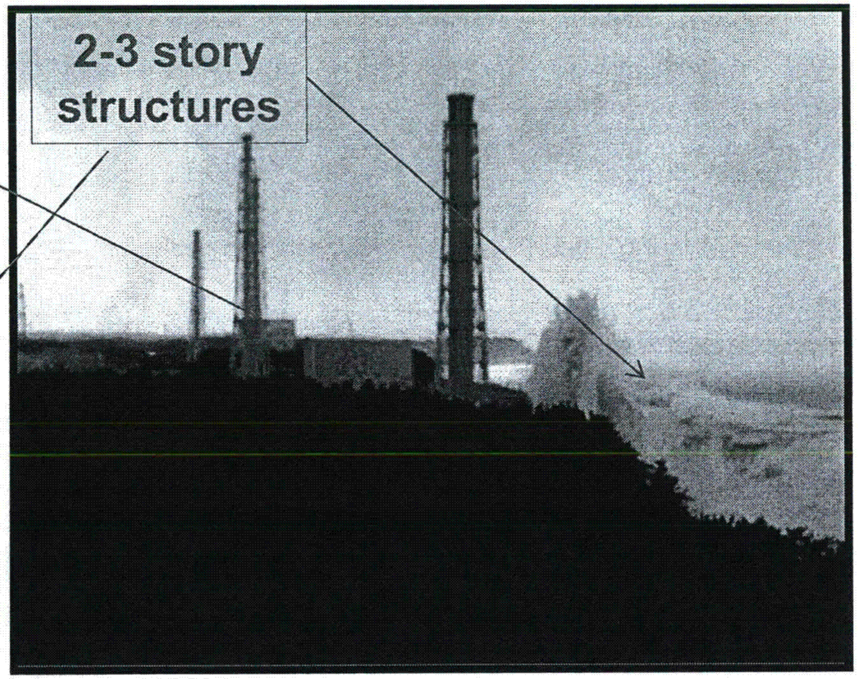
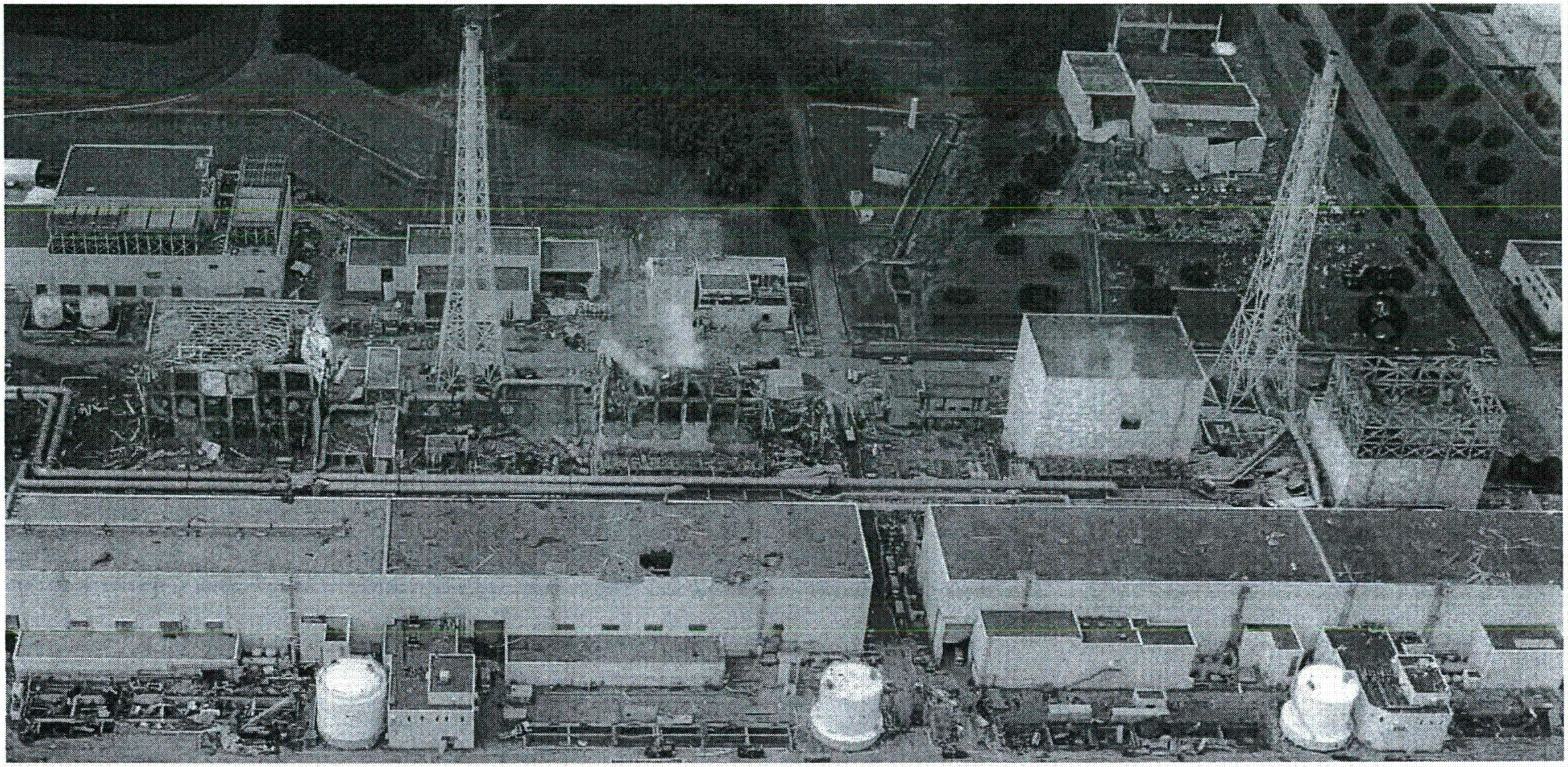
Tsunami

- Site designed to withstand ~6 meters (20 foot) tsunami
- Actual size estimated ~14 meters (46 feet)





After Hydrogen Explosions



UNIT 4 UNIT 3 UNIT 2 UNIT 1

March 2011

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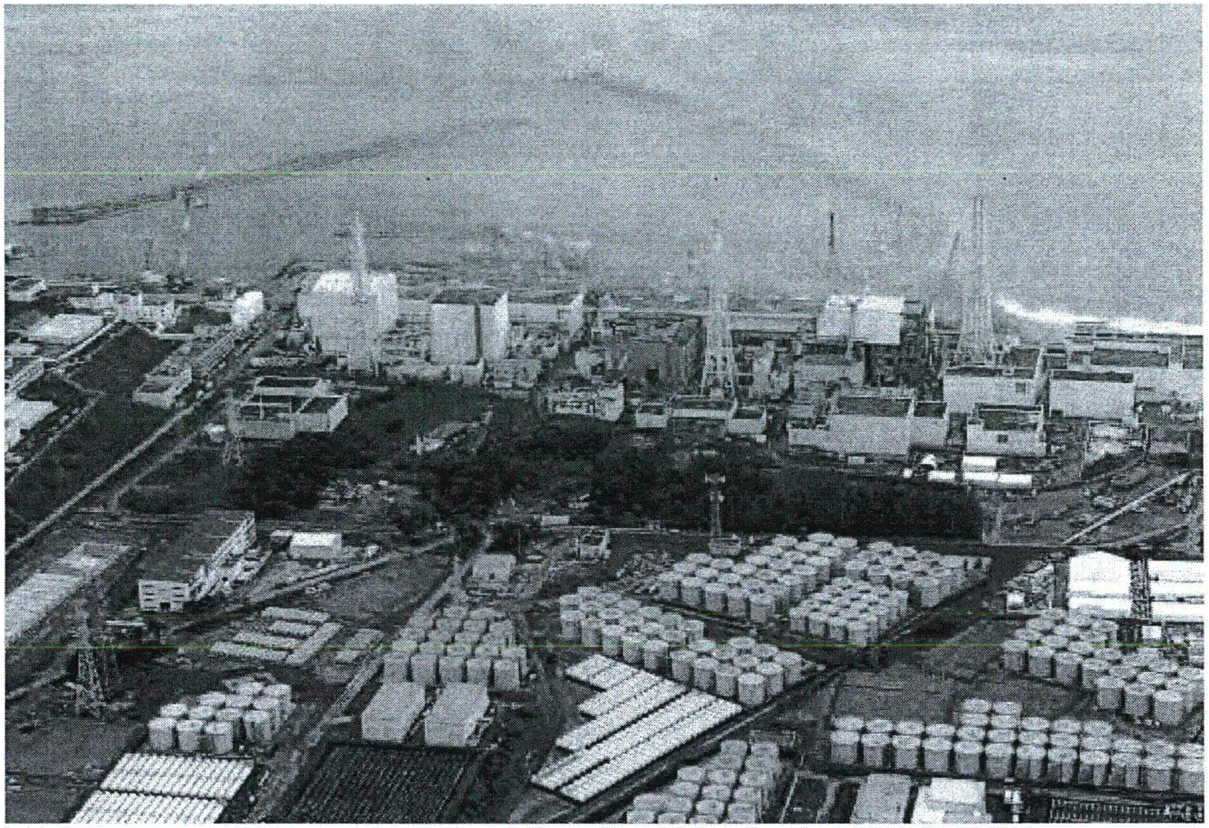
Fukushima Daiichi Today



October 2013

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Contaminated Water Issues

Many Factors Contribute to the Contaminated Water Situation at Fukushima:

- Circulating water to cool the reactor debris
- Accident water left in trenches
- Ground water flow into and through the nuclear power plants
- Leaking Storage Tanks Containing Highly Contaminated Water

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TEPCO's Principles to Cope with Contaminated Water

1. Eliminate contamination source

2. Keep clean water from contamination source

3. Avoid leaking contaminated water

TEPCO's Short Term Countermeasures

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1. Remove highly contaminated water from the trenches [principle 1]

2. Pave land surface, inject sodium silicate, pump underground water [principles 2 and 3]

3. Bypass ground water [principle 2]

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TEPCO's Longer Term Countermeasures

1. Pumping water from sub drains [principle 2]
2. Install seaside impermeable wall [principle 3]
3. Install frozen wall [principles 2 and 3]

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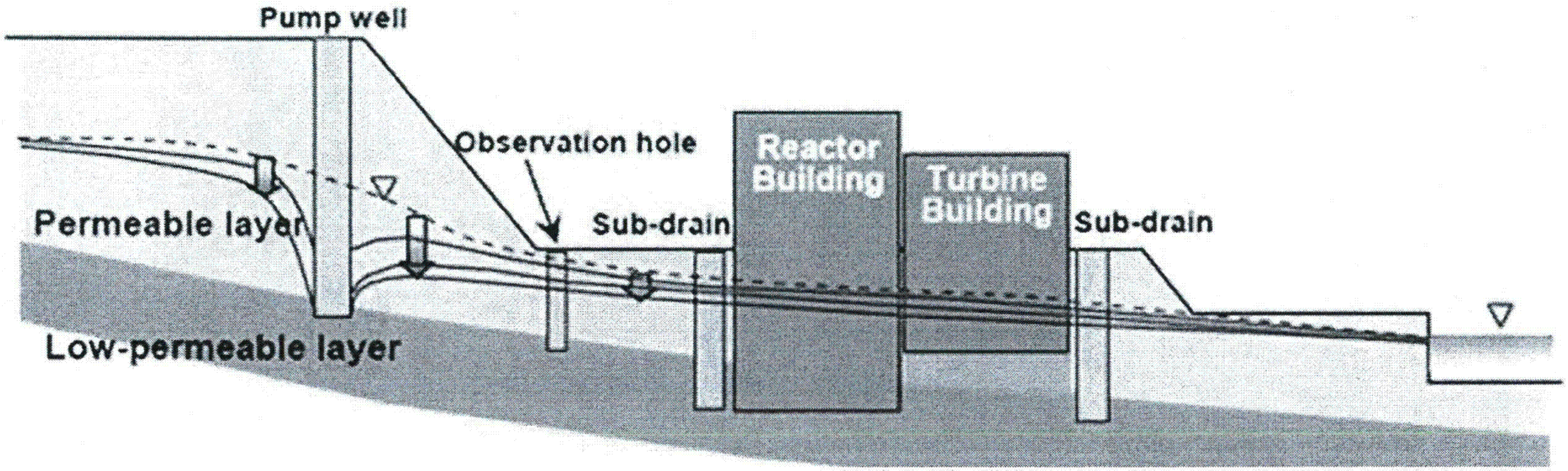
Ground Water Bypass and Sub-Drain Systems



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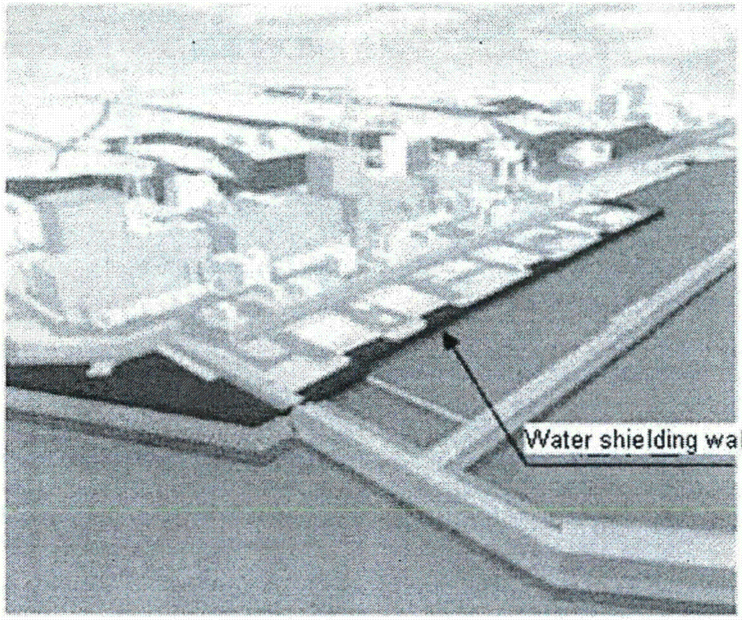
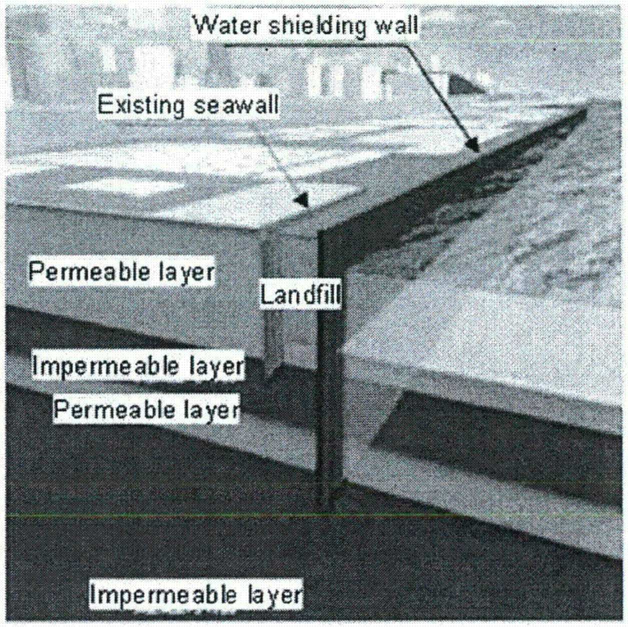
Impermeable Seaside Steel Wall

Overview



Cross-section



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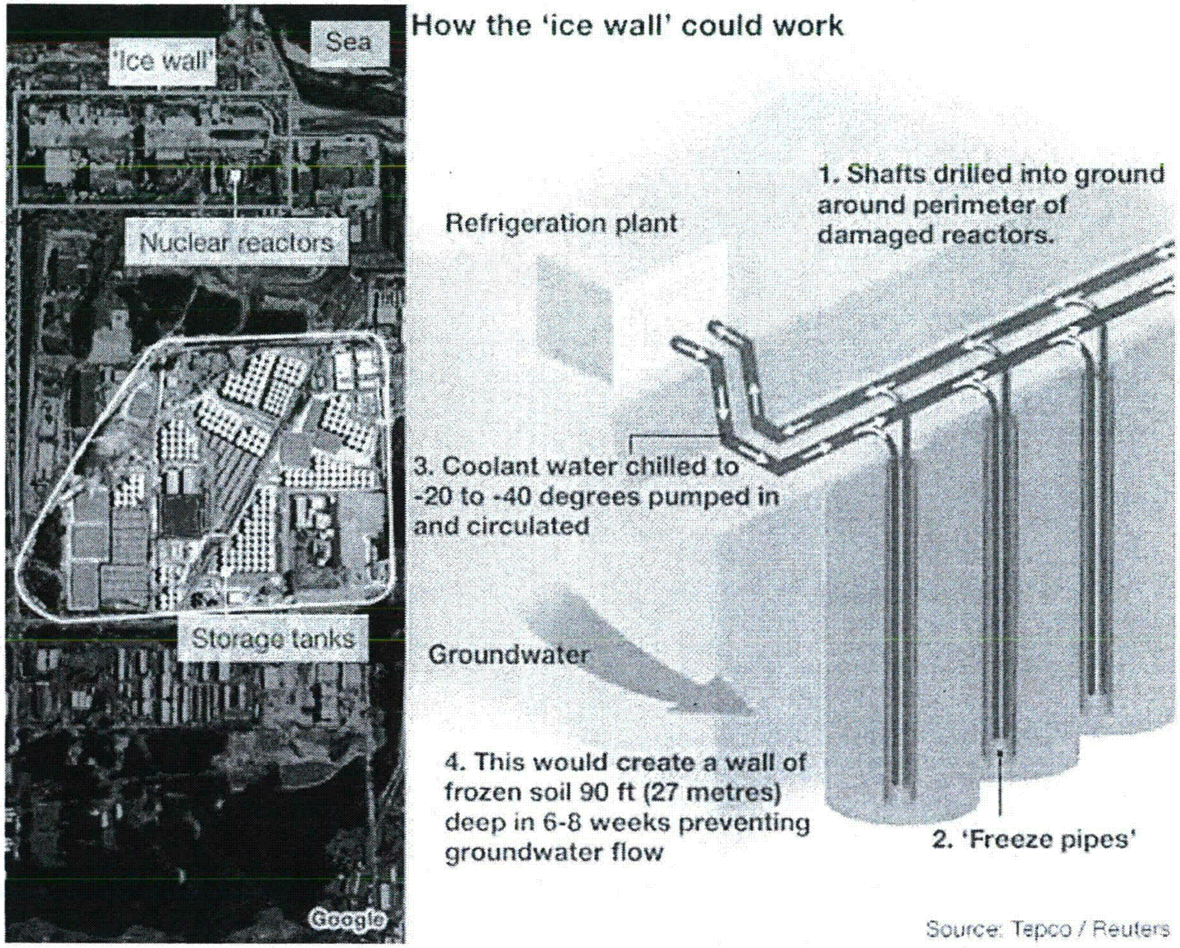
Subterranean Wall



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Leaking Storage Tanks

No. 5 Tank

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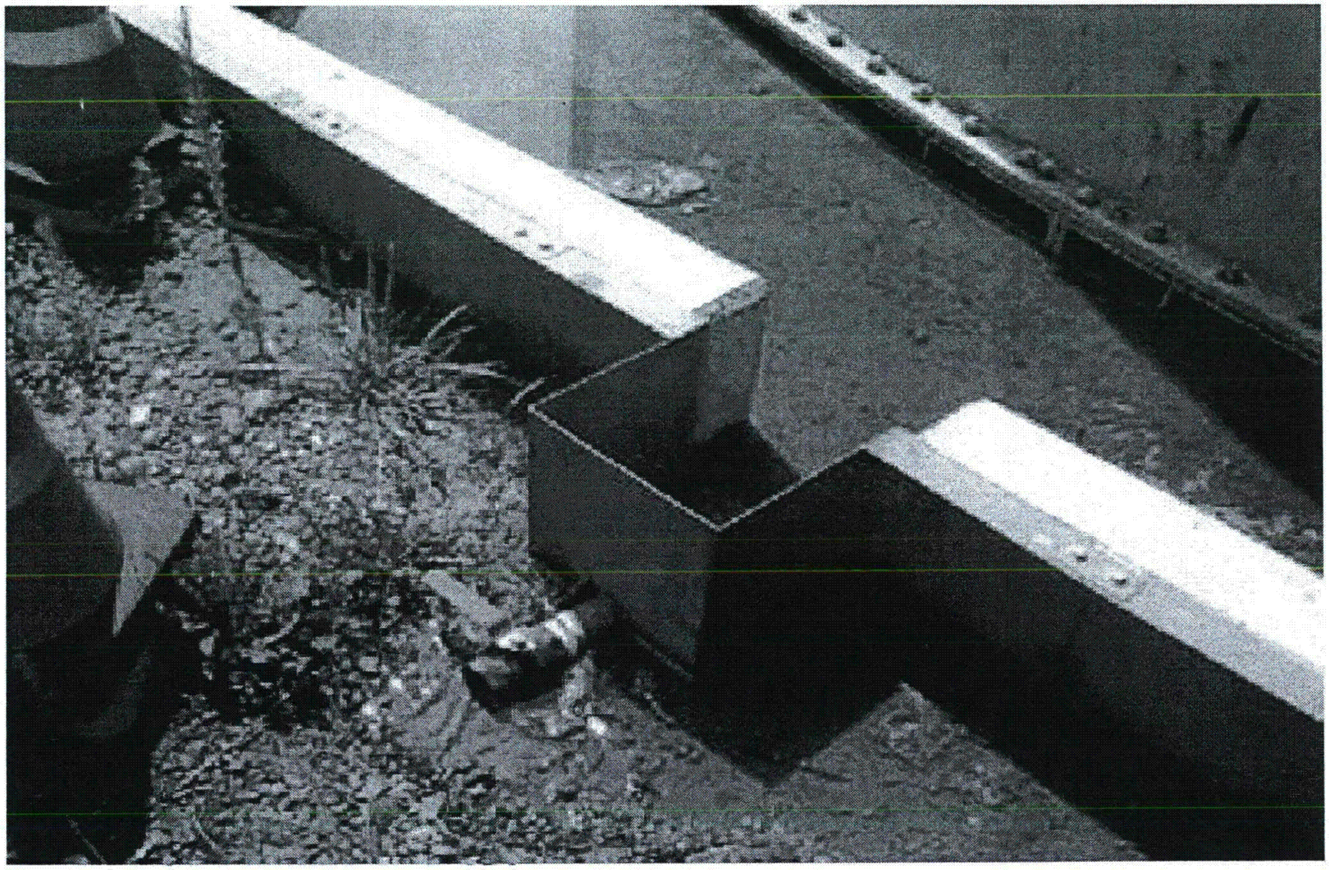
Berm Rainwater Drain



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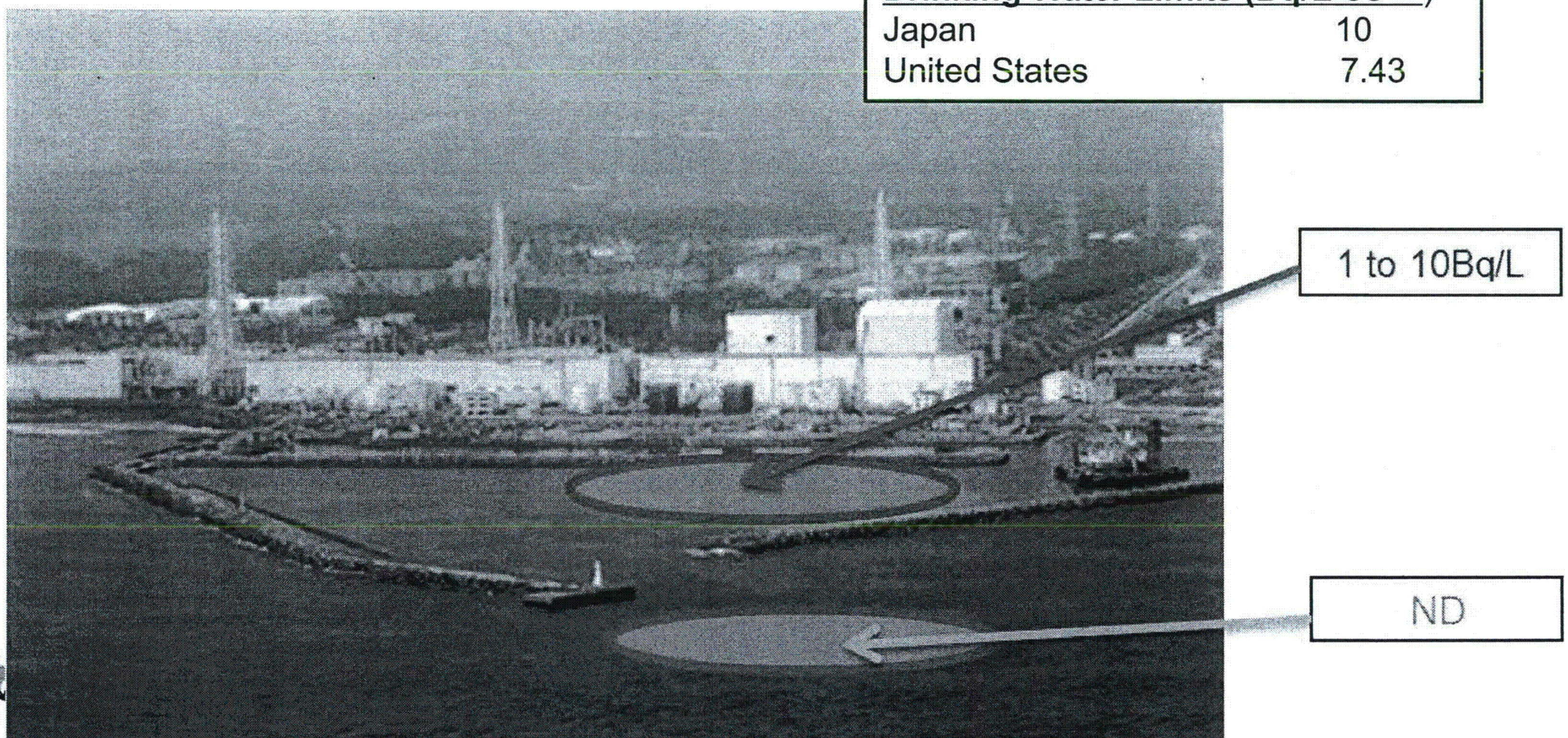
Harbor and Ocean Contamination

Drinking Water Limits (Bq/L Cs^{137})	
Japan	10
United States	7.43



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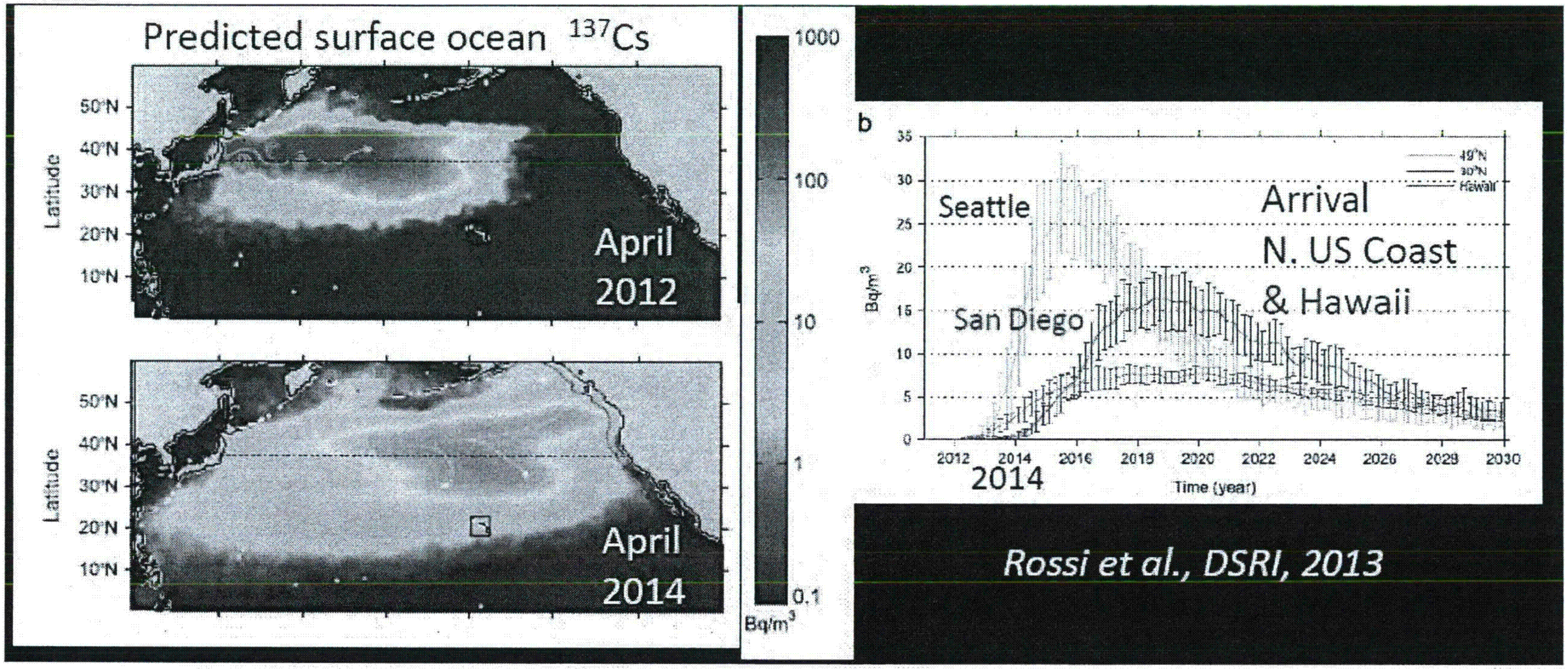
Projected Radioactivity Migration across Ocean



Note: The highest expected peak (~30Bq/m^3) is much lower than the drinking water limit.

Drinking Water Limits (Bq/M^3 Cs^{137})	
Japan	10000
United States	7430

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NRC Involvement

- The NRC continues to regularly discuss the situation with JNRA (Japanese Nuclear Regulatory Authority) and TEPCO, and stands ready to support JNRA if asked. In addition, the NRC is communicating routinely with other federal and state agencies.

- The Department of Energy has been providing assistance to the government of Japan.

- TEPCO has also created an international advisory team with independent members who are former senior regulators from Britain, France, Russia, Ukraine, and the U.S.

Other U.S. Agencies

- FDA is handling questions on the safety of fish consumption. For more information, please see: http://www.fda.gov/newsevents/publichealthfocus/ucm247403.htm..
- NOAA is conducting ocean modeling and handling questions on marine debris. For more information, please visit: http://marinedebris.noaa.gov/tsunamidebris/.
- EPA continues to track the situation. For more information, please see http://www.epa.gov/radnet/.

Impact to the United States

- Any radioactivity from the Fukushima nuclear accident predicted to reach the United States or its territories in the next several years is expected to be well below regulatory limits, and will not impact public health and safety

- FDA has determined that Pacific seafood is currently safe and will continue to monitor the situation

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Path Forward

- NRC will continue to monitor Japanese Nuclear Regulatory Authority (JNRA) and TEPCO efforts, and stands ready to support JNRA if needed.
- NRC will incorporate Japan lessons learned into US regulations
- NRC will coordinate with other Federal agencies (DOE, NOAA, EPA, etc.) as appropriate

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Lessons-Learned from the Fukushima Daiichi Accident

David Skeen

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November 5, 2013

Japan Lessons Learned

Lessons Learned: NRC's Near-Term Task Force

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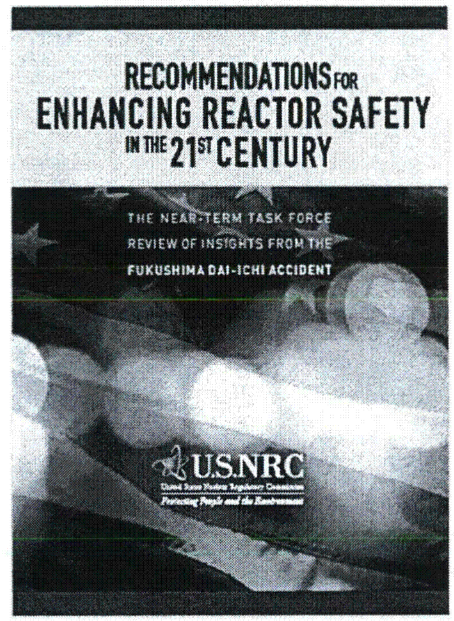
- Within weeks of the accident, NRC created a task force to review the events and provide recommendations to enhance safety at U.S. plants

- Near-Term Task Force report issued July 2011



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Task Force Conclusions

- Similar sequence of events in the U.S. is unlikely
- Existing mitigation measures in US could reduce the likelihood of core damage and radiological releases
- No imminent risk from continued operation and licensing activities
- However, potential safety enhancements were identified (12 overarching recommendations provided)

Prioritization of NTTF Recommendations

- Subsequent to the NTTF Report, NRC staff prioritized the recommendations:
  - Tier 1 - To be implemented without unnecessary delay
  - Tier 2 - Could not be initiated in the near term due to resource or critical skill set limitations
  - Tier 3 - Require further staff study to determine if regulatory action is necessary
- Tools to implement recommendations include Orders, Rulemaking, and Requests for Information

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Order Implementation, Review & Oversight

Orders Issued

- Mitigation strategies for beyond design basis external events
- Containment venting system for BWR Mark I and II containments
- Spent fuel pool water level instrumentation

Next Steps

- ❑ NRC issue Interim Staff Evaluations of licensee plans, *December 2013 for SFP and February 2014 for Mitigation Strategies*
- ❑ NRC inspection to verify implementation be each reactor licensee - *after 2nd outage*

Full licensee implementation is required within 2 refueling cycles or December 2016, whichever comes first

Note: Because the Commission revised the order for containment vents in June 2013 to ensure operability under severe accident conditions, reactor licensees will have additional time to implement this order.

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Rulemaking Activities

- Station Blackout Mitigation Strategies (SBOMS)
  - Will make Mitigation Strategies Order a regulation
- Onsite Emergency Response Capabilities
  - Will integrate plant emergency procedures
- Filtering and Confinement Strategies
  - Will consider additional protections to limit potential release of radioactive material

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Requests for Information

- Seismic and Flooding Walkdowns
  - Licensees performed walkdowns at all nuclear power plants
  - The NRC has conducted audits at selected sites
  - Initial insights indicate licensees can protect against current design basis seismic and flood hazards
- Flooding Reevaluation
  - First group of plants submitted their reevaluation in March 2013
  - We expect to complete our review by Spring 2014
  - The remaining two groups are expected to submit in 2014 and 2015
  - Many plants have identified interim actions to enhance their ability to cope with floods that may be beyond their current design basis

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Requests for Information

- Seismic Reevaluation
  - NRC endorsed use of an updated ground motion model for Central and Eastern United States plants
  - Central & Eastern U.S. Plants
    - Partial hazard reevaluations received September 2013
    - Complete hazard reevaluations due March 2014
    - Includes 6-month extension to update the ground motion model
  - Western U.S. Plants (Columbia, Palo Verde, Diablo Canyon)
    - Complete hazard reevaluation due March 2015
- Emergency Preparedness staffing and communications
  - NRC staff is currently reviewing staffing submittals
  - Safety Assessments for the communications portion are have been issued

Tier 2 Recommendations

- Spent Fuel Pool Makeup Capability
  - Addressed under mitigation strategies*
- Emergency Preparedness
  - Addressed under mitigation strategies*
  - Multiunit dose assessment capability will be in place by end of 2014
- Reevaluation of "Other" External Hazards
  - Dependent on insights from seismic/flooding reevaluations and staff resources
  - Request for Information planned after the seismic and flooding hazards are resolved

***Items addressed under mitigation strategies are therefore being treated with Tier 1 priority**

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Tier 3 Recommendations

2.2	Periodic confirmation of seismic and flooding hazards
3	Enhanced capability to prevent /mitigate seismically induced fires and floods
5.2	Reliable hardened vents for other containment designs
6	Hydrogen control and mitigation inside containment or in other buildings
9.1/9.2	Emergency preparedness (EP) enhancements for prolonged SBO and multiunit events
9.4	Improve ERDS capability
10	Additional EP topics for prolonged SBO and multiunit events
11	EP topics for decision-making, radiation monitoring, and public education
12.1	Reactor Oversight Process modifications to reflect the recommended defense-in-depth framework
12.2	Staff training on severe accidents and resident inspector training on SAMGs
-	Revisit Emergency Planning Zone Size
-	Prestage potassium iodide beyond 10 miles
-	Expedited transfer of spent fuel to dry cask storage
-	Reactor and Containment Instrumentation

Conclusion

- Considerable progress has been made
  - Seismic and flooding walkdowns complete
  - FLEX equipment arriving at sites and licensees are implementing mods to protect against loss of power and loss of heat sink events
- Substantial safety enhancements by 2016
  - Mitigation strategies fully in place
  - SFP level instrumentation installed
  - Flooding and seismic interim actions
  - Enhanced EP communications and staffing in place
- Some enhancements will extend beyond 2016
  - Final flooding and seismic safety enhancements
  - Severe accident capable containment vent systems for BWR MK-I and MK-II
  - Implementation of rules

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More Information

- Public website

  From www.nrc.gov, find link under "Spotlight" section called "Japan Lessons Learned"

THANK YOU

福島第1原子力発電所を対象とした地下水流動解析

平成25年12月10日

日本原子力研究開発機構

EA/5

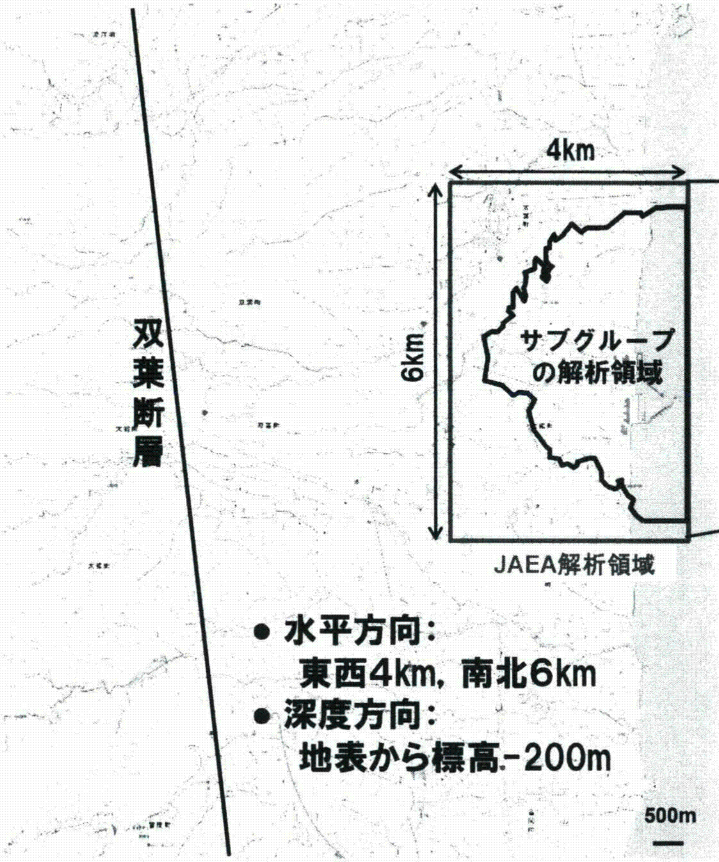
目的

- 汚染水処理対策委員会のサブグループ①「地下水・雨水等の挙動等の把握・可視化」が実施している地下水流動解析モデルの妥当性を確認すること
（汚染水処理対策委員会事務局からの依頼事項）

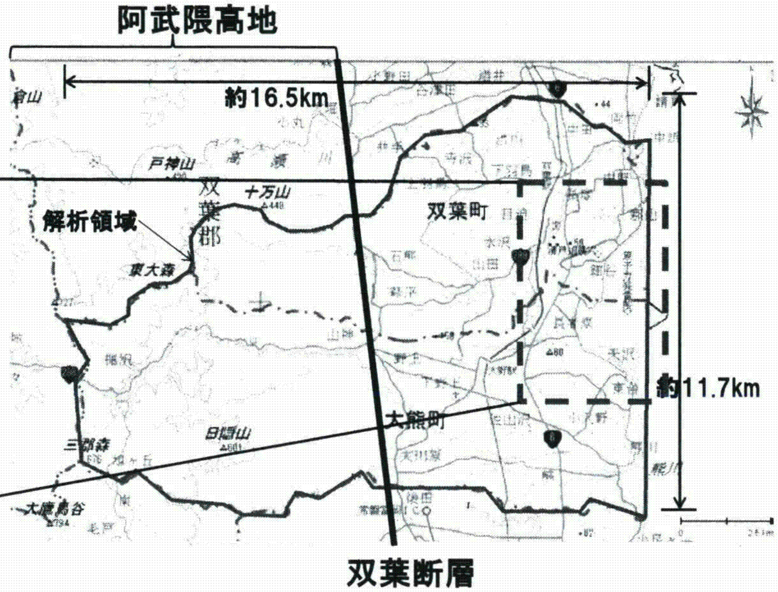
実施内容

- 解析領域設定
- 地質構造モデルの構築
- 水理地質構造モデル（解析メッシュに水理特性を設定したモデル）の構築
- 地下水流動解析
  - ✓ 対策工実施前の飽和不飽和定常解析
  - ✓ 対策工を考慮した飽和不飽和定常解析
- JAEA解析結果とサブグループ解析結果の比較

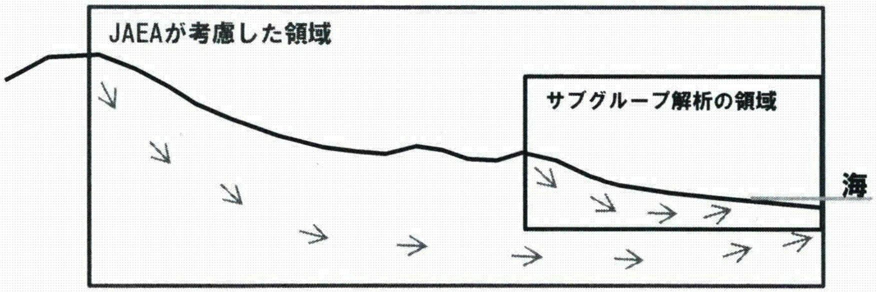
解析領域



- 水平方向：
  東西4km，南北6km
- 深度方向：
  地表から標高-200m



2011年に実施した広域地下水流動解析領域



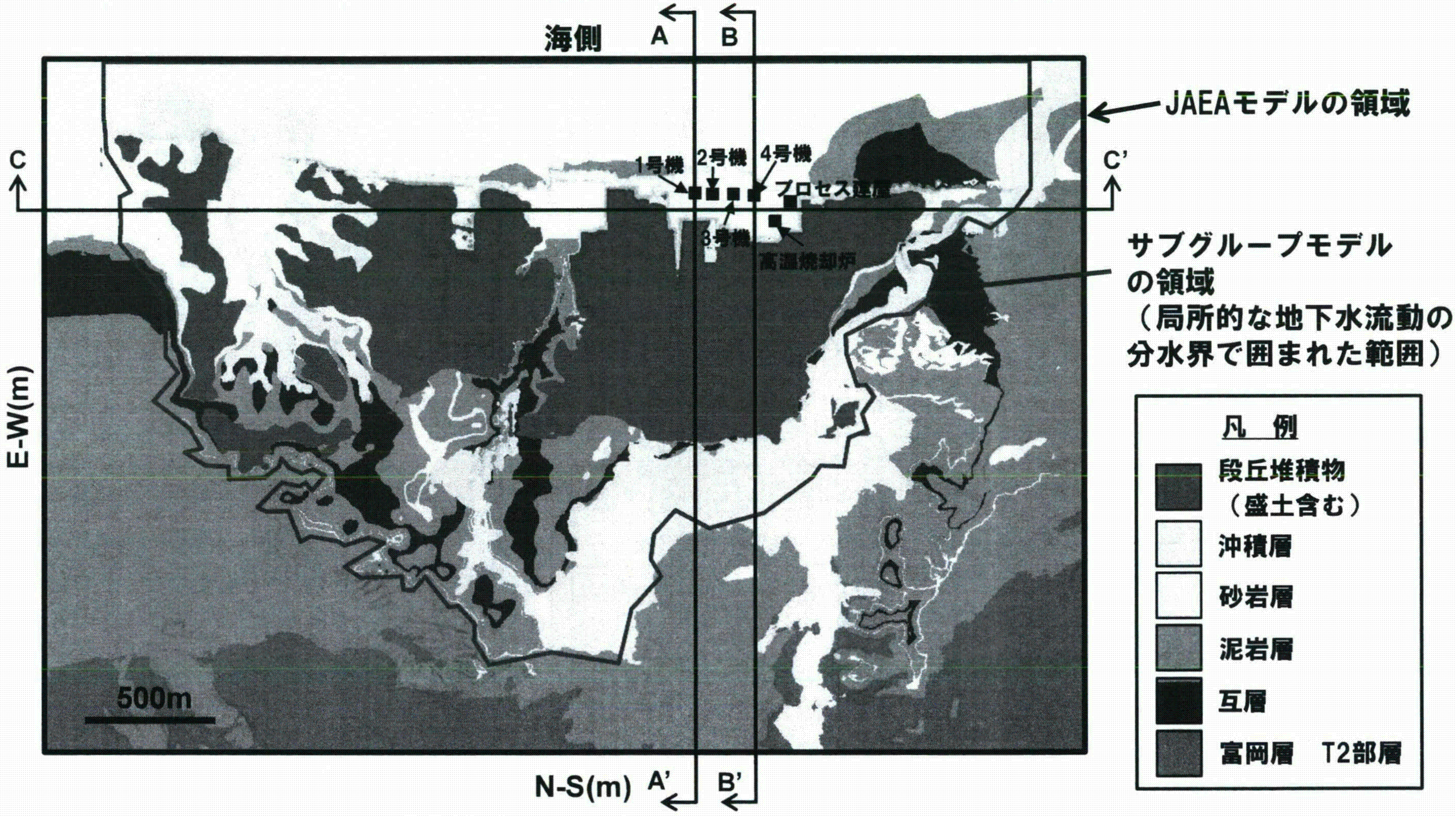
広域的な地下水流動と局所的な地下水流動のイメージ

サブグループ解析の領域（局所的な地下水流動の分水界で囲まれた範囲）よりも広域的な地下水流動が敷地内の地下水流動に与える影響の有無を確認することを目的

- ✓ 平面方向および深度方向を拡張した範囲を領域として設定
- ✓ 側方境界条件には広域地下水流動解析結果の水頭分布を設定

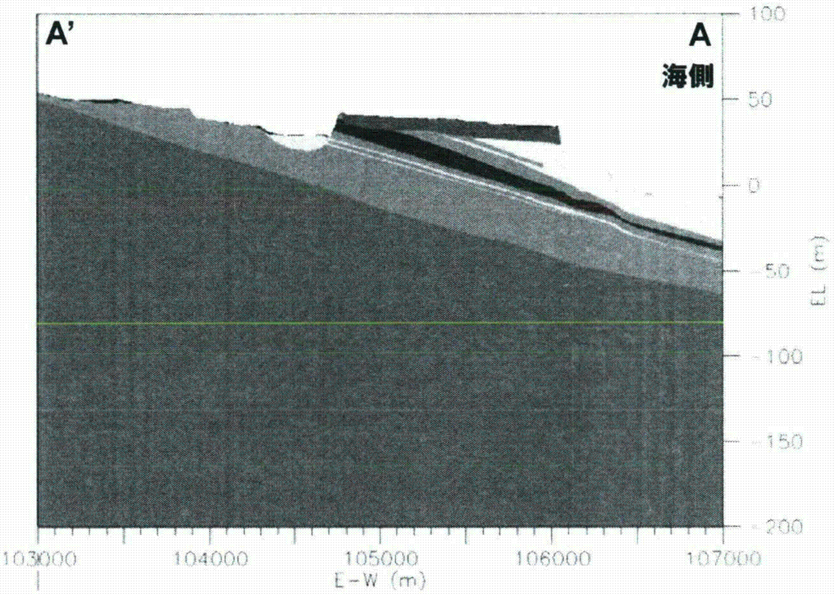
地質構造モデルの構築

- 東電提供データに基づいて，地質構造モデル作成ツール(Earth Vision)を用いて，三次元地質構造モデルを構築
- モデル化領域：平面方向に4km×6km四方，深度方向に地表から標高-200m

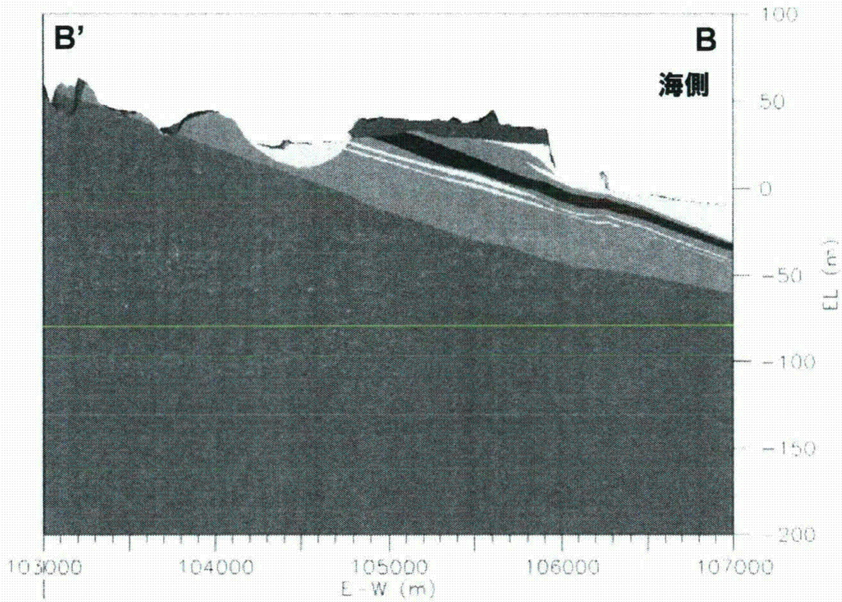


地質構造モデル（平面図）

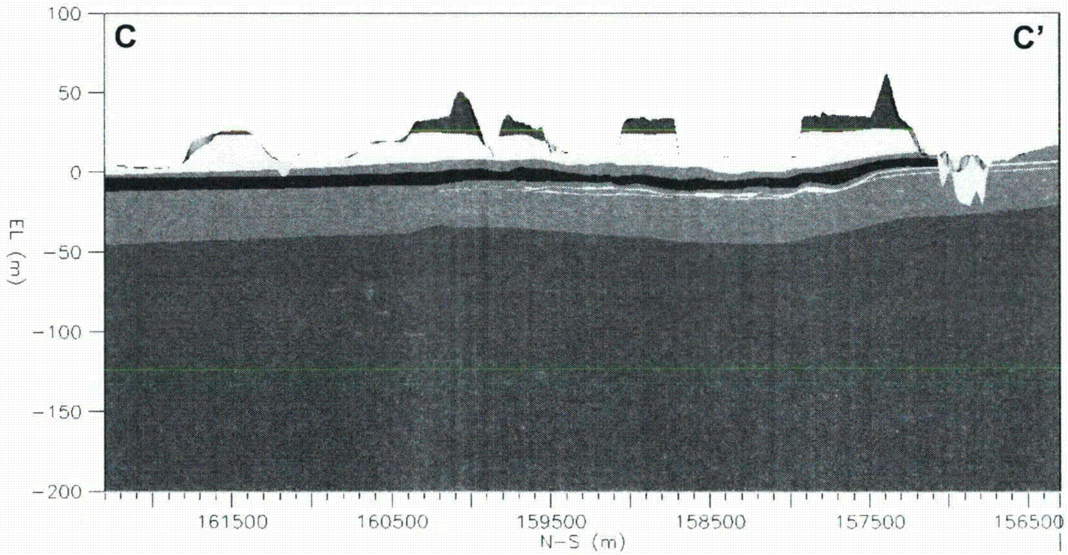
地質構造モデルの構築



地質構造モデル（1号機(A-A')断面図）

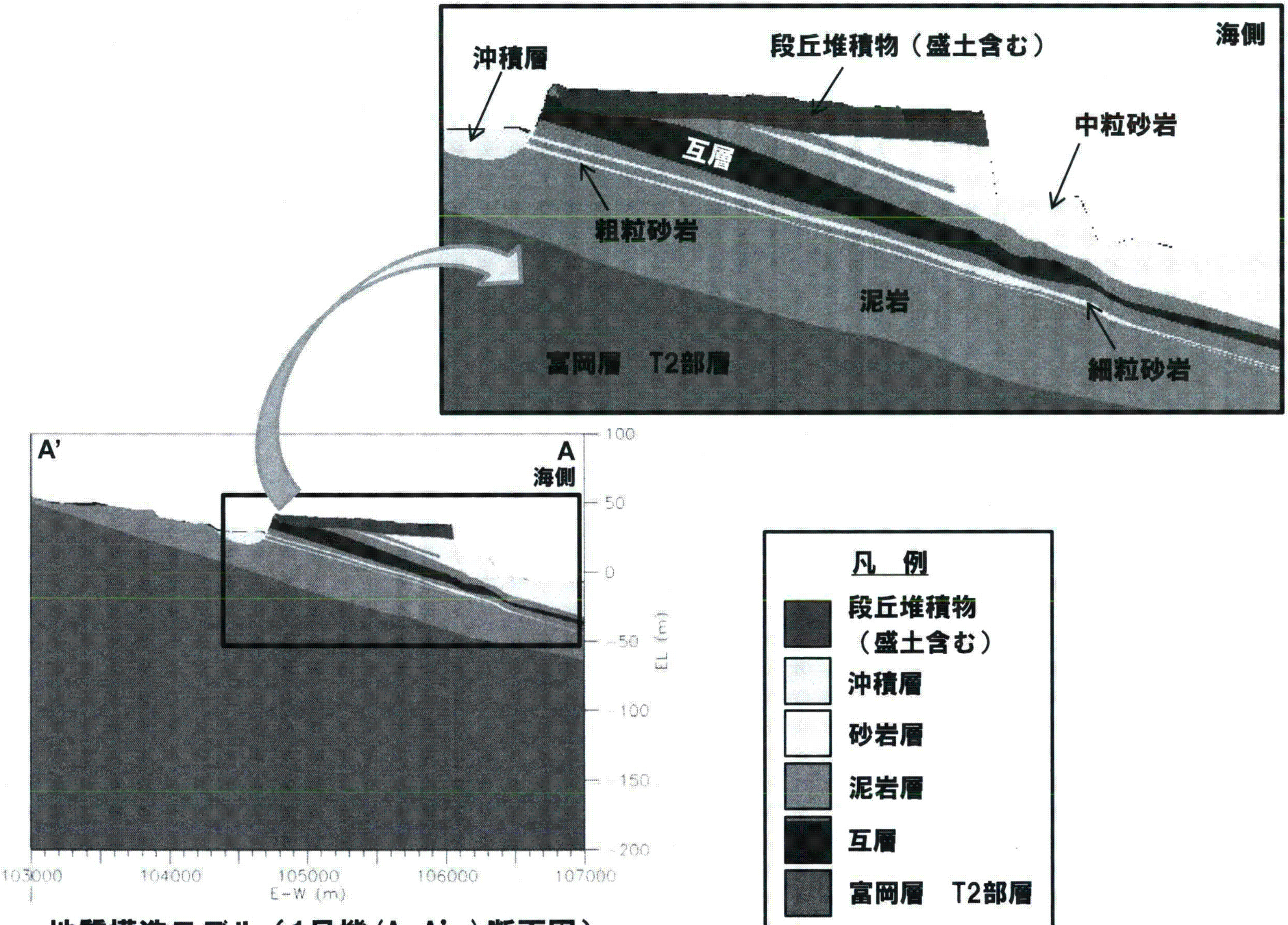


地質構造モデル（4号機(B-B')断面図）



地質構造モデル（C-C' 断面図）

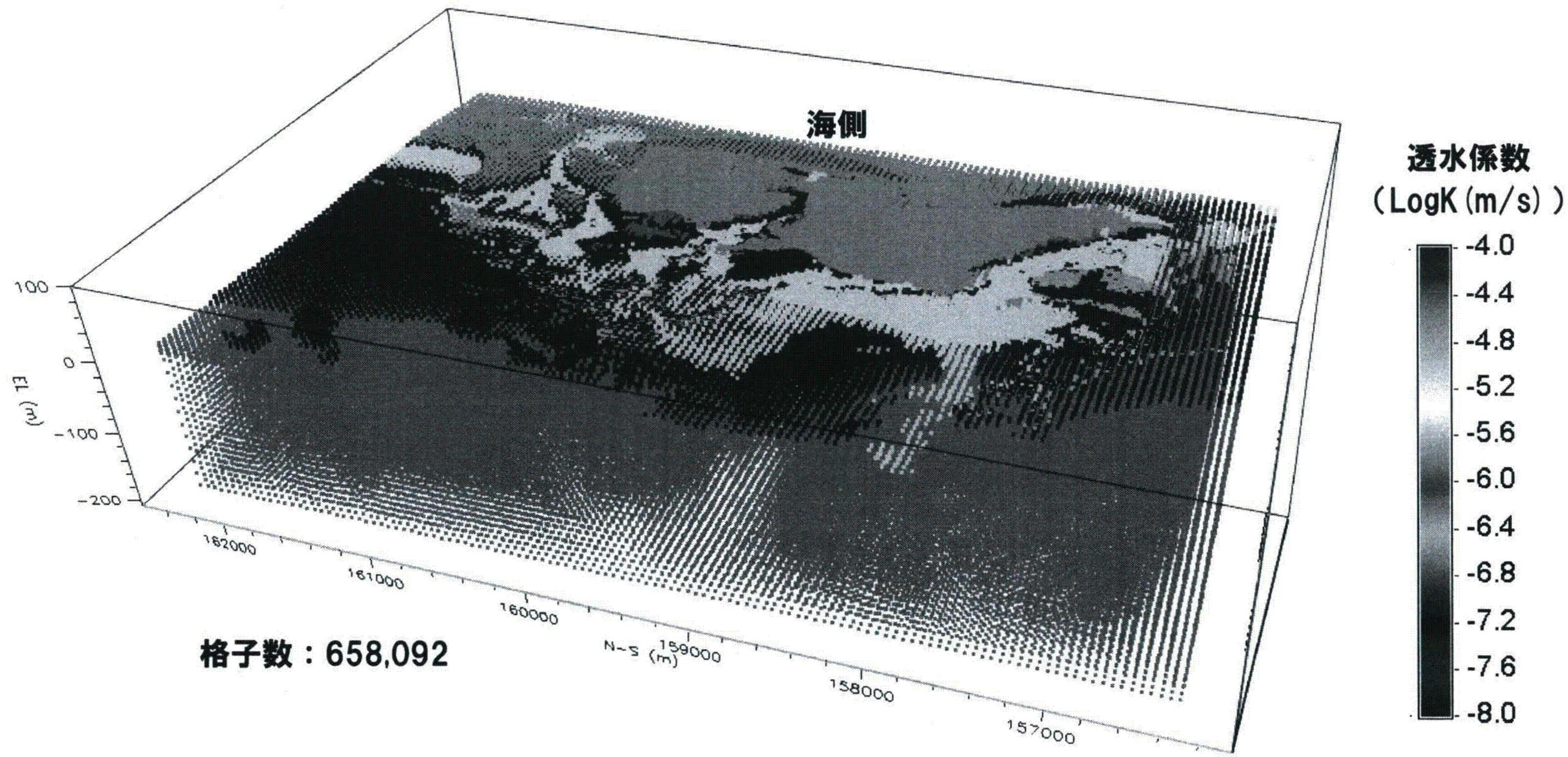
地質構造モデルの構築



地質構造モデル（1号機(A-A’　)断面図）

水理地質構造モデルの構築

- 地質構造モデルに基づいて，地下水流動解析コード(FracAffinity: Ohyama and Saegusa, 2008)を用いて，三次元水理地質構造モデルを構築
- 格子分割としては，
  - ✓ モデル全体：50m×50m×20mに分割
  - ✓ 建屋を含む2km×3.5km領域：25m×25m×20mに分割
  - ✓ 地表から標高−30mの範囲：砂岩層及び互層などの連続性を表現するため，深度方向に1mで分割



水理地質構造モデル

水理地質構造モデルの構築　－水理特性－

- 水理地質構造の水理特性は，サブグループ解析と同一に設定（下表）
- 富岡層（T2部層）については，文献資料（梅田ほか，1995）に基づき設定

水理地質構造に設定した水理特性

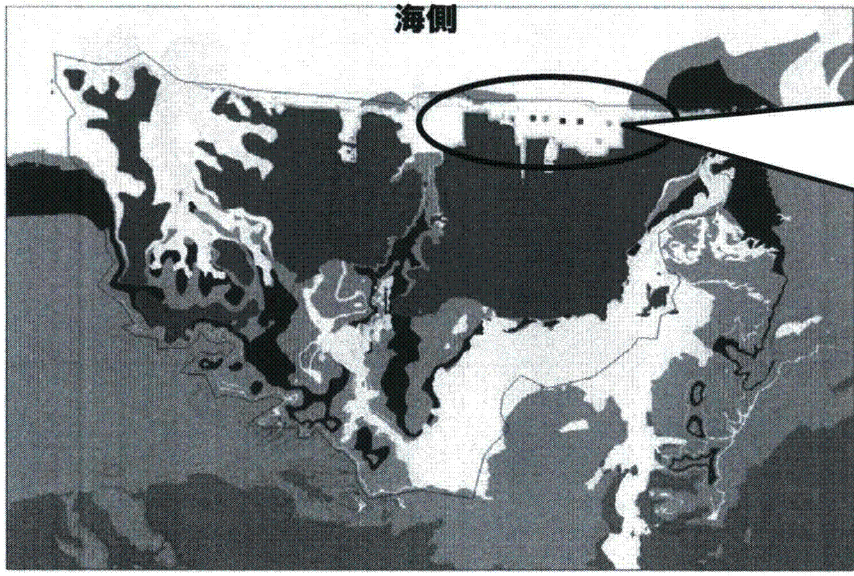
地層区分		透水係数（log（m/s））		
地層名	記号	水平	鉛直	
段丘堆積物	tm	-4.52	-4.52	サブグループ解析と同一
沖積層	al	-5.00	-5.00	
中粒砂岩	ss1	-4.52	-4.52	
中粒砂岩（南側、上部）	ss3	-6.00	-6.00	
泥岩	m0	-7.96	-7.96	
中粒砂岩（南側、下部）	ss2	-6.00	-6.00	
泥岩	m1	-7.96	-7.96	
互層	alt	-5.00	-7.96	
泥岩	m2	-7.96	-7.96	
細粒砂岩	fs	-4.64	-4.64	
泥岩	m3	-7.96	-7.96	
粗粒砂岩	cs	-4.70	-4.70	
泥岩	m4	-7.96	-7.96	
富岡層（T2部層）	T2	-6.10	-6.10	

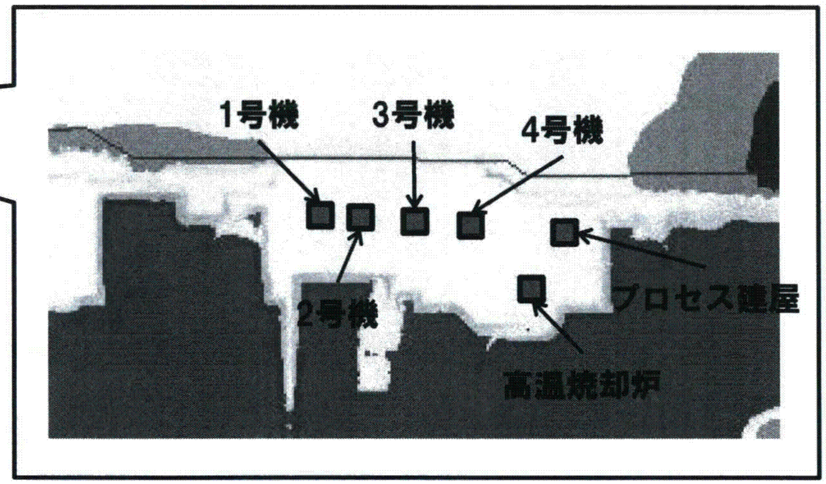
水理地質構造モデルの構築　－建屋のモデル化方法－

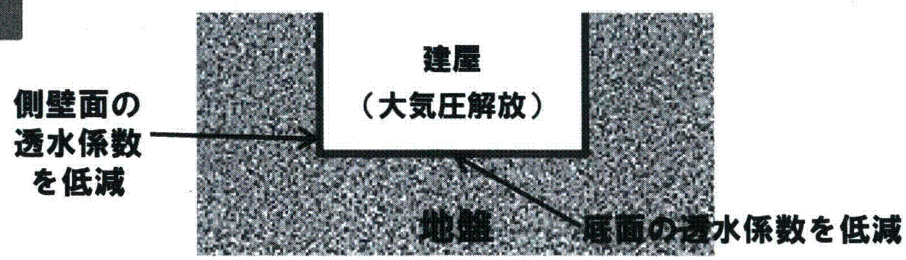
- 水理地質構造モデルに，建屋への地下水の流入量が確認されている1～4号機建屋，プロセス建屋，高温焼却炉を考慮
- 各建屋の概略面積と等価な面積となるように，四角柱でモデル化
- 建屋壁面・底面の境界条件；自由浸出境界

<u>※建屋側面のコンクリート壁や底面のコンクリート台座の影響を考慮するため，壁面の透水係数を低減させる係数αを適用</u>

<u>・建屋壁面・底面の透水係数(K_{wall})＝建屋近傍の地盤の透水係数(K_{rock})×α</u>



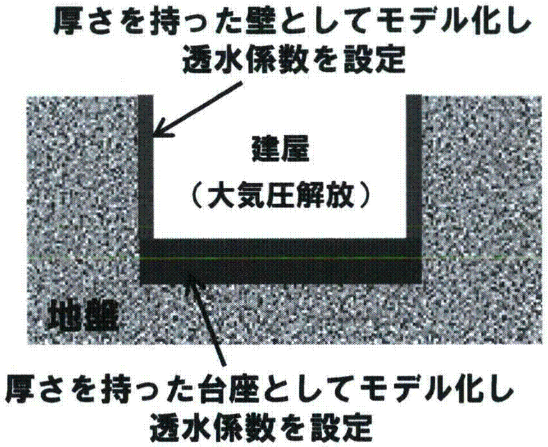


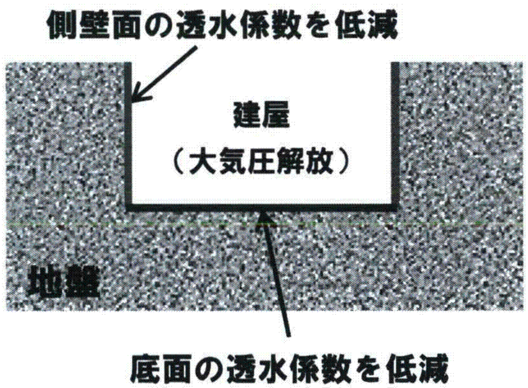


JAEAモデルとサブグループモデルとの相違点

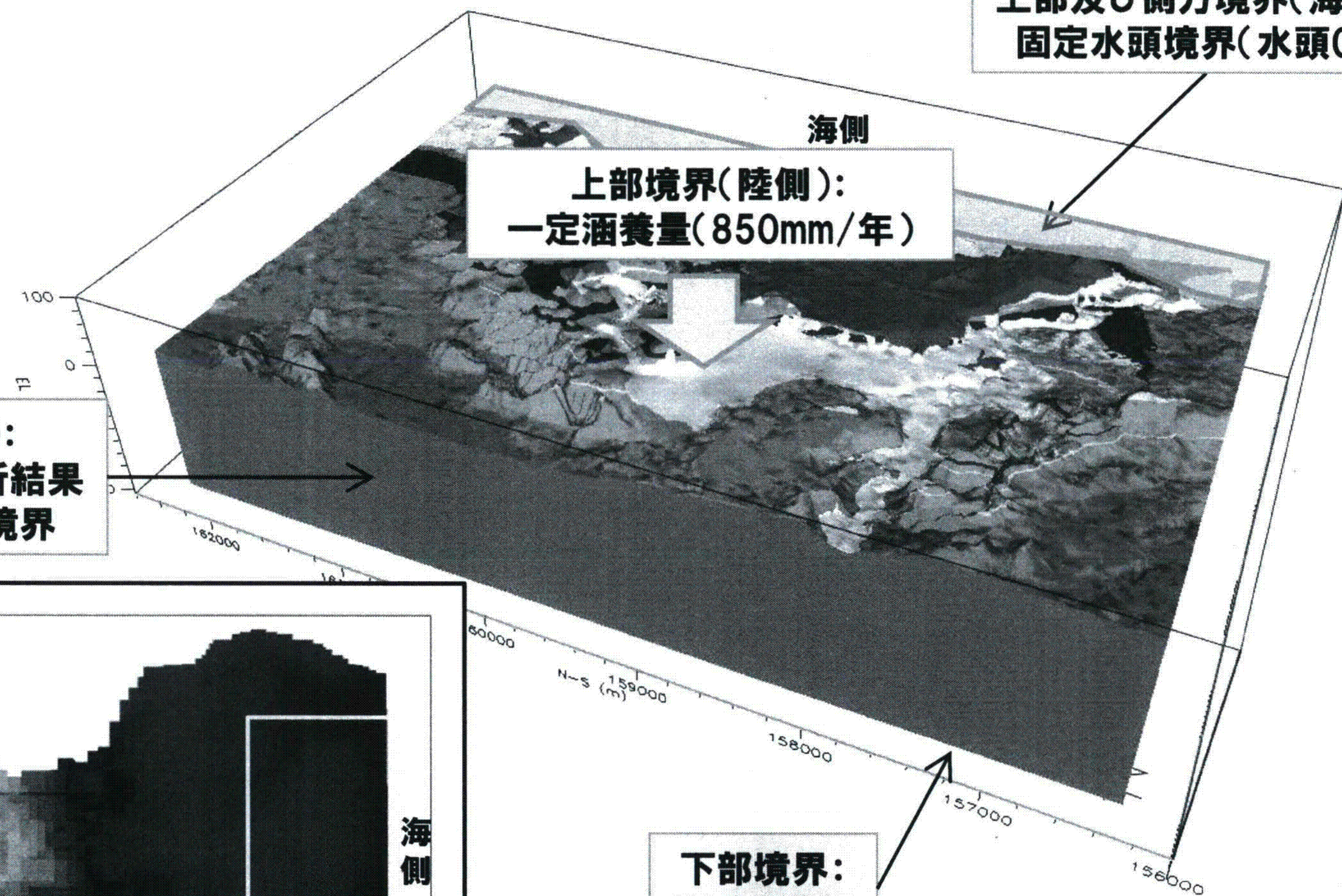
	サブグループモデル	JAEAモデル
建屋の形状	• 現実に即した形状を解析メッシュに再現	• 四角柱として解析メッシュに表現
建屋側面のコンクリート壁	• 厚さを持った壁としてモデル化	• 低透水性の面としてモデル化
建屋底面のコンクリート台座の厚さ	• 厚さを持った台座としてモデル化	• 低透水性の面としてモデル化

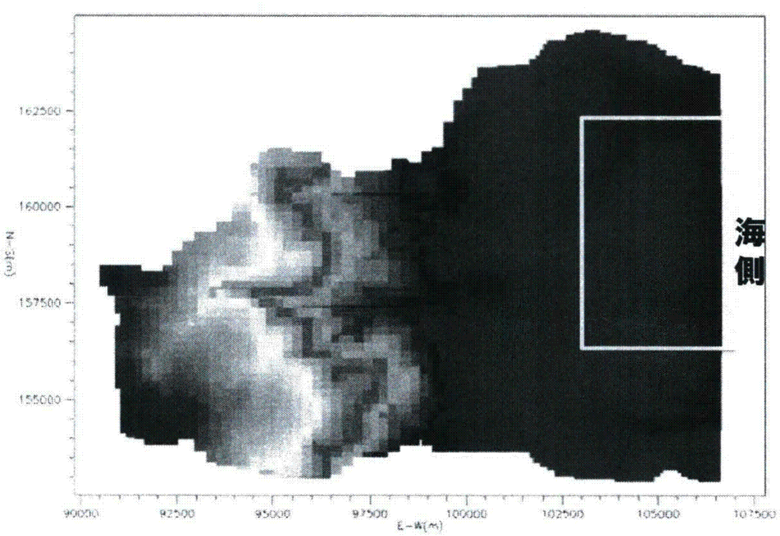
モデル化のイメージ





境界条件の設定





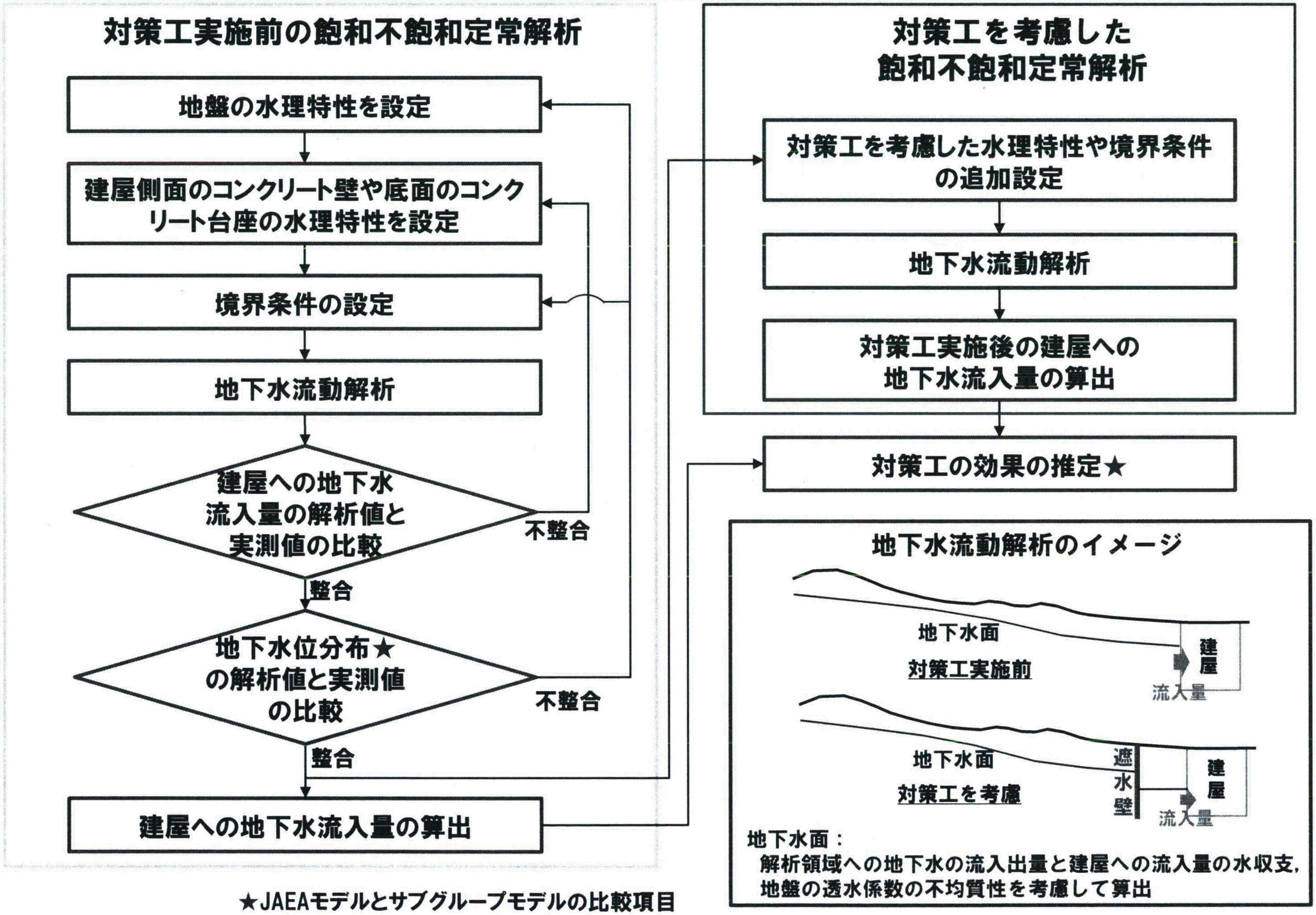
広域地下水流動解析結果(水頭分布;地表面)

✓ **涵養量:年間降水量(1,545mm/年)の55%(東電提供資料参照)**

サブグループモデルと同一条件

サブグループモデルと異なる条件

解析の進め方(JAEA/サブグループ共通)

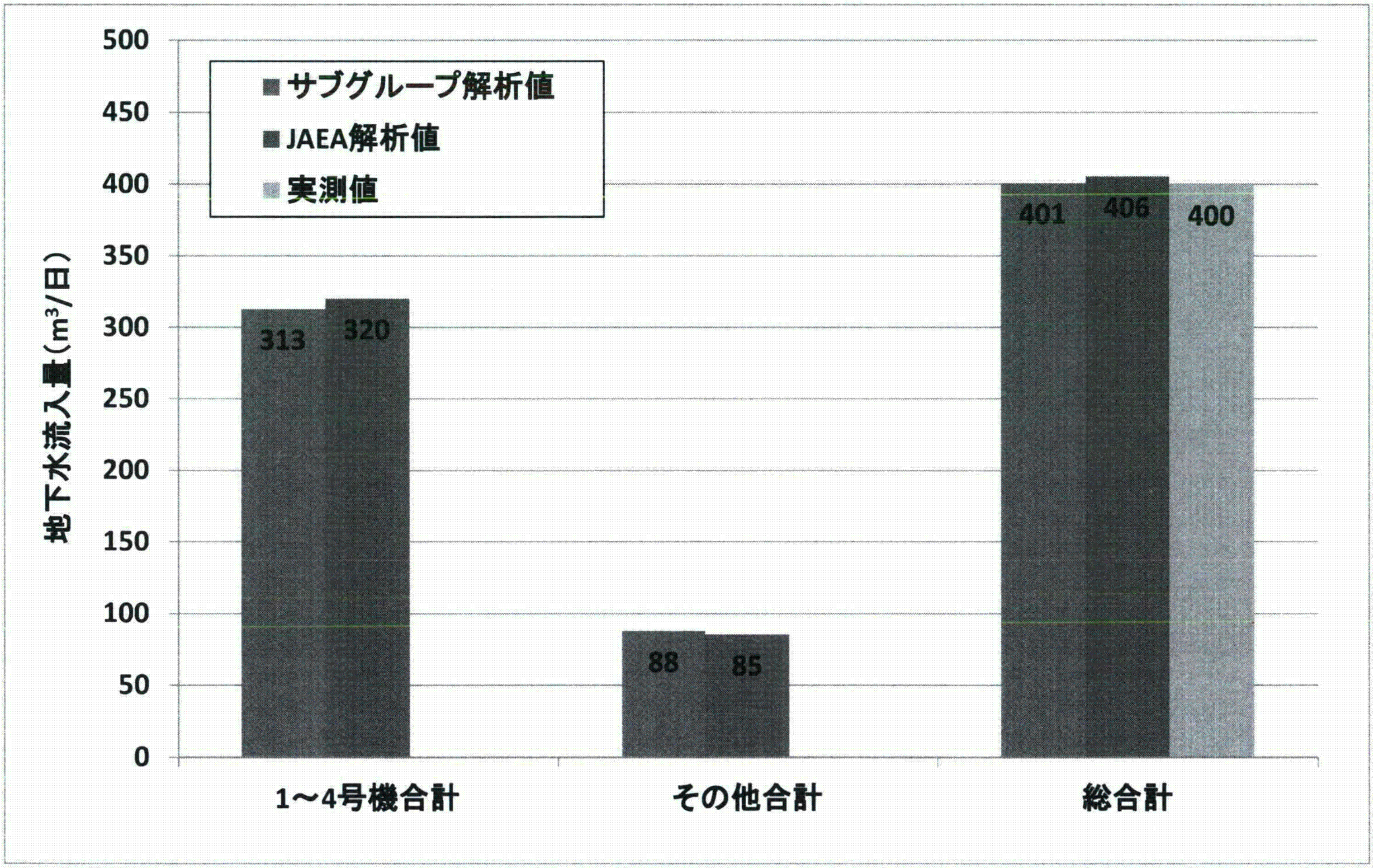


★JAEAモデルとサブグループモデルの比較項目

JAEAモデルとサブグループモデルとの比較項目

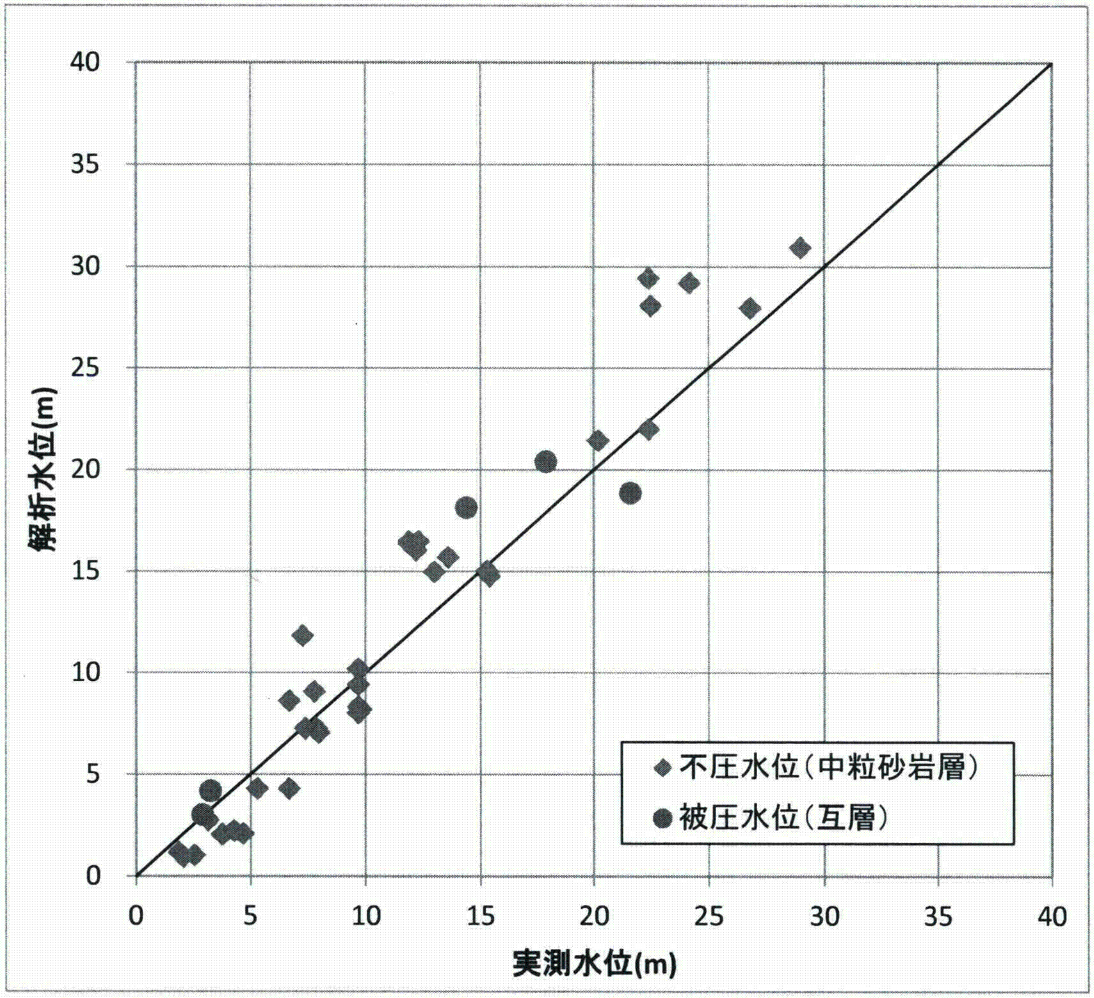
- 対策工実施前の解析結果
  - ✓ 地下水位分布：水理地質構造モデル（水理特性の設定値）や境界条件の妥当性を確認
- 対策工を考慮した解析結果
  - ✓ 建屋への地下水流入量の低減率：対策工の効果の推定結果の妥当性を確認

対策工実施前の解析結果（建屋への地下水流入量）



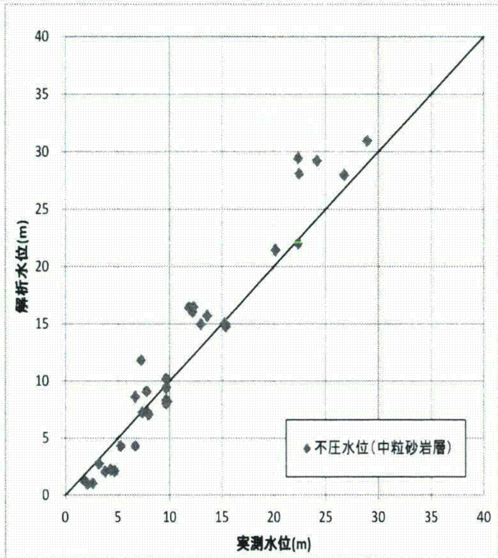
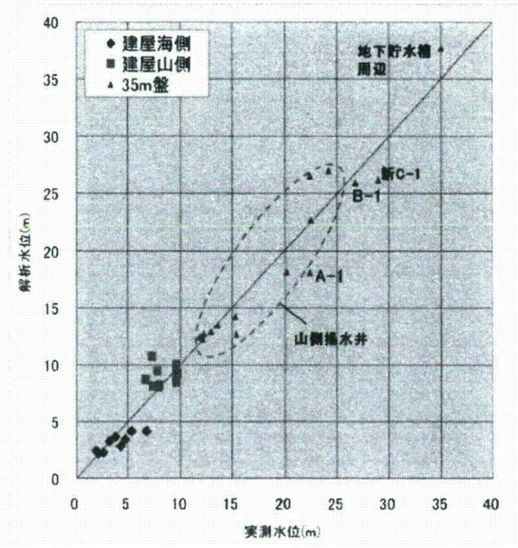
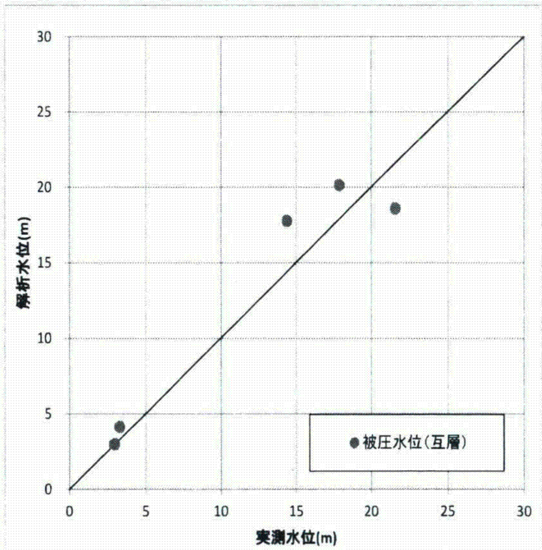
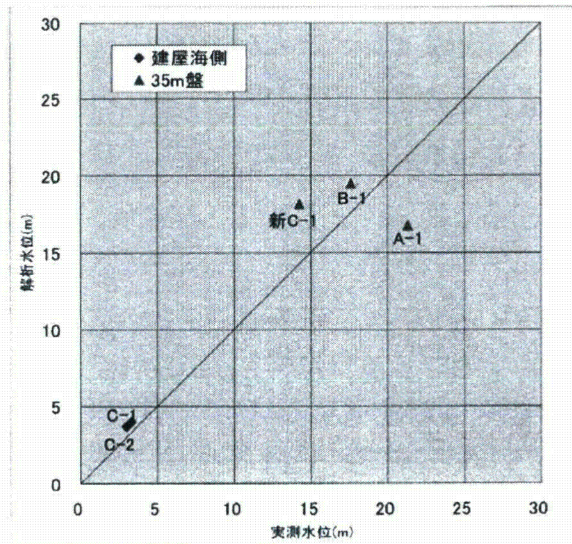
*グラフ中「その他合計」とは，高温焼却炉とプロセス建屋への流入量の合計を指す

対策工実施前のJAEA解析結果（地下水位分布）



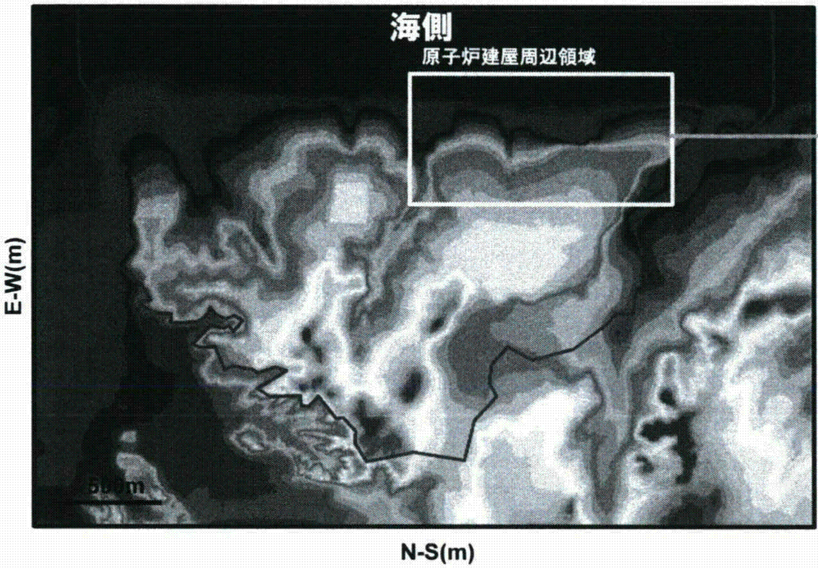
JAEAの対策工実施前の解析結果は，敷地内の地下水位の空間分布を概ね再現できている

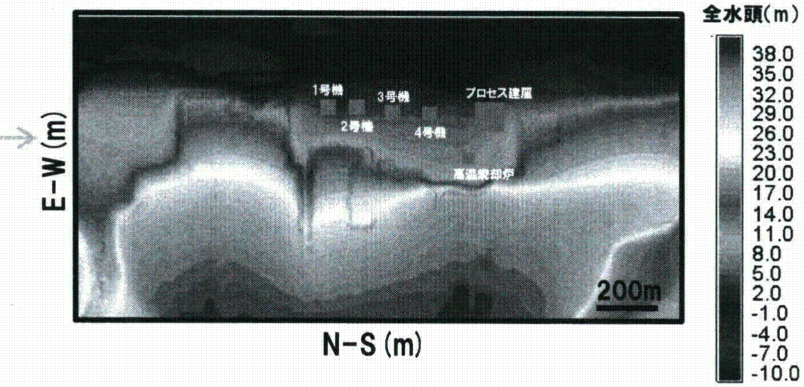
対策工実施前の解析結果の比較(地下水位分布)

<table>
<tr><th></th><th>JAEA解析結果</th><th>サブグループ解析結果</th></tr>
<tr><td>不圧水位(中粒砂岩層内)</td><td>
</td><td>
</td></tr>
<tr><td>被圧水位(互層内)</td><td>
</td><td>
</td></tr>
</table>

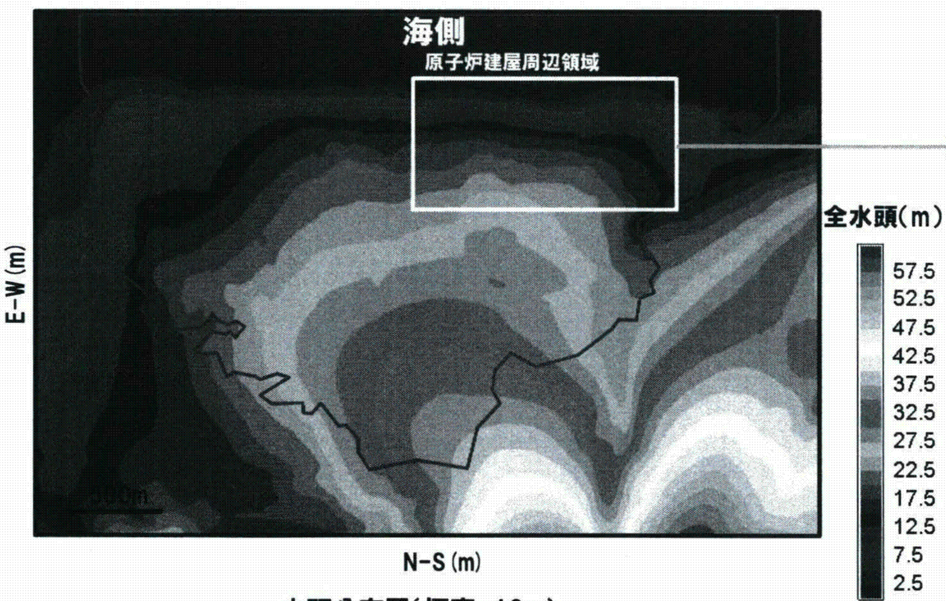
JAEAとサブグループの対策工実施前の解析結果はほぼ同様

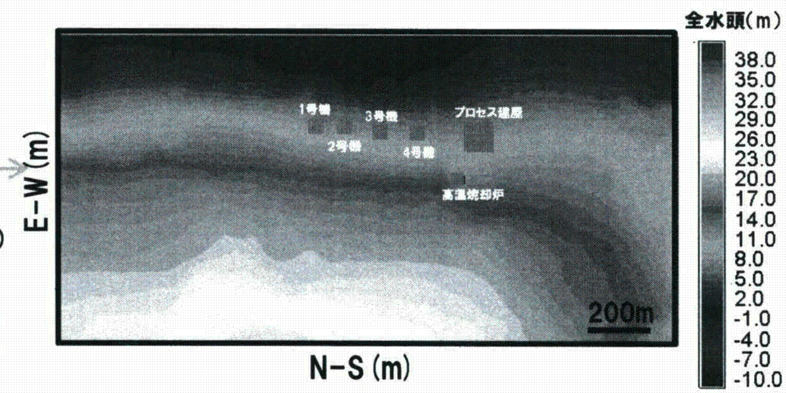
対策工実施前のJAEA解析結果（水頭分布）





水頭分布図（地表面）

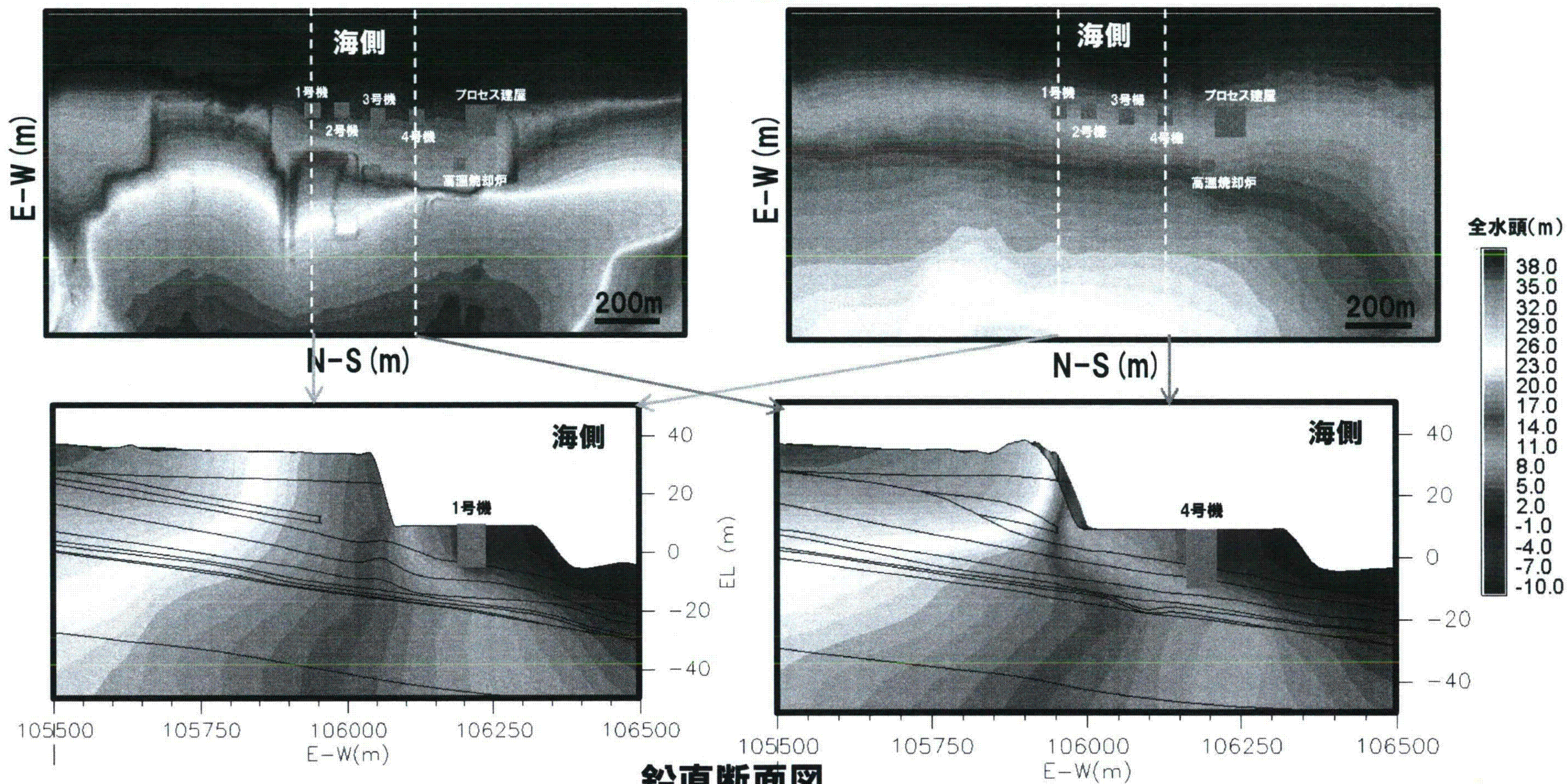




水頭分布図(標高-10m)

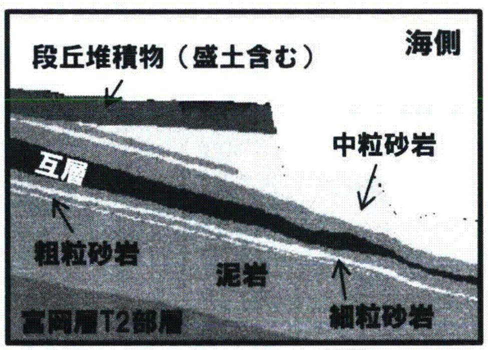
対策工実施前のJAEA解析結果（水頭分布）

水平断面図



鉛直断面図

（下図中の黒線は地層境界を示す）



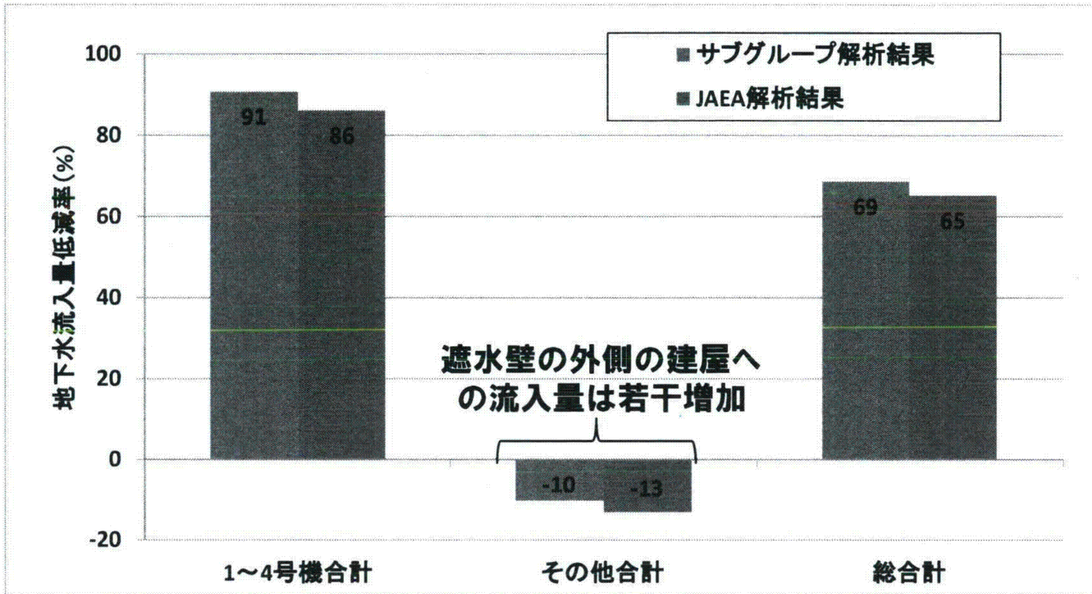
対策工を考慮したJAEA解析ケース

JAEA 解析ケース	対策工①: 陸側遮水壁	対策工②: 海側遮水壁	対策工③: 山・海側SD	対策工④: 地下水バイパス	サブグループ 解析ケース
ケースA	−	−	−	−	ケース 0
ケースB-1	○	−	−	−	ケース 6
ケースB-2	○	○	○	○	ケース 10

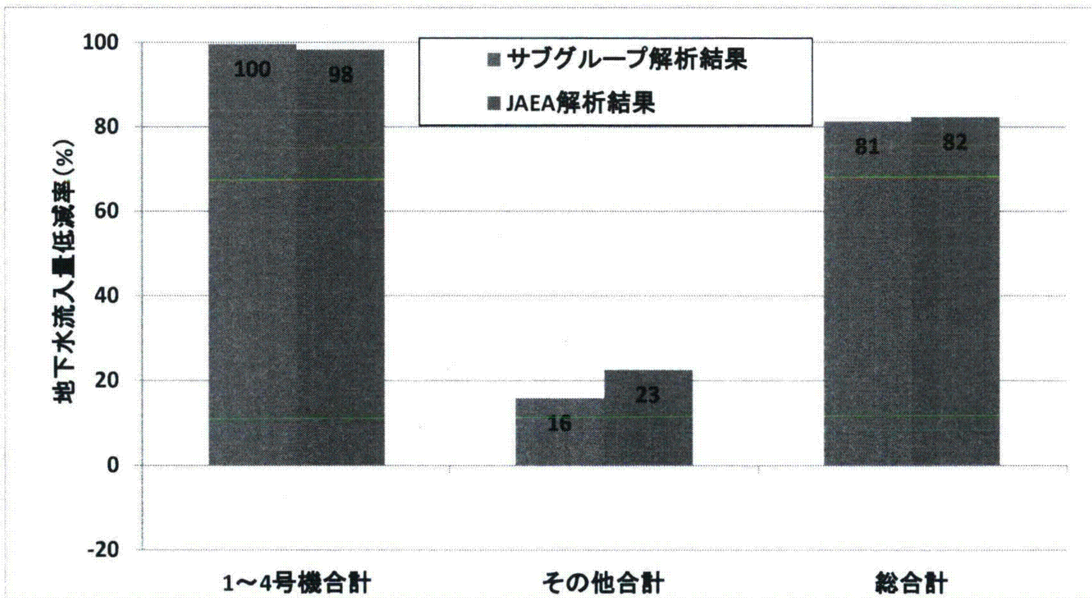
《 モデル化内容 》	
対策工①:陸側遮水壁 (フェーシング含む)	地表からEL-25mまでモデル化
対策工②:海側遮水壁	地表からEL-25mまでモデル化(主に「漏らさない」ための対策であるもの，規模が大きいため「近づけない」ための対策に影響がある可能性があるためにモデル化)
対策工③:山・海側SD	山側サブドレン:35本，海側サブドレン:16本，計51本
対策工④:地下水バイパス	35m盤に12本の揚水井

対策工の効果の推定結果

ケースB−1



ケースB−2



*グラフ中「その他合計」とは，高温焼却炉とプロセス建屋への流入量の合計を指す

まとめ

- 解析領域や境界条件，建屋のモデル化方法に違いがあるにも係らず，JAEA解析値とサブグループ解析値を比較した結果，以下の点において整合的であることが確認できた。

  - 対策工実施前の解析結果：地下水位分布
  - 対策工を考慮した解析結果：建屋への地下水流入量の低減率