

Transforming **“Poison”** into **“Medicine”** :  
**Vaccination**

- **Nagarjuna**

*Scholar of Mahayana Buddhism, 150-250 CE*

# *A DSTA Case Study:* **Underground Ammunition Facility**

Creating & Valuing **Flexibility** in Systems  
Architecting: Transforming **Uncertainties** into  
**Opportunities** using **Real Options Analysis**



**Angela H0**

Defence Science & Technology Agency (Singapore)



# Uncertainties: Risk Mitigation

*a common approach*





# Uncertainties: Flexibility

## *a complementary approach*

4

“Flexibility is the **lifecycle property** that allows a system to endure ... changes with ease.

It is an **active** and largely external approach to **managing change** ... [**& uncertainties**]”

(adapted from Moses, 2003)

# Real Options *definition*

5



Road as a Runway



Real Options  
Thinking



Real Options  
Valuation

“The **right**, but not the obligation to take some **action** at a pre-determined **cost** at a pre-determined **time**”





# Real Options Suitability

## *Engineering Projects with:*

**Staged Investments**



**Possibility of Exercising Option with Time**

**Considerable Uncertainties**



**Higher Uncertainty -> Higher Option Value**

**Possibility of Learning**



**Value of Information & Application of Knowledge**



Source: [http://www.nexus.gov.sg/imindef/publications/cyberpioneer/features/2008/apr08\\_fs.html](http://www.nexus.gov.sg/imindef/publications/cyberpioneer/features/2008/apr08_fs.html)

*A Case Study:*

**Underground  
Ammunition  
Facility (UAF)**



Real Options Thinking

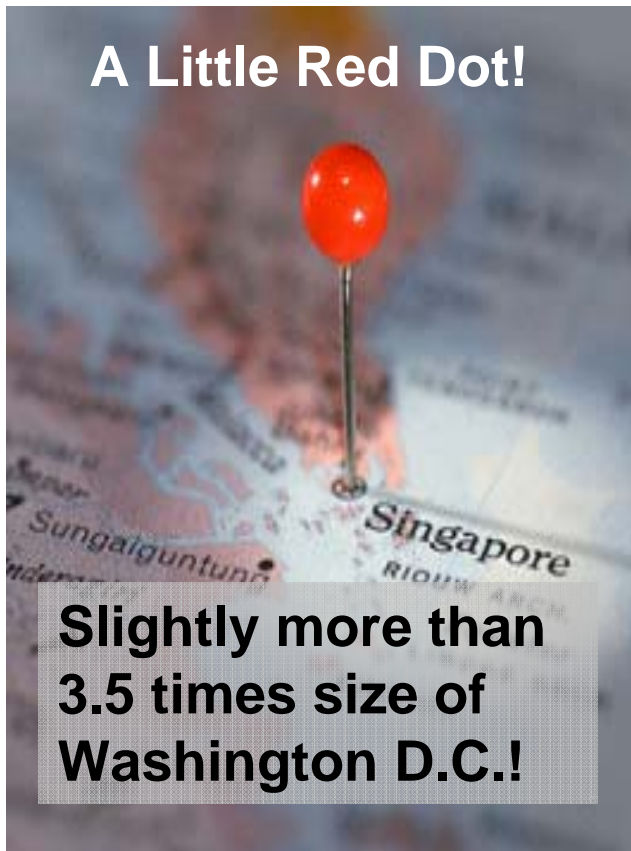


# New Ammo Storage Facility

## Need *mid 1990s*

8

A Little Red Dot!

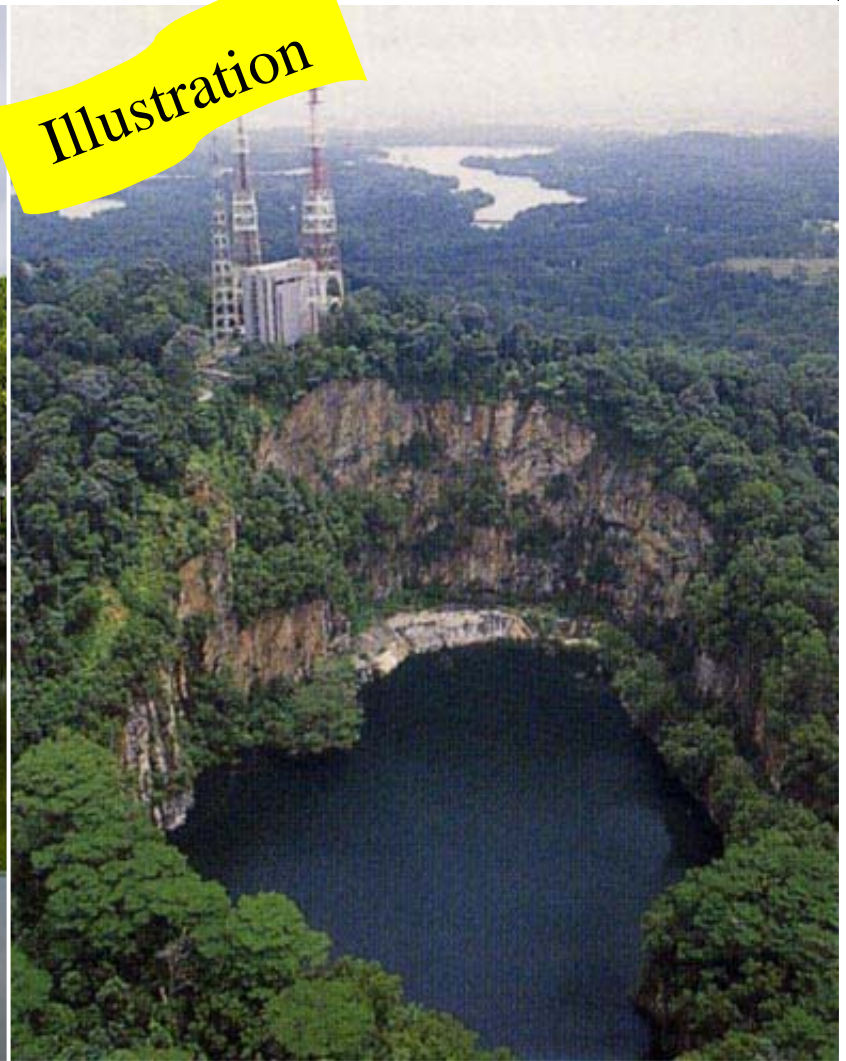


Slightly more than  
3.5 times size of  
Washington D.C.!

- Need for new Ammo Storage facility
  - Existing Demands: To store Ammo to be relocated from an existing depot
  - Future Demands: To support Long-Term Ammo Storage Planning
- **Underground** storage was suggested, due to limited land space



# UAF Possibility *at Quarry*





## UAF Feasibility *in Singapore*

10

***Conservative & Inadequate existing safety codes:***

### **Land-Scarce**

**Too conservative to be feasible in Singapore (bigger hazard safety zone)**

### **Mixed Geological Rock**

**Didn't address ground shock propagations for mixed rock**

### **High Population Density**

**Didn't address ground shock effects to Reinforced Concrete buildings**

**A Little Red Dot!**



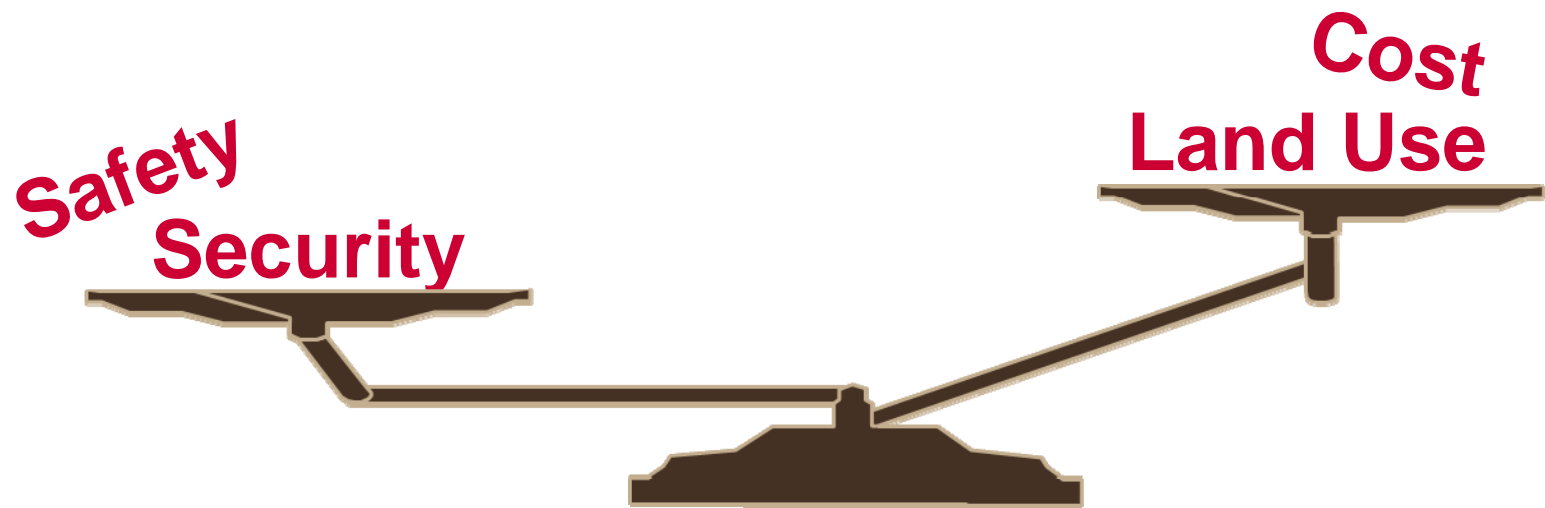
**Slightly more than 3.5 times size of Washington D.C.!**



## UAF Objective *design tradeoffs*

11

“to design and develop an ammunition storage facility that would enhance **safety** and **efficiency**, while achieving significant **land savings** in land-scarce Singapore”





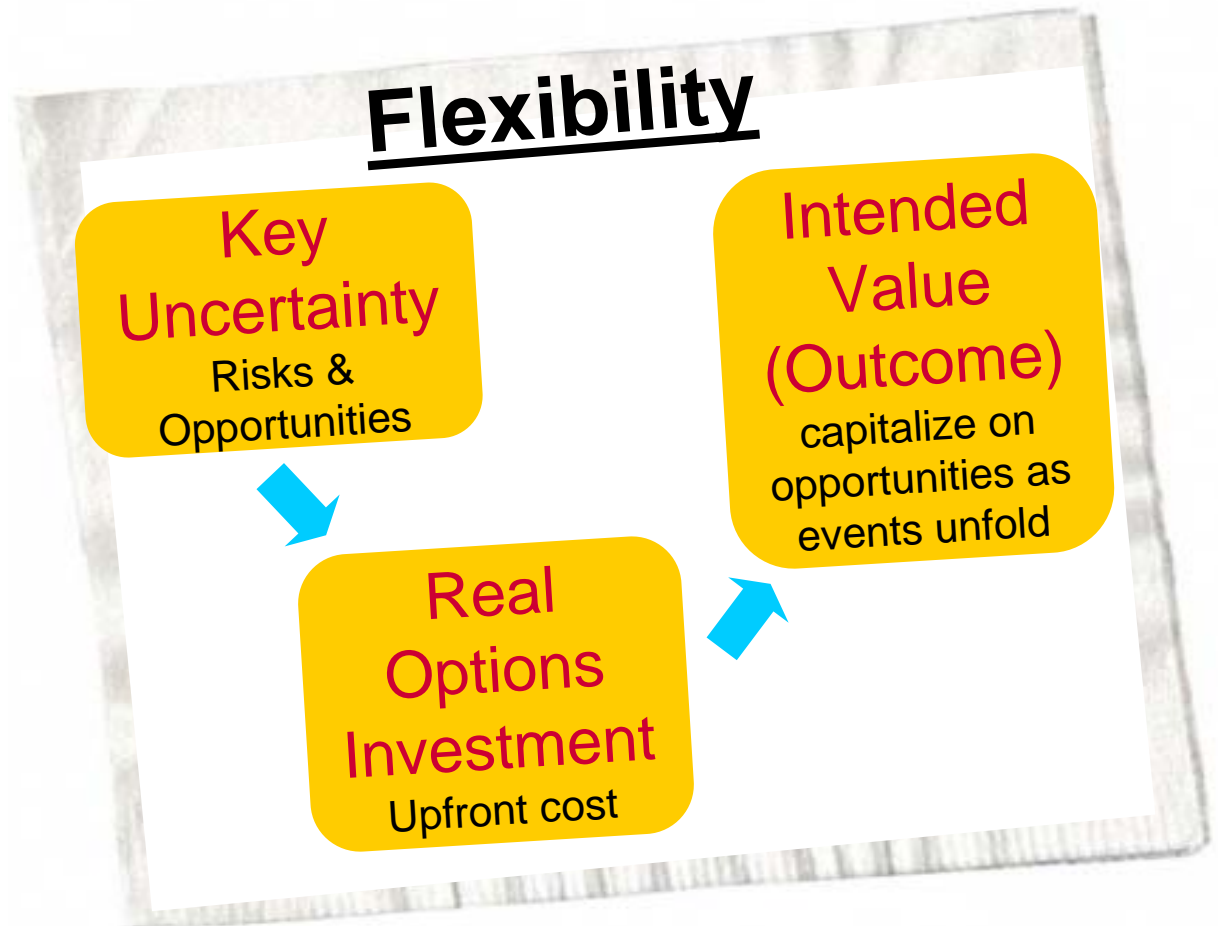
# UAF Project *Considerable Uncertainties*

12

## Key Uncertainties:

- *Can we do it? Is a UAF **feasible**?*
- *How do we do it? What's the UAF design & layout to **maximise safety** & **minimise land use**?*
- *How do we **manage the UAF project** if no one locally has done it before? What's a good cost & schedule estimate?*
- *Is there value to **sustain** local capabilities?*

# Back of a Napkin *graph*





# Uncertainty #1: Is UAF Feasible?

## >> *Option to Grow*

14

### Uncertainty:

- Technology gap & lack of information on **safety standards**, design guidelines & blast effects

### Real Option Investment:

- Option to Grow (long-term) by seeding investment into ~10 yrs of **R&D** in ammo storage safety, rock engineering

### Intended Option Value:

- Make decision with confidence that UAF is feasible, safe, & secure

### Emergent Option Value:

- Save more land than expected
- Contribute to NATO safety codes
- Explore other underground developments in Singapore

# Singapore The Straits Times 6 April 2009

“So far, Singapore has used underground caverns for **ammunition** storage...the Government is also building the first five caverns ... to store **crude oil and attendant oil products**”

The Straits Times page B4 - Monday 6 April 2009

## DIGGING DEEPER

In the first major update on the geology of Singapore since 1976, a team of 10 engineers and geologists dug about 200m below ground to unearth new facts about the ground beneath. Here are some of the findings from the new book.

The formation – about six times stronger than concrete – covers about 200 sq km, stretching from Orchard Road to Woodlands and from Sembawang to Bukit Batok. Singapore's first underground ammunition facility is housed beneath this granite formation.

Singapore's oldest rock is in the Sajahat Formation in Pulau Tekong. The rock is more than 300 million years old.

Fossils of shellfish, more than 200 million years old, can be found in the Upper Jurong, Bencu, Jalan Buroh and Labrador Park areas.

Limestone deposits sit below a 10-km stretch from Telok Banglah Road to West Coast Road. The rocks – harder than concrete – can also be found at the Tuas Second Link.

The strongest rock in Singapore is found in the Gombak North. The rock formation, which once supported nine quarries, is more than 10 times stronger than concrete.

The Fort Canning Boulder Bed, about half the size of the Central Business District, is found between Fort Canning Park, Cathay Building, Middle Road and Raffles City. The other area is bounded by Telok Ayer Street, Bencu 1st Street, Singapore River and the old shoreline near Raffles Quay.

Source: GEOLOGY OF SINGAPORE

### Imagine a city 50m below ground

Limestone deposits in western S'pore ideal for building caverns to store food and house people

By JEREMY CHOW

NO SPACE in Singapore for buildings? Try digging underground.

In the west are limestone deposits – fertile ground for urban planners to build caverns that can be used to store water and food, or even house people.

A team of 10 geologists and researchers from the Defence Science and Technology Agency (DSTA) has found limestone deposits sitting underground with a 10km stretch of land from Telok Banglah to West Coast Road, including the Edge and Boon Lay. Limestone and granite, both stronger than concrete, can also be found in Changi in the east.

Dr Zhen Yiqin, a DSTA senior principal engineer, said the abundance of limestone deposits, found 50m below ground, is enough to “build an underground city”.

“We could replicate what you see above ground...shopping centres, schools, offices and streets, among other things,” he said, adding that a more detailed study will have to be done to determine the amount of underground space urban planners can tap on.

DSTA is documenting the presence of limestone deposits in Singapore's geological maps for the first time since they were first found in 1987 in Pulau Merlimau on Jurong Island. Its findings have been published in the second edition of *Geology of Singapore*, first published in 1976.

“In fact, Singapore has used underground caverns for ammunition storage for defence forces. The Government is also building the first five caverns beneath Jurong Island to store crude oil and attendant oil products. They will start operations at the end of next year.

The DSTA, with geologists from the Nanyang Technological University and the Building and Construction Authority, studied soil samples over the past two years to compile the book.

It will be a useful reference for construction and urban planning experts as they continue to look for space to develop amid the concrete jungle.

The 90-page dossier also lists Singapore's oldest rock, in Pulau Tekong, and 200 million-year-old fossils in Jurong.

Another key finding is what lies underneath the city centre between Fort Canning Park, Middle Road and Telok Ayer Street: A hard rock, christened the Fort Canning Boulder Bed by the researchers.

Mr Michael Lee, who co-authored the book, said the sandstone boulder is three times tougher than concrete and a nightmare for civil engineers. “It slows down and hampers excavation work, pushing up the construction costs,” said the geologist at the former Public Works Department.

He added that knowledge of this “troublesome” rock, which is half the size of the Central Business District, is a bonus for construction companies.

Mr Colin Tan, senior project manager of local construction firm Tiong Seng, said the information will come in handy as contractors could halve the month-long soil investigation at some sites.

jeremy@big.com.sg

GRAPHICS: S. CHANBAGAN



# Uncertainty #2: What is the ammo storage amount? >> *Option to Expand*

16

## Uncertainty:

- UAF design for ammo **storage** amount (*Quantity*)

## Real Option Investment:

- Option to Expand & Utilize enabled by UAF site layout for future growth:
  - Modular chambers, with spare storage capacity
  - Infrastructure: power supply, tunnel access, monitoring

## Intended Option Value:

- Flexibility for future expansion (spare ammo storage capacity with minimal time-delay and costs) with Masterplanning



# Uncertainty #3: How to handle the ammo types? >> *Option to Switch*

17

## Uncertainty:

- UAF design for safe **handling** of existing & future basket of ammo (*Types*)

## Real Option Investment:

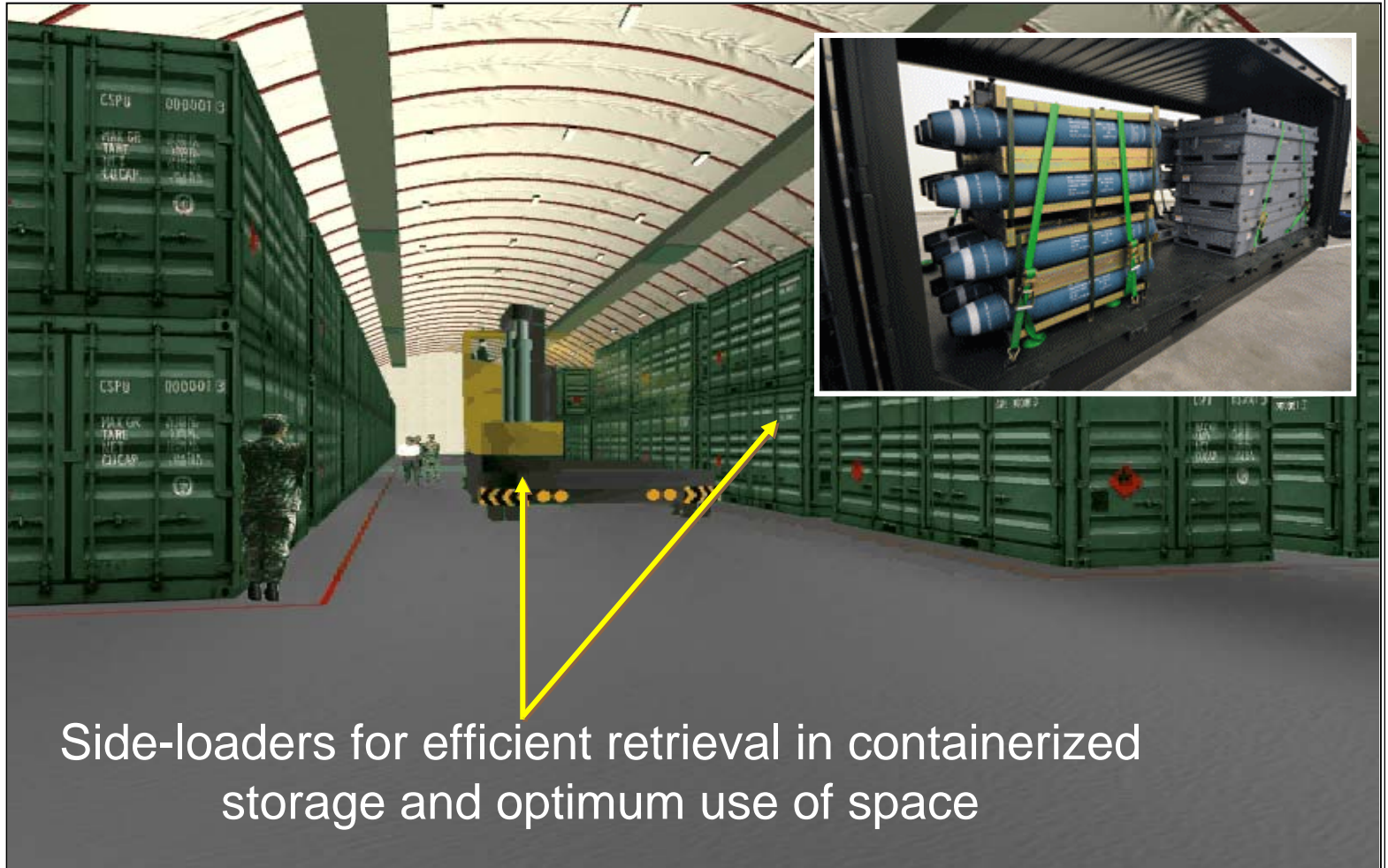
- Option to Switch enabled by UAF site layout:
  - Chamber Design: Bigger chamber & bigger blast door, costing more
  - Storage mode: containers needing bigger openings vs. pallet needing smaller openings
  - Transport type: prime-movers, side-loaders

## Intended Option Value:

- allow for change / growth of ammo profile & associated mechanical handling equipment



# Flexibility in Chamber Design *enabling storage & transport options*

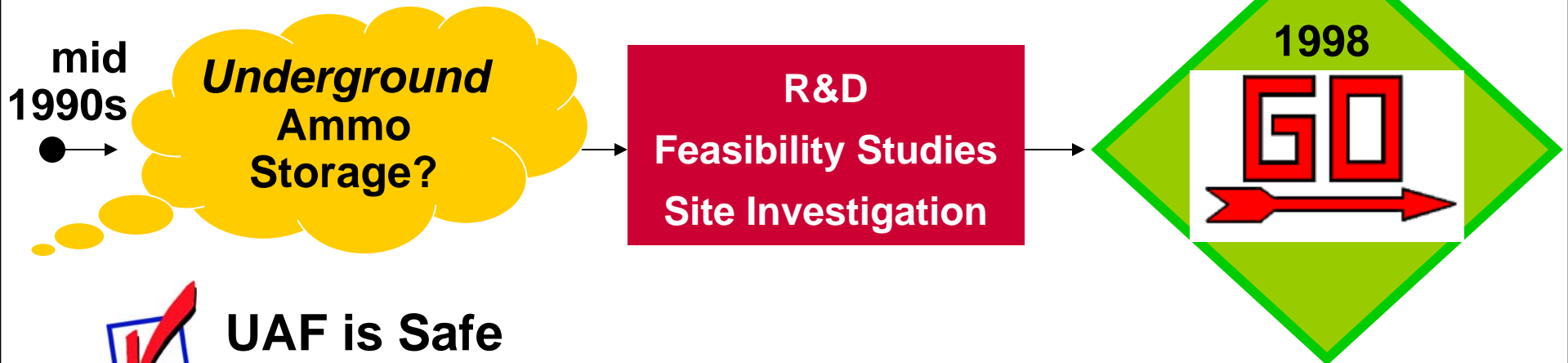


Side-loaders for efficient retrieval in containerized storage and optimum use of space



# UAF Decision Point “Go or No Go?”

19



## UAF is Safe

Ground shocks, air blasts, debris, fire, etc



## UAF is Technically Feasible

within land constraints, ground shock studies in Singapore's rock media, ground shock studies to Reinforced Concrete buildings



## UAF is Economically Viable

low development cost (good rock quality, advancement in Cavern technologies), low maintenance cost (energy savings, exterior)



# Uncertainty #4: How do we manage the UAF? >> *Option to Stop/Defer/Continue*

20

## Uncertainty:

- Management of the UAF Design & Construction with no local experience; schedule, cost estimation & security considerations

## Real Option Investment:

- Option to Stop/ Defer/ Continue via a highly interactive, iterative, phased approach in project management, with early involvement of all parties
  - Phase 1: Pilot Construction Phase ('99-'01)
    - Verify design assumptions from Feasibility studies
    - Technology transfer from foreign consultants with Rock Excavation for Cavern Construction
  - Phase 2: Main Construction Phase ('01-'08)

## Intended Option Value:

- Agility to change (stop, defer, continue) with uncertainties



# Uncertainty #5: Is there value to sustain local capabilities? >> *Option to Stage*

21

## Uncertainty:

- Is there value in keeping /sustaining local capabilities once built-up? Will there be new demands once the UAF is completed?

## Real Option Investment:

- Option to Sustain (keep knowledge current) by investing into NTU Research program in Underground Technologies & Rock Engineering with projects for students

## Intended Option Value:

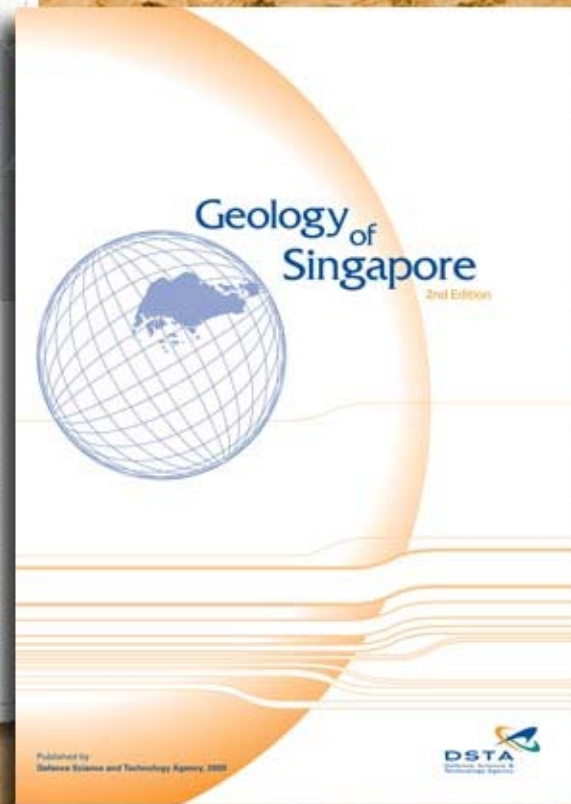
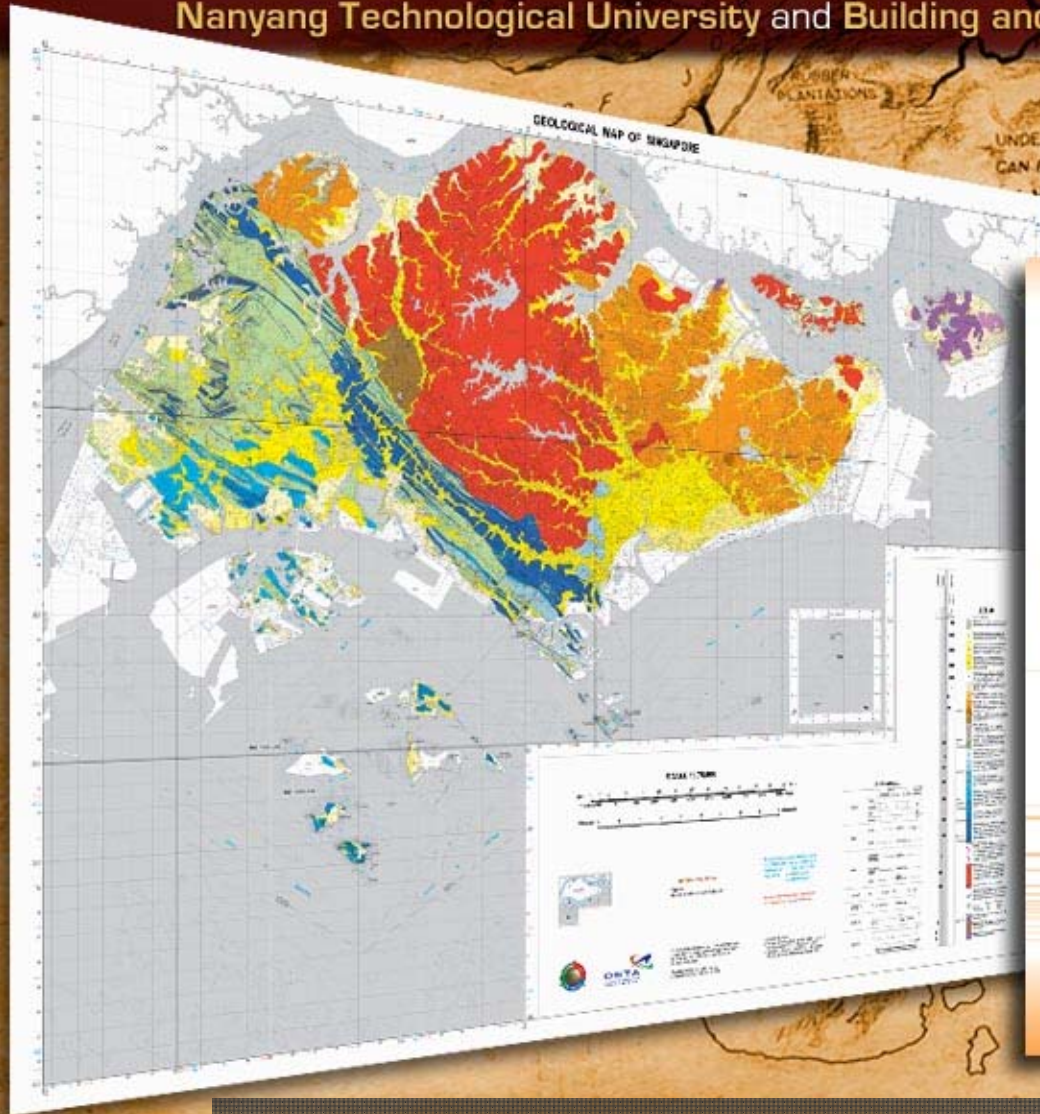
- When new demands came up, DSTA was able to tap on local capabilities and contribute:
  - Oil Storage: DSTA as Technical Advisor for Cavern Project
  - Masterplan Long-Term Underground Development for Singapore: DSTA a part of National Inter-Agency initiative for Underground planning

# UAF Commissioned *7 march 2008*



Source: [http://www.nexus.gov.sg/imindef/publications/cyberpioneer/features/2008/apr08\\_fs.html](http://www.nexus.gov.sg/imindef/publications/cyberpioneer/features/2008/apr08_fs.html)

Published by Defence Science and Technology Agency, in collaboration with Nanyang Technological University and Building and Construction Authority



Geology of Singapore Launched *18 march 2009*



# Uncertainties *revealed*, Options *invested*

24

- Can we do it? Is a UAF **feasible**?
- How do we do it? What's the UAF design to **maximise safety** & **minimize land**?
- What is the **ammo storage amt**?
- How to **store** & **handle** different **ammo types**?
- How do we **manage the UAF project** if no one locally has done it?
- Is there value to **sustain** local capabilities?

Option to **G**row  
 Option to **U**timize  
 Option to **E**xpand  
 Option to **S**witch  
 Option to **S**top/Defer..  
 Option to **S**ustain

**Flexibility in  
 Ammunition Storage,  
 Operations & other  
 Underground uses**



# UAF Outcomes *achieved*

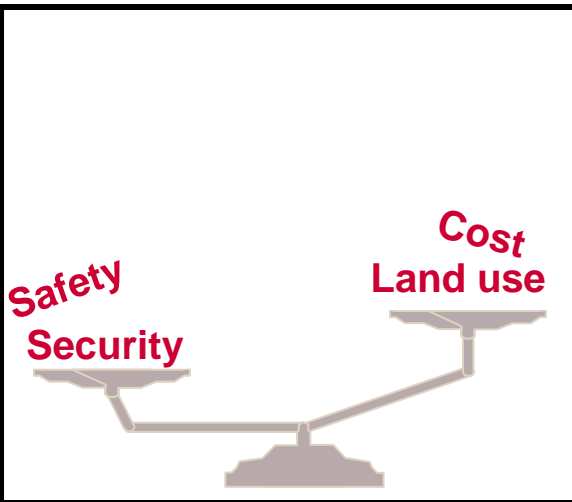
## Significant Land Savings



## Enhanced Safety & Security



## International Contribution



## Local Capability Built-Up



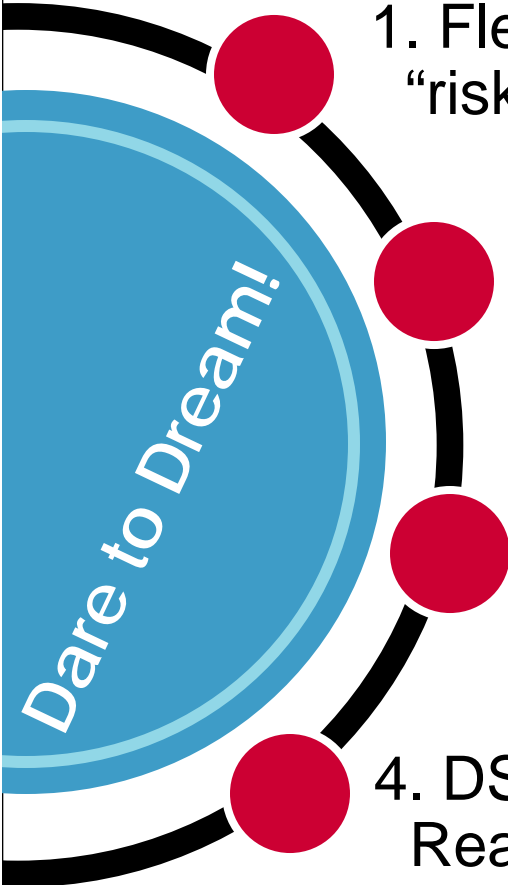
## Capability for Other Underground Devt





# Conclusions *& Takeaways*

26

- 
- A graphic on the left side of the slide consists of a blue circular area with the text 'Dare to Dream!' written in white, curved along its edge. This area is connected to a black arc that contains four red circular markers, each corresponding to one of the four numbered points in the list.
1. Flexibility is a strategy to complement the common “risk mitigation” approach for managing uncertainties.
  2. A system with Real Options is a flexible system. Real Options have upfront cost, but have value.
  3. DSTA designed Flexibility into the UAF, applying Real Options Thinking, & created a paradigm shift, leveraging uncertainties as opportunities.
  4. DSTA is now benefiting from these investments in Real Options from the UAF program.



## Embrace Uncertainty



## Enjoy the Ride!

“I took the road less travelled by, and it has made all the difference”

*-Robert Frost*

*American Poet, 1874–1963*



# Acknowledgement to UAF Project Team!

## UNDERGROUND AMMUNITION FACILITY COMMISSIONING CEREMONY

Guest-of-Honour

**Mr Teo Chee Hean**

Minister for Defence



# THANK YOU!



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