AleffGroup

Phosphogypsum (PG): Uses and Current Handling Practices Worldwide

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Lakeland FL, London UK

25^{th} Annual Lakeland Regional Phosphate Conference

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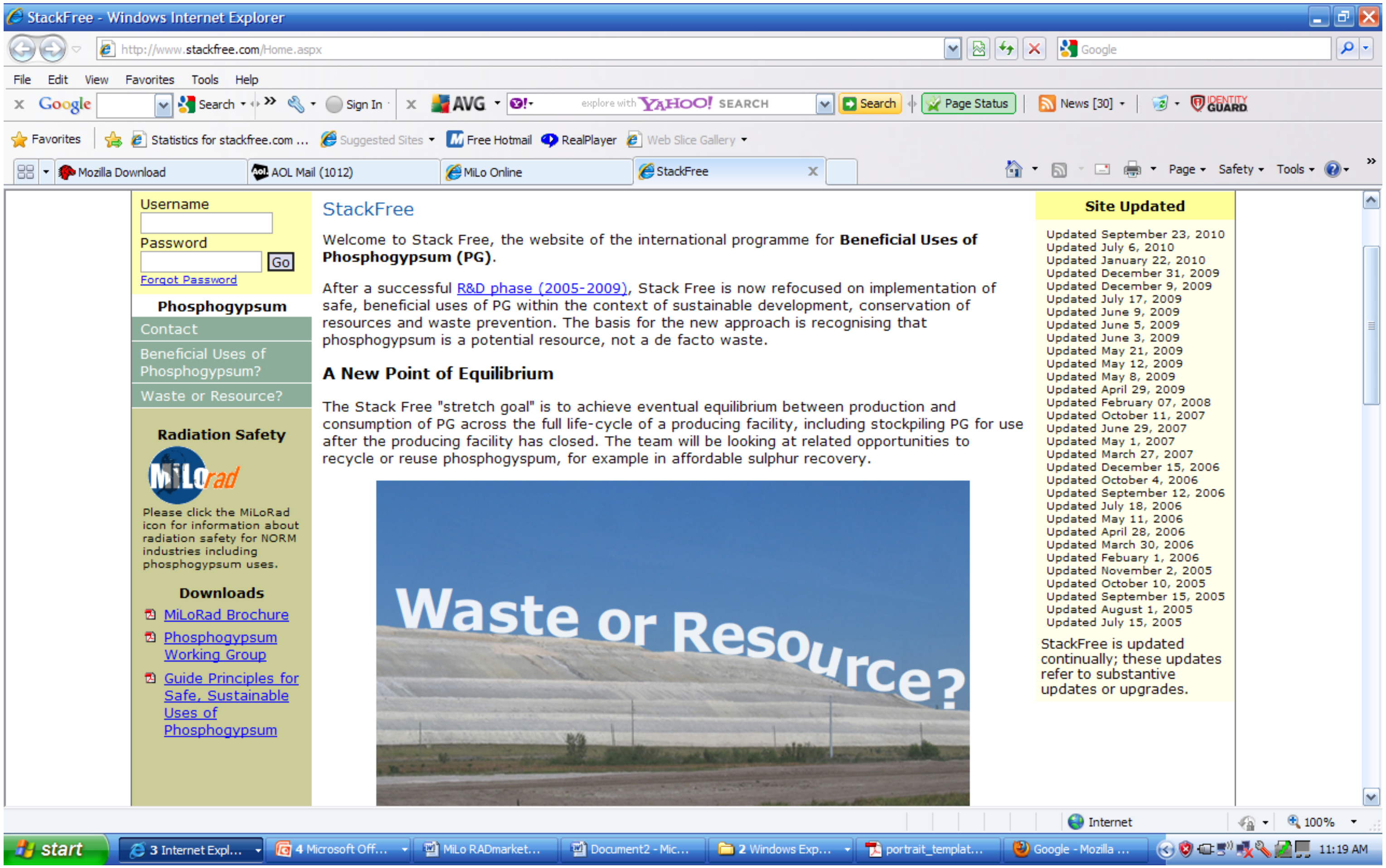
You can sometimes move the cheese

With profound thanks to fellow cheese movers

Mike Lloyd, Brian Birky, Regis Stana, Johnny Johnston, Bhaskar Bandyopadhyay, Karen Stewart, Patrick Zhang, Malika Moussaid, Vinod Bhandari, Rafael García Tenorio, Manzoor Qadir, Peter Waggitt, Denis Wymer and members of the International Phosphogypsum Working Group

What is PG? Waste or Resource



Fresh from Florida...How Much PG?

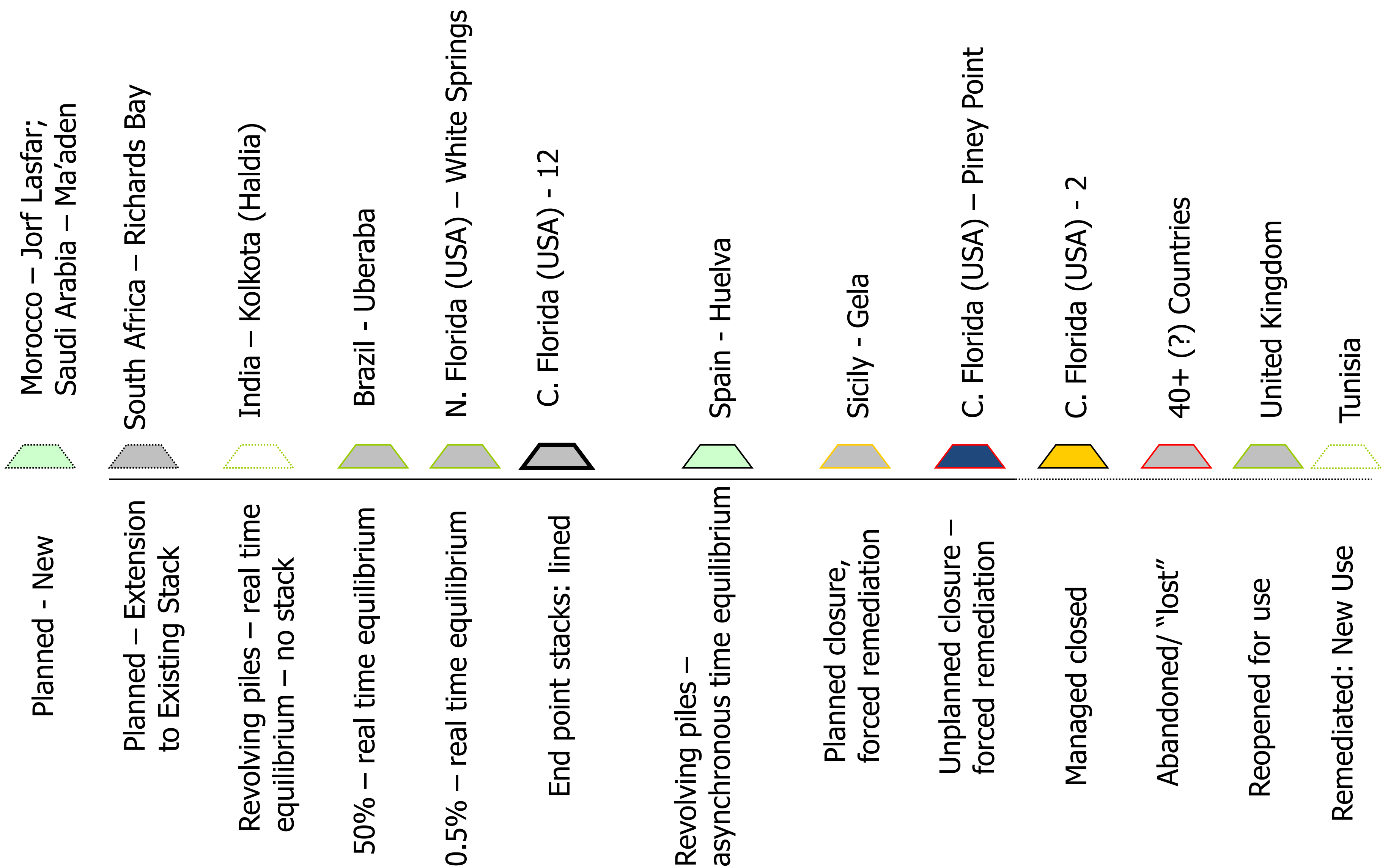
- **5.6 – 7.0 billion tonnes of PG produced in lifetime of industry to date (5 tonnes of PG per tonne of acid)**
- **Some 3 - 4 billion tonnes (Hilton 3bn, Birky 4bn... What's a bn between friends) now available, of which 1.1 bn in Florida**
- **"Stacks" identified in some 52 countries, and rising**
- **5 primary types... Full life-cycle approach**
  1. **Legacy / "lost"/ abandoned**
  2. **Active/ managed**
  3. **Closed/ managed**
  4. **New/ in planning**
  5. **Fully remediated**

- **PG holding growing at c. 150-200 million tonnes pa at present with prospect of 250 M tonnes pa by 2015**
- **Total global holding will probably double sometime between 2025 and 2040**
- **Stacks are taking up an unknown, but increasing quantity of land…**
- **Often in prime, highly sensitive, increasingly populated areas, such as central Florida**

Some more numbers…

- Up to $25 per tonne life-time storage cost
- $150m bond or equivalent per new stack
- Up to $500m liability for major legacy stacks
- $60-120bn potential value swing hangs on the outcome of how we manage PG

PG Stacks Whole Life-cycle Management: The Evidence Base



Waste or Resource?

- Waste: "Something for which no use is foreseen or foreseeable"
- Therefore PG not a waste
- Current commercial/ pilot uses
  - Agriculture
  - Roads (US, Europe, Middle East, Africa)
  - Construction
  - Coastal and Marine
  - Landfill
- Hundreds of possible uses… new ones being developed all the time
- There is a spotty but growing global agricultural market – prices from $0 tonne, $8, $12, $75 for a 50kg bag (Brazil)…

Constraints

- Radionuclides (Ra goes to PG and U goes to the acid; other radionuclides – Pb and Po also go to PG; Th variable but most in the acid (?))
- Heavy metals – usual suspects; would be good to remove these anyway, if viable
- Organics
- Real waste in stacks
- Acidity
- P_2O_5 content
- Mechanical and engineering properties – need to be very careful in selecting and using the source materials
- Transportation costs
- Incoherent, inconsistent regulations

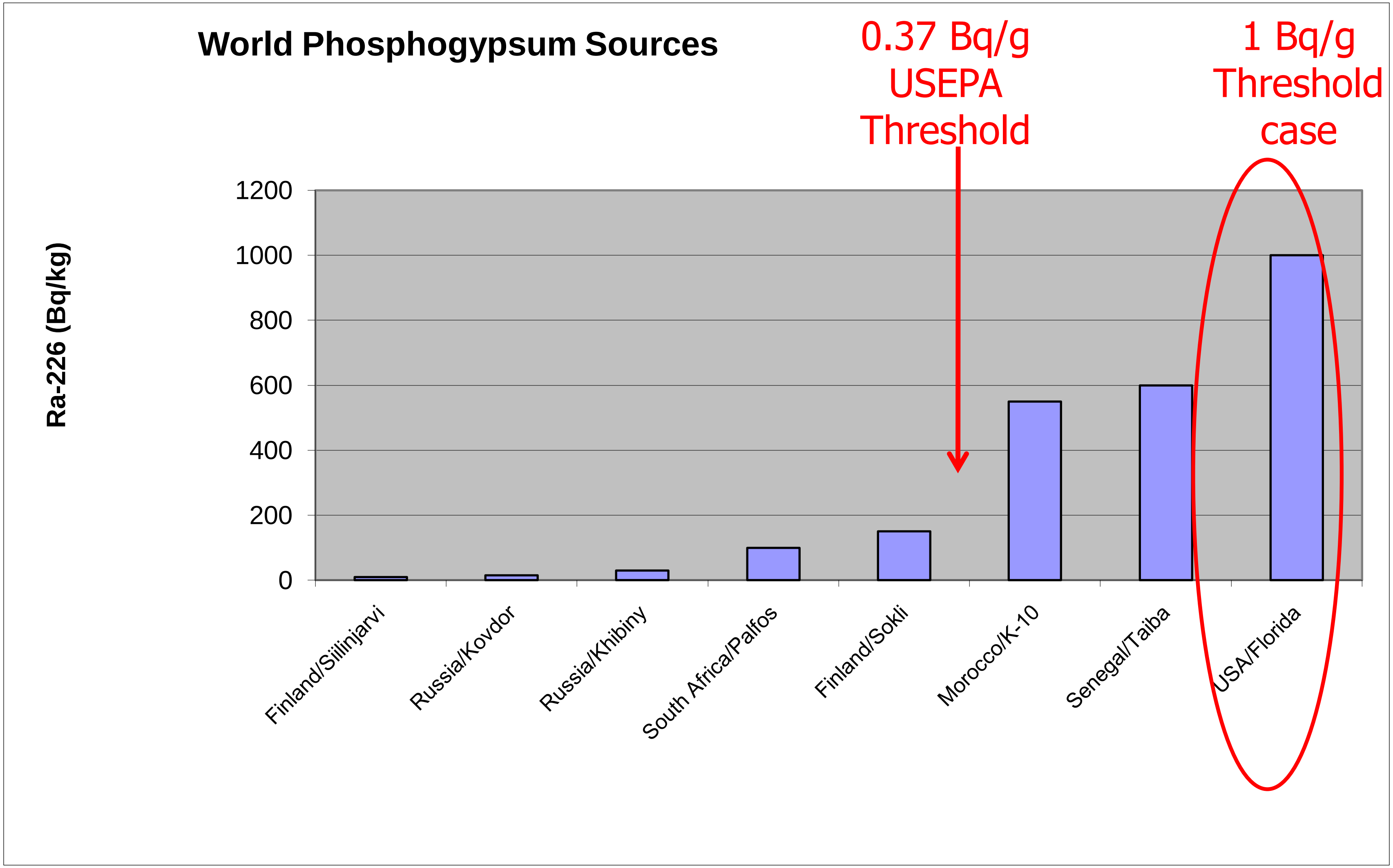
Incoherent

Inconsistent approaches

Selective Comparative Management of PG Life-cycle

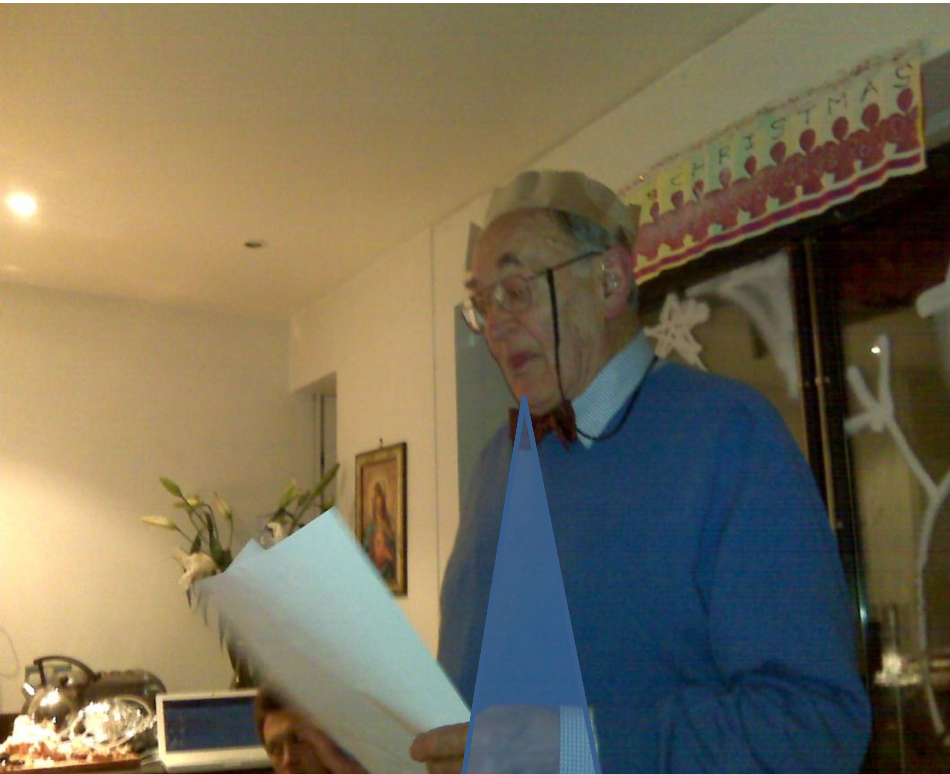
Country	Discharge	Stack (Working)	Legacy	PG - Experimental Use	PG - Commercial Use (%) (Incentive)	Full Site Remedi-ation
50+			X			
Brazil		X	X	X	X (40%)	
China	X (ceased ?)	X	X	X	X (20%)	
India		X	X	X	X (I)	
Jordan		X	X	X		
Kazakhstan			X	X	X	X
Lebanon	X					
Morocco	X					
Netherlands	X (stop 1999)			X	X	X
Spain	X (stop 1998)	X	X	X	X	
Syria		X		X		
Tunisia	X (Gabes stops 2012)	X	X	X		X (Taparura)
US	X (stop)	X	X	X	X (reduced post 1989)	
UK	X (stop 1998)		X			X ? (Immingham)

FIPR Data: The Impact of a Regulation




3 Billion Tonnes, rising at 150-
250 Million Tonnes Per Year:
Waste or Resource? =
Risk of Use vs Risk of Non-Use


Why don’t you boys do something useful with PG instead of just looking at it?


Bless my soul, why didn’t we think of that? ... Send for the cavalry!

The Stack Free Boys Come Boiling Over the Ridge…

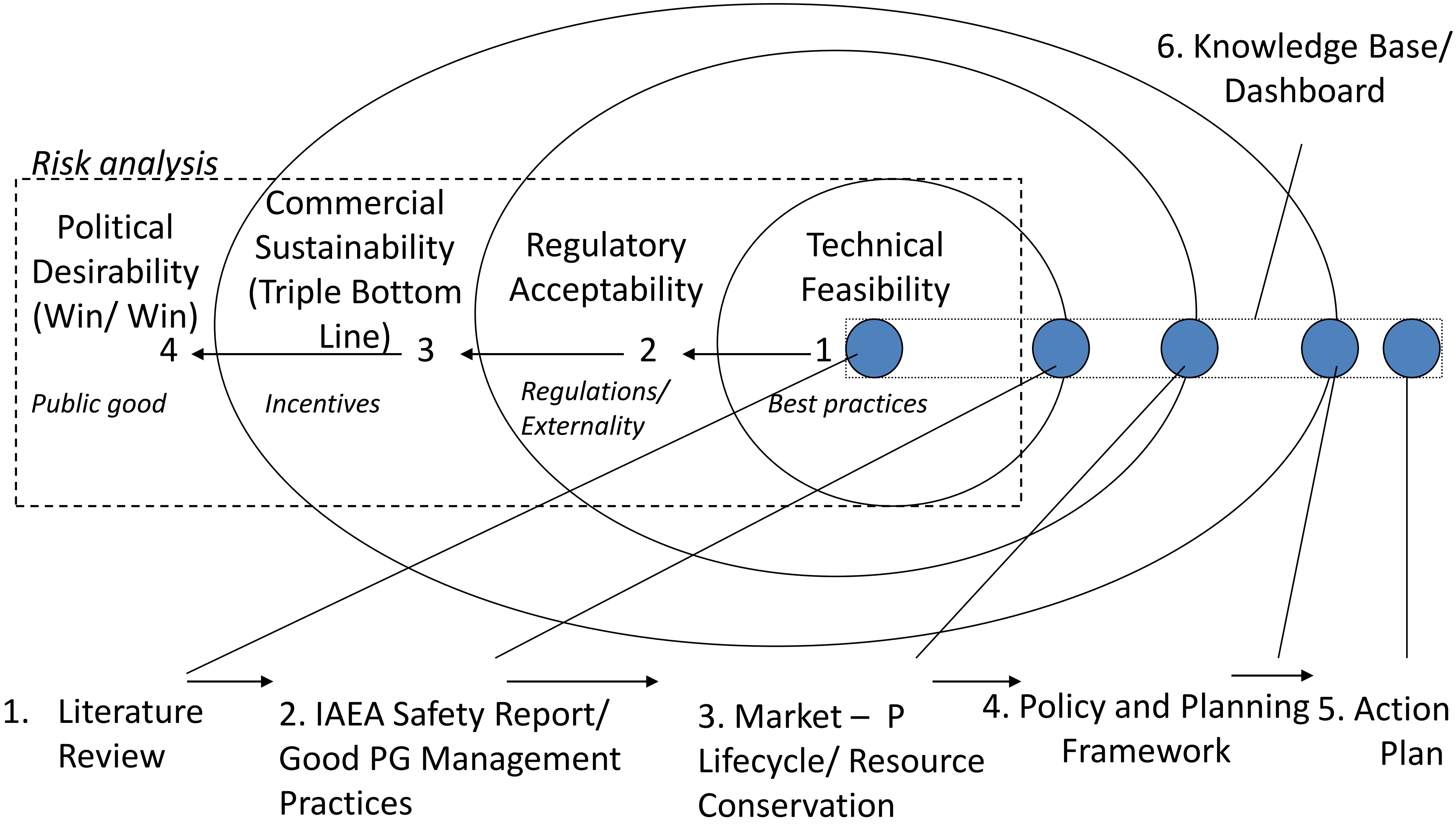
…the Phosphogypsum

Working Group Scouts the Frontier

Using a systematic, evidence-based approach…

With thanks to FIPR and Aleff Group

The Onion Rings Methodology



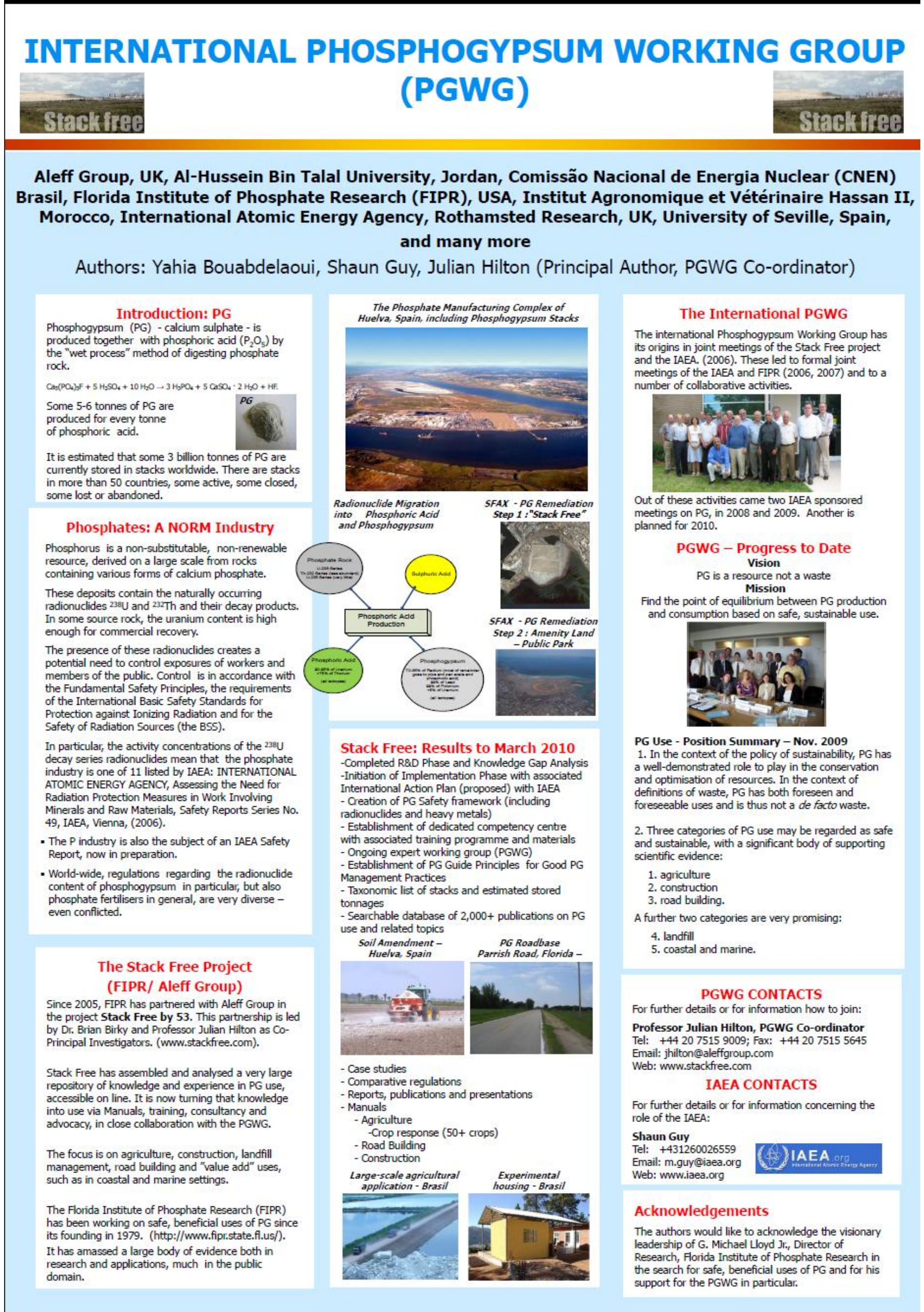
Stack Free Results:
October2010 (1)

- Completed R&D Phase and Knowledge Gap Analysis
- Initiation of Implementation Phase with associated International Action Plan (proposed) with IAEA
- Creation of PG Safety Framework (including radionuclides and heavy metals)
- Development of dedicated Competency entre with associated training programme and materials
- Ongoing Expert Working Group (PGWG)
- Establishment of PG Guide Principles for Good PG Management Practices
- Taxonomic list of stacks and estimated stored tonnages
- Searchable database of 2,000+ publications on PG use and related topics
- IAEA Safety Report on Phosphate Industries – Major Chapter on PG

Stack Free Results:
October 2010 (2)

- Case studies
- Comparative regulations
- Reports, publications and presentations
- Manuals
  - Agriculture
    - Crop response (50+ crops)
    - Soil reclamation
    - Remediation
    - Fertiliser/ amendment
    - Irrigation / water efficiency
  - Construction
  - Road Building

Meets 2x per year: Meeting 1, 2010 @ NORM VI, Marrakech, March 2010



INTERNATIONAL PHOSPHOGYPSUM WORKING GROUP (PGWG)

Stack free

Aleff Group, UK, Al-Hussein Bin Talal University, Jordan, Comissão Nacional de Energia Nuclear (CNEN) Brasil, Florida Institute of Phosphate Research (FIPR), USA, Institut Agronomique et Vétérinaire Hassan II, Morocco, International Atomic Energy Agency, Rothamsted Research, UK, University of Seville, Spain, and many more

Authors: Yahia Bouabdelaoui, Shaun Guy, Julian Hilton (Principal Author, PGWG Co-ordinator)

Introduction: PG

Phosphogypsum (PG) - calcium sulphate - is produced together with phosphoric acid (P_2O_5) by the "wet process" method of digesting phosphate rock.

$Ca_5(PO_4)_3F + 5\ H_2SO_4 + 10\ H_2O \rightarrow 3\ H_3PO_4 + 5\ CaSO_4 \cdot 2\ H_2O + HF$

Some 5-6 tonnes of PG are produced for every tonne of phosphoric acid.

PG

It is estimated that some 3 billion tonnes of PG are currently stored in stacks worldwide. There are stacks in more than 50 countries, some active, some closed, some lost or abandoned.

Phosphates: A NORM Industry

Phosphorus is a non-substitutable, non-renewable resource, derived on a large scale from rocks containing various forms of calcium phosphate.

These deposits contain the naturally occurring radionuclides ^{238}U and ^{232}Th and their decay products. In some source rock, the uranium content is high enough for commercial recovery.

The presence of these radionuclides creates a potential need to control exposures of workers and members of the public. Control is in accordance with the Fundamental Safety Principles, the requirements of the International Basic Safety Standards for Protection against Ionizing Radiation and for the Safety of Radiation Sources (the BSS).

In particular, the activity concentrations of the ^{238}U decay series radionuclides mean that the phosphate industry is one of 11 listed by IAEA: INTERNATIONAL ATOMIC ENERGY AGENCY, Assessing the Need for Radiation Protection Measures in Work Involving Minerals and Raw Materials, Safety Reports Series No. 49, IAEA, Vienna, (2006).

- The P industry is also the subject of an IAEA Safety Report, now in preparation.
- World-wide, regulations regarding the radionuclide content of phosphogypsum in particular, but also phosphate fertilisers in general, are very diverse – even conflicted.

The Stack Free Project (FIPR/ Aleff Group)

Since 2005, FIPR has partnered with Aleff Group in the project **Stack Free by 53.** This partnership is led by Dr. Brian Birky and Professor Julian Hilton as Co-Principal Investigators. (www.stackfree.com).

Stack Free has assembled and analysed a very large repository of knowledge and experience in PG use, accessible on line. It is now turning that knowledge into use via Manuals, training, consultancy and advocacy, in close collaboration with the PGWG.

The focus is on agriculture, construction, landfill management, road building and "value add" uses, such as in coastal and marine settings.

The Florida Institute of Phosphate Research (FIPR) has been working on safe, beneficial uses of PG since its founding in 1979. (http://www.fipr.state.fl.us/). It has amassed a large body of evidence both in research and applications, much in the public domain.

The Phosphate Manufacturing Complex of Huelva, Spain, including Phosphogypsum Stacks

Radionuclide Migration into Phosphoric Acid and Phosphogypsum

Phosphate Rock

Sulphuric Acid

Phosphoric Acid Production

Phosphoric Acid

Phosphogypsum

SFAX - PG Remediation Step 1 :"Stack Free"

SFAX - PG Remediation Step 2 : Amenity Land – Public Park

Stack Free: Results to March 2010

-Completed R&D Phase and Knowledge Gap Analysis
-Initiation of Implementation Phase with associated International Action Plan (proposed) with IAEA
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Soil Amendment – Huelva, Spain

PG Roadbase Parrish Road, Florida –

- Case studies
- Comparative regulations
- Reports, publications and presentations
- Manuals
  - Agriculture
    -Crop response (50+ crops)
  - Road Building
  - Construction

Large-scale agricultural application - Brasil

Experimental housing - Brasil

The International PGWG

The international Phosphogypsum Working Group has its origins in joint meetings of the Stack Free project and the IAEA. (2006). These led to formal joint meetings of the IAEA and FIPR (2006, 2007) and to a number of collaborative activities.

Out of these activities came two IAEA sponsored meetings on PG, in 2008 and 2009. Another is planned for 2010.

PGWG – Progress to Date

Vision

PG is a resource not a waste

Mission

Find the point of equilibrium between PG production and consumption based on safe, sustainable use.

PG Use - Position Summary – Nov. 2009

1. In the context of the policy of sustainability, PG has a well-demonstrated role to play in the conservation and optimisation of resources. In the context of definitions of waste, PG has both foreseen and foreseeable uses and is thus not a *de facto* waste.

2. Three categories of PG use may be regarded as safe and sustainable, with a significant body of supporting scientific evidence:

1. agriculture
2. construction
3. road building.

A further two categories are very promising:

4. landfill
5. coastal and marine.

PGWG CONTACTS

For further details or for information how to join:

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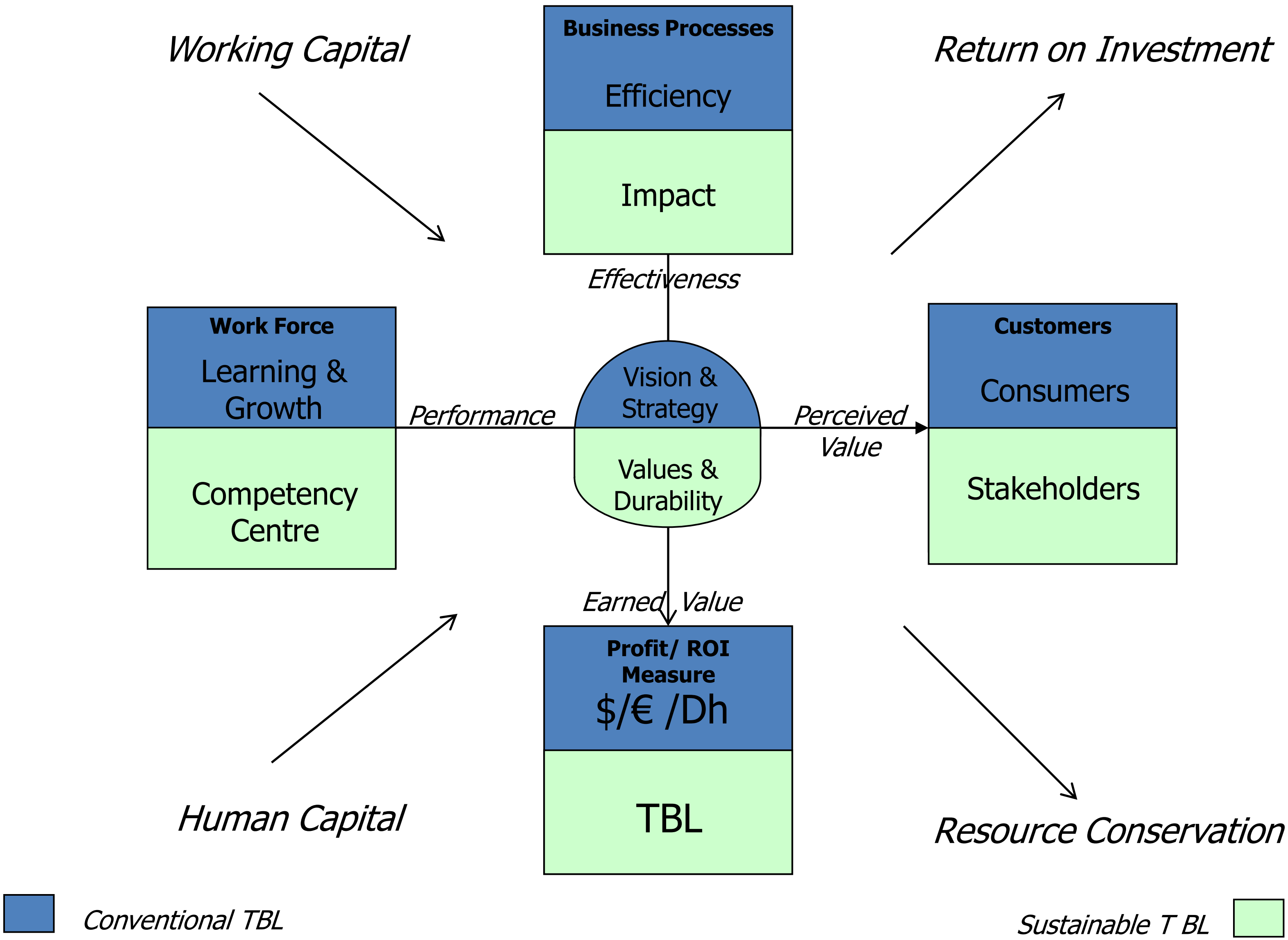
IAEA.org International Atomic Energy Agency

Acknowledgements

The authors would like to acknowledge the visionary leadership of G. Michael Lloyd Jr., Director of Research, Florida Institute of Phosphate Research in the search for safe, beneficial uses of PG and for his support for the PGWG in particular.

Using the balanced TBL scorecard, PG would not be classified *de facto* or *de iure* as a waste…

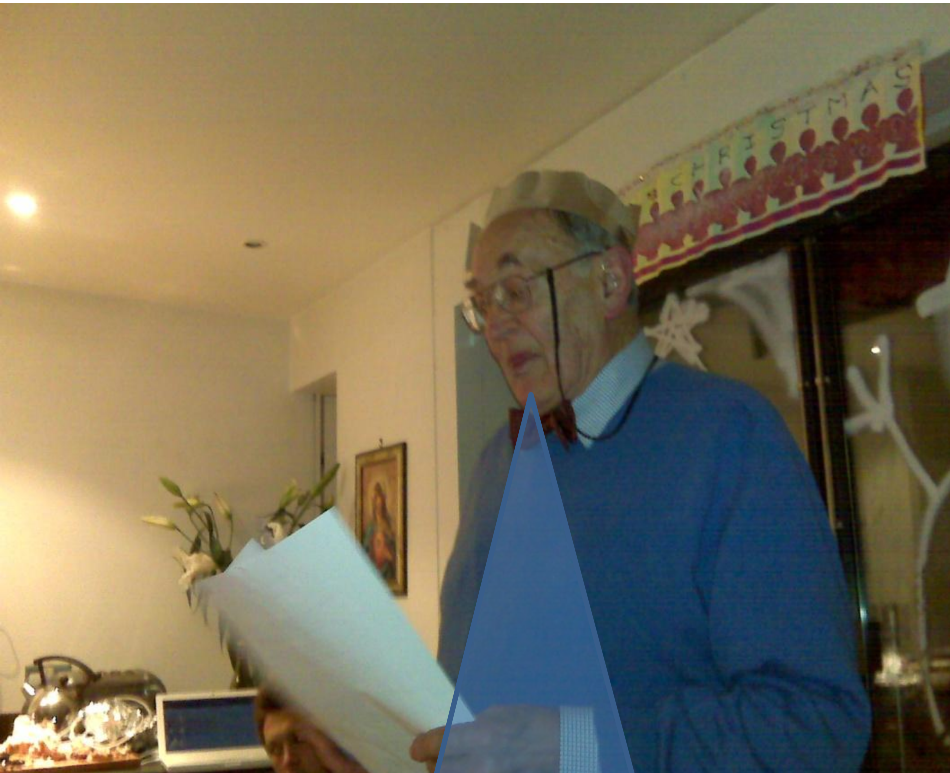
It would become mandatory to have a long-term plan for use, rather than indefinite containment



Working Capital
Business Processes
Efficiency
Impact
Return on Investment
Effectiveness
Work Force
Learning & Growth
Competency Centre
Performance
Vision & Strategy
Values & Durability
Perceived Value
Customers
Consumers
Stakeholders
Earned Value
Profit/ ROI Measure
$/€ /Dh
TBL
Human Capital
Resource Conservation
Conventional TBL
Sustainable T BL

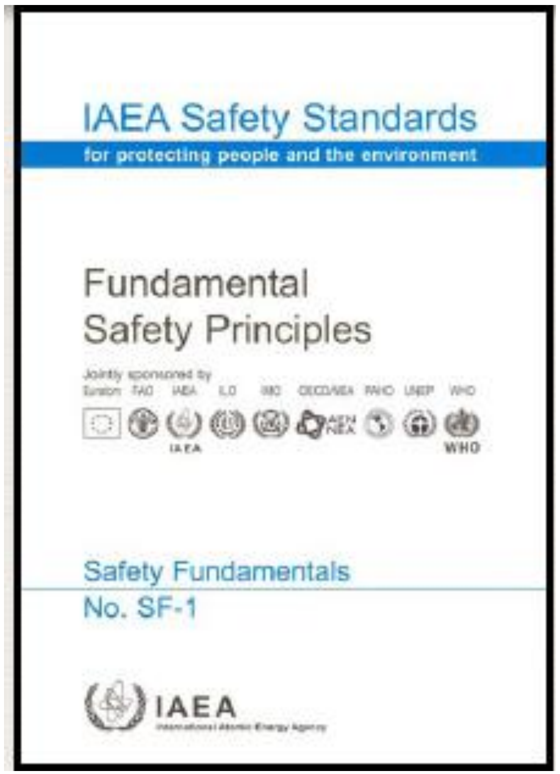
Traditional ROI	Economic
Rock	•Price per processed tonne
Chemical Processing	•DAP/ MAP – spot and futures
Agriculture **•Food** **•Feed**	•Yield per ha •Nutrient conversion
Waste	•Lost land use •Unused PG •Unrecovered uranium •Pollution •Externality
Profit / (Loss)	

Sustainable ROI	Economic	Social	Environmental	TBL Rating
Rock	•Global reserves •BPL value/ grade •Cost per tonne rock •Beneficiation cost	•Jobs	•Lost productive land •Disturbance	
Chemical Processing	•Efficient P recovery •Inputs and emissions	•Jobs	•Acidic water discharges •Fluorides •Atmospheric discharges of ammonia and sulphur compounds •Radionuclides •Heavy Metals •Residue piles/ PG	
Co-Product **•U recovery** **•PG**	•Nuclear fuel source •Market for PG in agriculture and construction	•Jobs •Aids energy security	•Reduced U in fertiliser •Sodic soils reclaimed to productive condition	
Agriculture **•Food** **•Feed**	•Soil fertility •Crop yield •Protein – body mass	•Jobs •Food security •Risk of conflict on land use (food vs energy)	•Pollution of water bodies due to improper application techniques and runoff	
Recycling	•Slows depletion of reserves •Cost of P recovery from waste streams vs value of P recovered	•Jobs •Social sustainability	•Resource conservation	
Land Reclamation	•Real estate	•Jobs •Increased tax base •Amenities\ recreational land	•Habitat favoured by endangered species	
Waste	•Cost/mass or volume for treatment •Cost/mass or volume for handling/shipping •Cost for vendor disposal	•Jobs	•Pollution from improperly discharged or contained waste	
TBLScore				

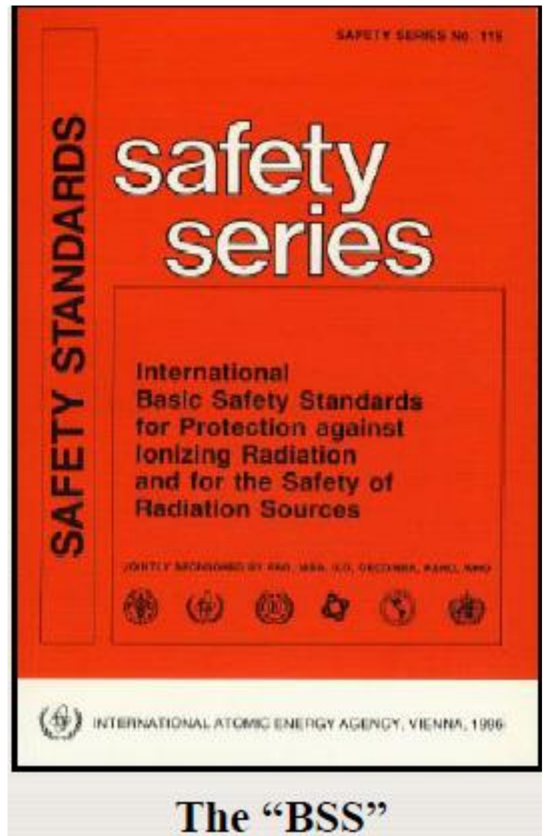

Well according to this excellent Safety Report it is... And it keeps you young too...


And is it safe?

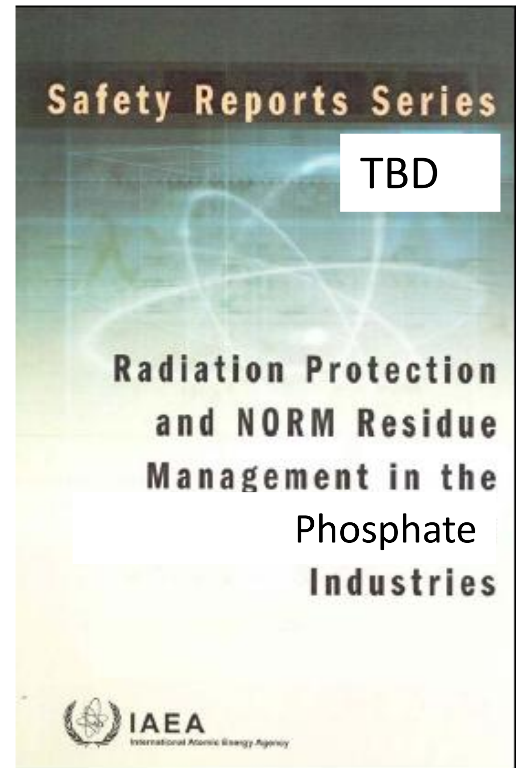
Safety: International Standards and Studies



2006



2011 – Revised BSS



2011 (expected)

Safety – National Examples: Benchmark Cases – 1999 onwards

SPAIN – AGRICULTURE, ENVIRONMENTAL IMPACT, EVIDENCE-BASED REGULATION

BRAZIL – AGRICULTURE, EXPERIMENTAL RANGE, LANDFILL

CHINA – CONSTRUCTION (MATERIALS)

FINLAND – FREEZE-THAW ROADS (WITH FLY ASH)

KAZAKHSTAN – AGRICULTURE, REMEDIATION, MARKET

SOUTH AFRICA – ROADS, HOUSING, EVIDENCE-BASED REGULATION

SYRIA - AGRICULTURAL WATER MANAGEMENT

TUNISIA – DISCHARGE TO USE, FULL REMEDIATION

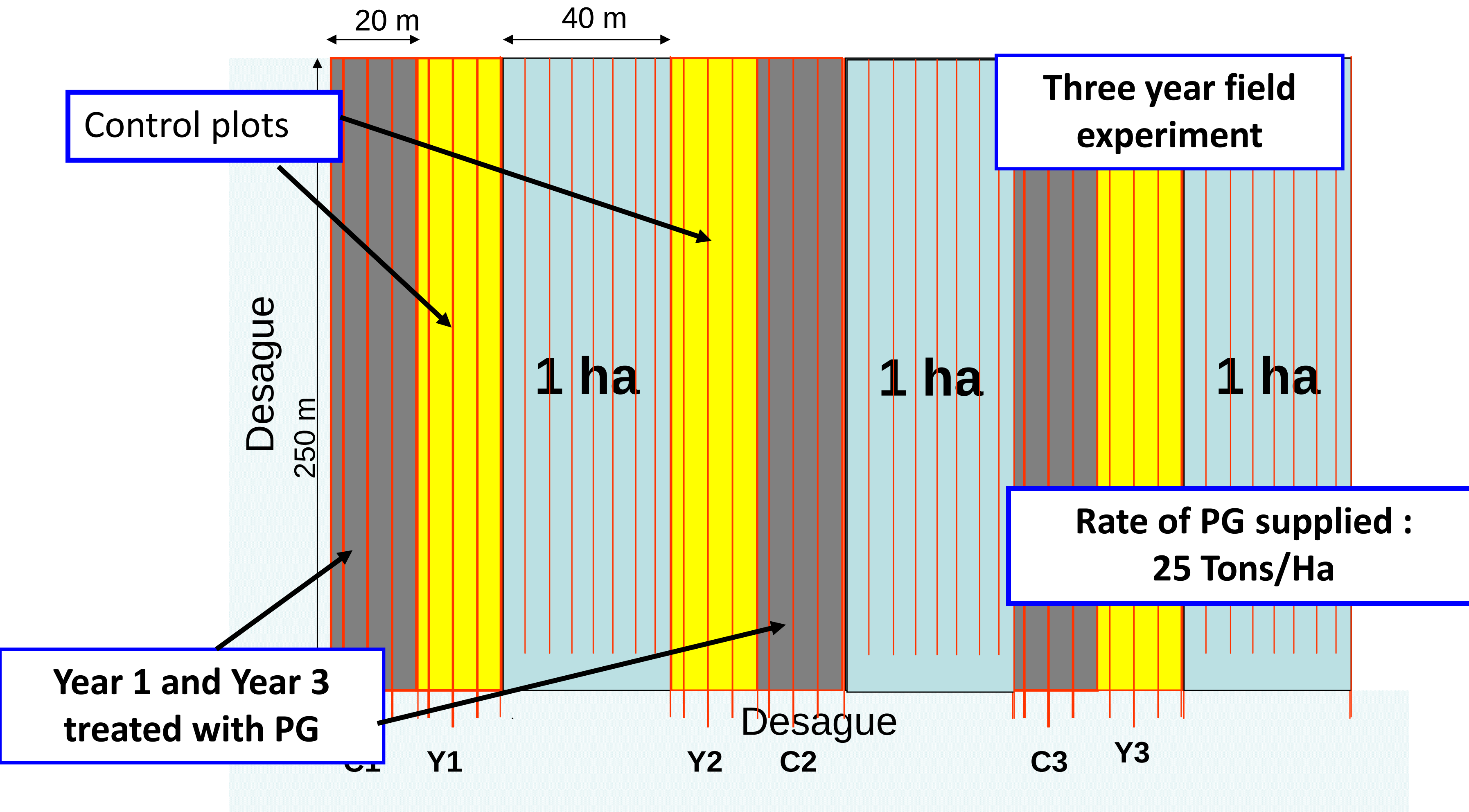
UNITED STATES – FULL LIFE-CYCLE STUDY, PARRISH ROAD

The Phosphate Manufacturing Complex of Huelva, Spain, including Phosphogypsum Stacks

The Agricultural Area Reclaimed and then Treated with PG in SW Spain

PG over 70 years of use in Huelva, Spain

The short-term radiological impact associated to the use of PG as soil amendement (I)



The short-term radiological impact associated to the use of PG as soil amendement (II)

Treatment	Number of samples	Depth cm	^{226}Ra (Bq/kg)	^{238}U (Bq/kg)	^{212}Pb (Bq/kg)	^{137}Cs (Bq/kg)	^{40}K (Bq/kg)
Control	**3**	**0 – 30**	**35.3 ± 0.8**	**25.3 ± 0.4**	**33.1 ± 0.7**	**2.8 ± 0.6**	**767 ± 20**
Control	**3**	**30 – 60**	**27.7 ± 0.4**	**23.5 ± 0.5**	**32.3 ± 1.0**	**0.9 ± 0.5**	**760 ± 50**
Control	**3**	**60 – 90**	**26.2 ± 0.7**	**19.4 ± 1.0**	**31.9 ± 0.7**	**N.D.**	**750 ± 20**
PG 25 Tons/Ha	**3**	**0 – 30**	**39.3 ± 2.3**	**23.9 ± 1.0**	**32.2 ± 1.0**	**2.3 ± 1.0**	**789 ± 27**
PG 25 Tons/Ha	**3**	**30 – 60**	**29.6 ± 1.8**	**25.2 ± 2.1**	**32.8 ± 0.4**	**1.0 ± 0.2**	**814 ± 11**
PG 25 Tons/Ha	**3**	**60 - 90**	**24.0 ± 0.9**	**21.7 ± 2.6**	**32.3 ± 1.0**	**N.D.**	**780 ± 50**

-No statistical differences between control and PG treated plots

-Hig

- Ra-226/U-238 activity ratios higher than one in all the plots

NO SHORT-TERM RADIOLOGICAL IMPACT

Case Study: Brazil

Agriculture

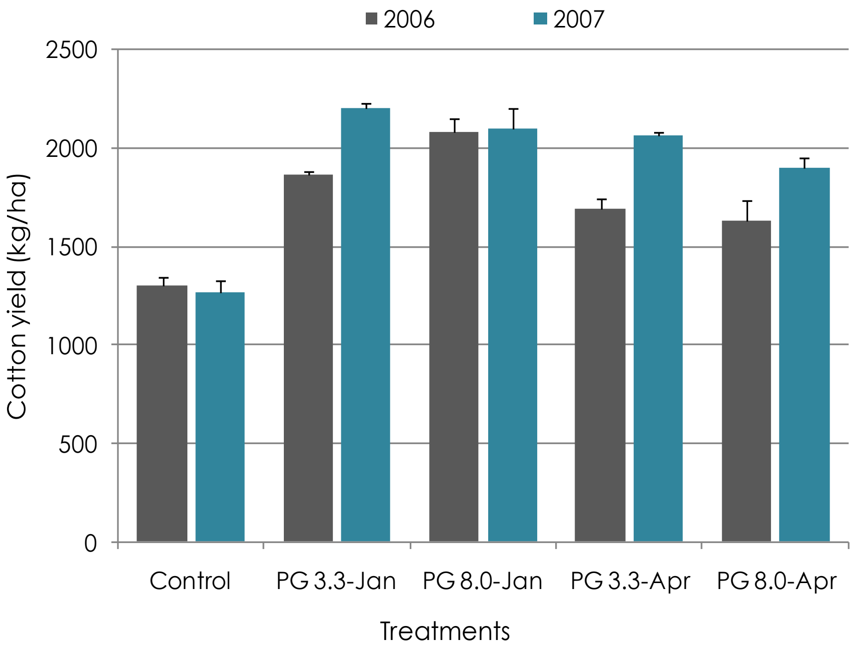
- Extensive annual use
- c.40% of PG produced is used in agriculture

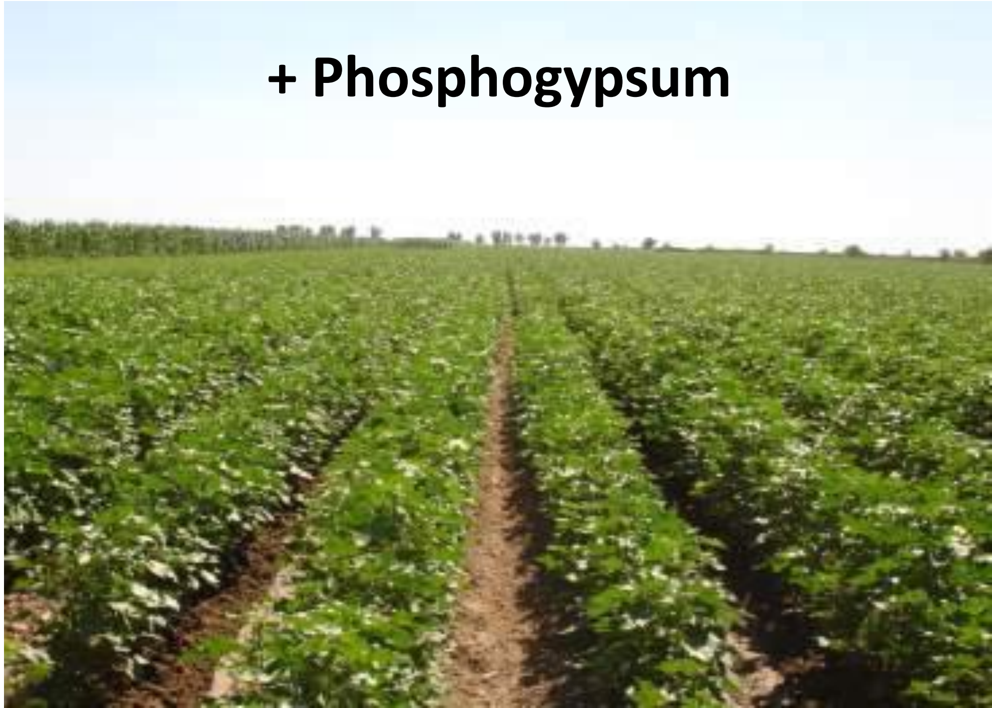
China: PG Use in Construction Wengfu Group's Demonstration Project

Innovative wall structure using PG

Kazakhstan

Cotton Growth and Yield





South Africa: Radiological content and dose assessment of PG

Source	Total annual effective dose to the critical group due to the application of Phosphogypsum in the agricultural sector. (mSv/a) (modelled)				
	o to 2 years	2 to 7 years	7 to 12 years	12 to 17 years	Adults
Phosphogypsum in Agriculture	0.0066	0.0047	0.0056	0.0086	0.0031
Road Construction	**Total annual effective dose to the members of the public and workers due to the application of Phosphogypsum in the Road construction (mSv/a)**				
				0.0046 (residents)	0.0063 (workers)
Cement production	**Total annual effective dose to the workers during the mining and processing of Phosphogypsum for Cement additives (mSv/a)**				
					0.46

South Africa: Regulator's Conclusions

- The economic advantages of PG has made its use to grow rapidly in the past few years (Applications).
- Radiological assessment to the members of the public is shown to be less than 1 mSv/a from identified pathways.
- Material can be exempted from regulatory control if that fulfills the criteria in Section 2.1.1.1 (b) of SSRP Regulation R388 which is explicit about Radon.

Syria: ICARDA Case Study, 2001-2005

- Treatments
  - Control (without application of phosphogypsum)
  - Soil application of phosphogypsum at 20 t/ha
  - Soil application of phosphogypsum at 40 t/ha
- Phosphogypsum application once at the beginning of the study
- Other farm-level practices were same in all treatments
- Multi-location trails on 8 sites

Syria, Major Results: Crop Yield and Water Productivity

- Significant increase in barley grain yield in phosphogypsum treatments; 40 and 49% increase in 20 and 40 t/ha treatments over control
- Significant increase in rain-water productivity in the phosphogypsum treatments
- Increase in soil moisture storage was the driving factor for crop yield and water productivity enhancement.

TUNISIA: PHOSPHOGYPSUM VALORIZATION

Construction of two rooms in scale (4 x 4 m^2) with:

1. ordinary cooked bricks
2. bricks containing phosphogypsum.

Installation of 22 radon dosimeters per room

and spatial and temporal monitoring of radiation during 72 days along two periods of summer and winter.

TUNISIA: TAPARURA – Stack to Beach...

UNITED STATES: A New Case

- At least one PG road (Parrish Road, Polk County) has been used long enough to undergo repaving
- One section of 3 test sections had failed
- The rest of the road was still fully functional
- The entire road was repaved, but the base was left in place

PG Road Base

- In mid cost range (materials)
- Strengthens over time (5-7% cement mix)
- Excellent life-cycle cost performance
- Environmentally safe
- Conserves up to 60% of virgin resource


PG
Joint between
Phosphogypsum and
Conventional Bed
Conventional

Environmental monitoring since 1992 – radionuclides and heavy metals

US EPA (1)

- PG was in active but informal commerce in US up to 1989, the year of the PG Rule
- Eg California $25 per short ton, FOB; still active demand from farmers. Good in sodic and sodic/saline soils; excellent for enhancing water efficiency/ irrigation
- Still in use in N Florida/ S Georgia for peanuts

US EPA (2)

- Approach is inconsistent in that PG is variously defined in the Rule as by-product, waste and toxic waste (of no commercial value)
- But uses in agriculture are specifically allowed
- Activity concentration threshold at the restrictive end of modern practice (typically 1 Bq/g) – EPA says 0.37 (= 10 picocuries/g)
- Obstacles to use are significant, especially the very onerous and costly application procedure
- But… there are some signs of accommodation

US EPA (3)

- Attended the IAEA PG TM, September 2010
- Accepted that the body of new scientific evidence is very significant
- Considering playing an active part in the 2011-2014 Action Plan
- EPA “blight” well illustrated by country with PG at 0.44Bq/g trying to devise a method to get below 0.37 (10 picocurie per gram)
- If that country followed BSS (as it should as an IAEA MS) it would not need that effort at all…

Goals of the Action Plan, 2011-2014

- A structured plan for using the entire present and future production of PG, supported by countries and international agencies
- New point of equilibrium – use as much as we produce
- Preliminary calculations indicate this is feasible focused on agricultural uses – crops, remediation, forage and irrigation/ water management – and construction including roads

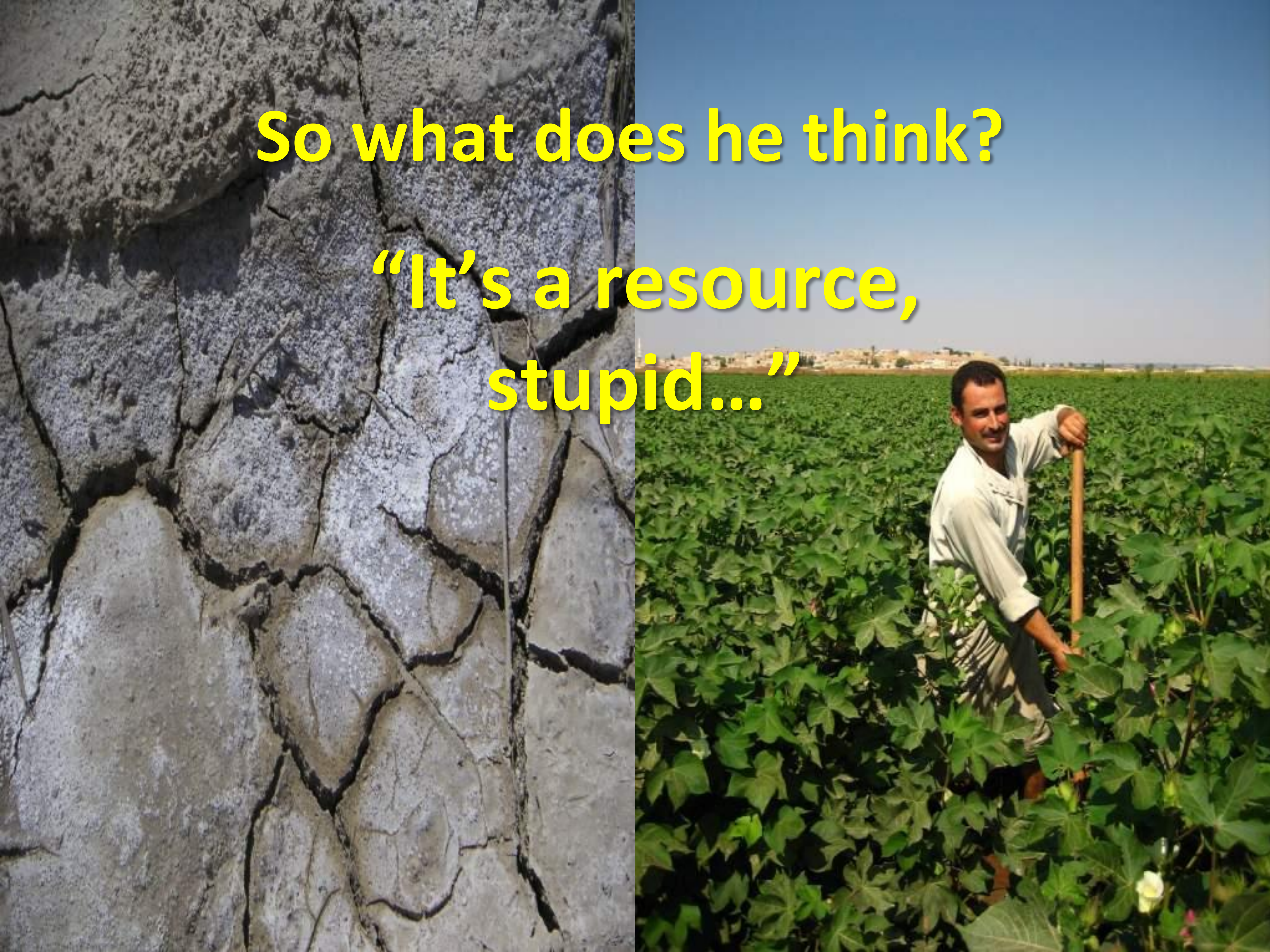
Summary: From R&D to Implementation

1. Evidence-based approach, using a vast technical and scientific knowledge base as well as expertise and very well documented Case Studies
   1. Agriculture - over 50 crops studied; generally safe assuming on-label use, with focus on Huelva, Brazil, Kazakhstan and Syria, alluding also to US –
   2. Roads - number of case studies, general usability, resource conservation, aggregate shortages, environmental impact - options for US –
   3. Construction - resurgence in interest eg for low cost housing China, India, S Africa, Senegal,
   4. Landfill - Brazil WIP
   5. Coastal and marine - obvious option for US,
2. Sustainability and resource conservation – themes (and hence encouragement) new BSS and Euratom BSS to encourage recycling and reuse...
3. Ongoing work plan recent meeting in Vienna, agreed Action Plan for 2011-2014, industry welcome to participate...
   1. Attended by USEPA

PGWG: At FIPR, 2007 and IAEA, 2010

PGWG, First meeting: FIPR 2007 - R&D: mapping safe, beneficial uses of PG. Outcome, Gap Analysis.

Meeting 2, 2010 - IAEA TM: Dialog between industry, academia (CoE) and regulators. Outcome, Action Plan 2011-2014 focused on PG use.


So what does he think?
"It's a resource,
stupid…"

AleffGroup

We're a resource too…

Thank You!

Jhilton@aleffgroup.com