ELICITING HEALTH AND SAFETY HAZARD SCENARIOS AND ASSESSING DERMAL EXPOSURE RISK AMONG WORKERS RELATED TO MARCELLUS SHALE HYDRAULIC FRACTURING ACTIVITY

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INTRODUCTION

- Drexel College of Engineering - Department of Civil, Architectural, and Environmental Engineering

- The hydraulic fracturing techniques used commonly today are relatively new and the health and safety risks associated with the processes are under-investigated

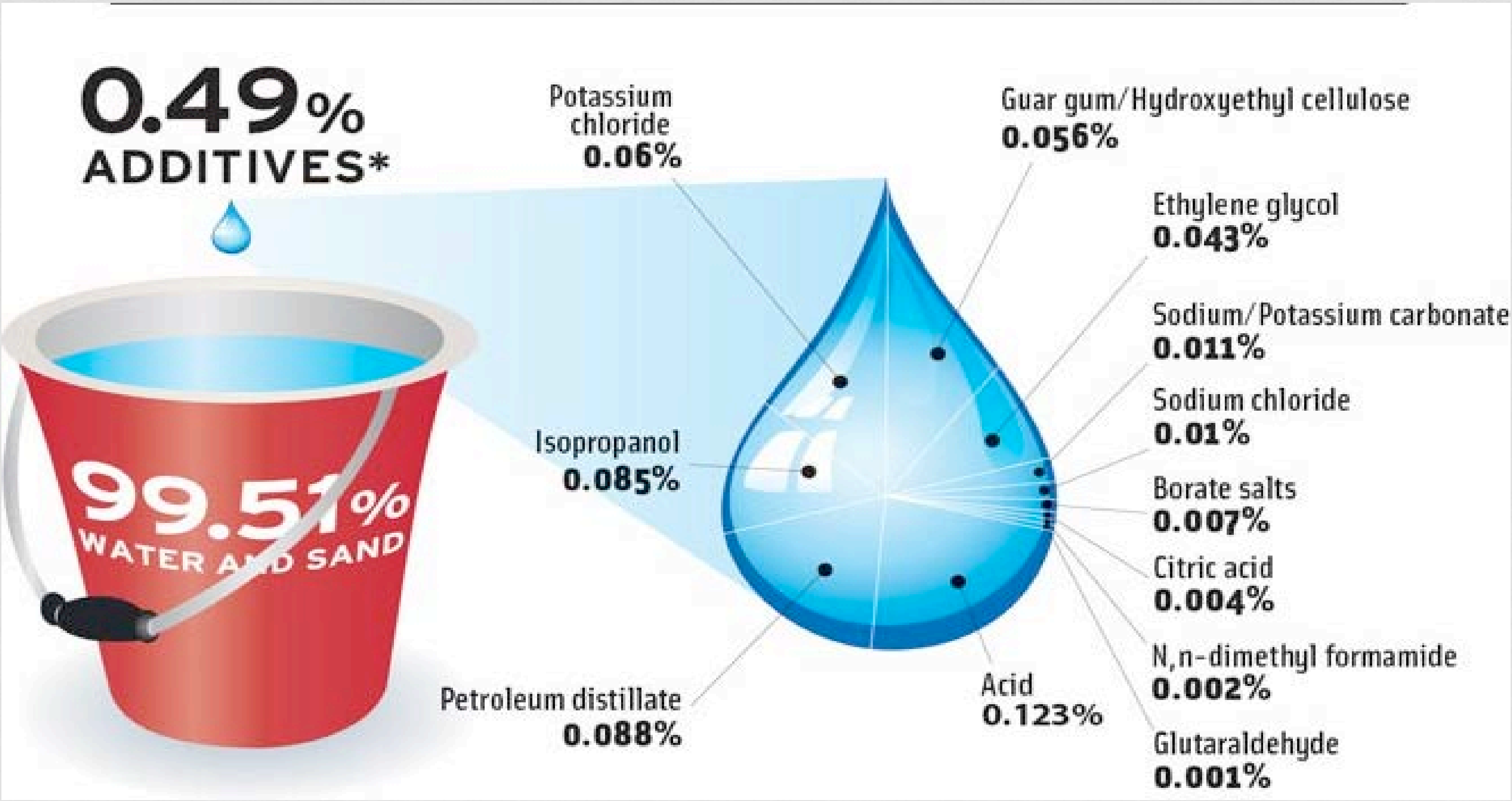
- This CBMP addresses:
  - The lack of knowledge concerning specific hazard scenarios that can result in direct exposure to hydraulic fracturing fluid or flowback water
  - The health risk related to dermal exposure to flowback water

BACKGROUND

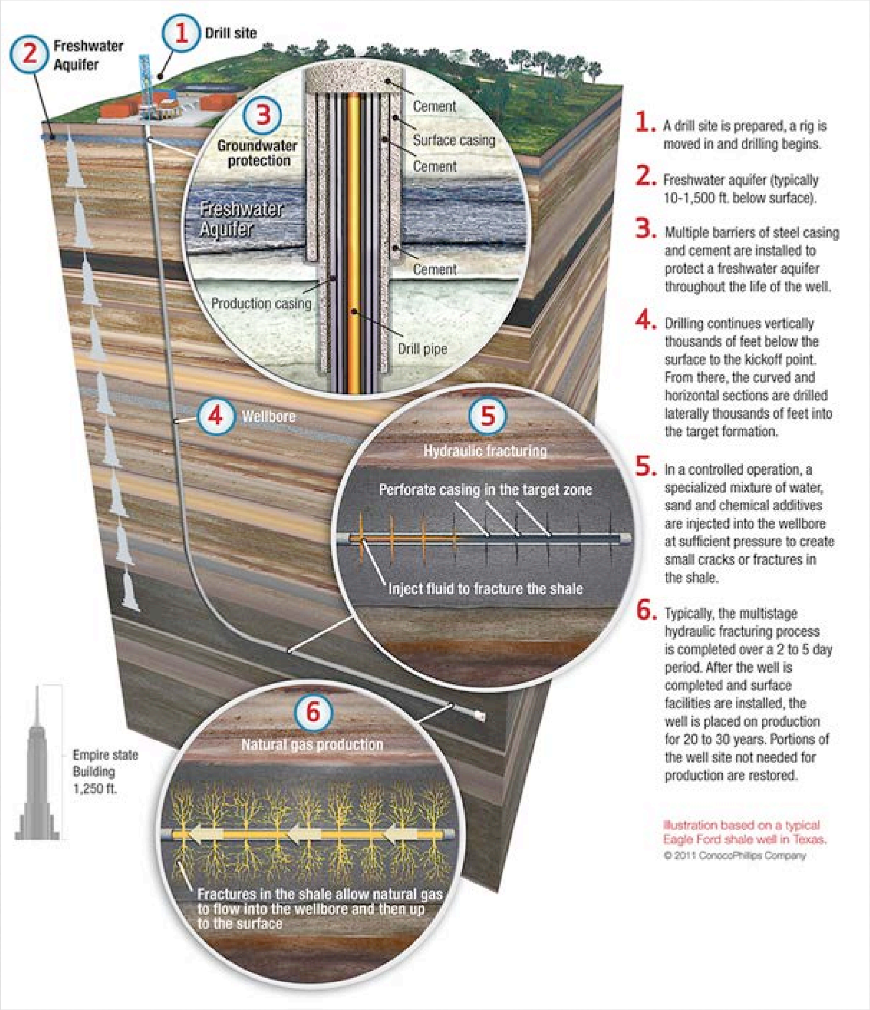
- Hydraulic fracturing - a well stimulation technique used in the production of natural gas
- Recent advances in drilling techniques and hydraulic fracturing fluid production
  - “Slickwater”- a combination of water, sand, and chemicals
- Flowback and produced water

BACKGROUND

Hydraulic Fracturing Fluid Composition



BACKGROUND



Horizontal Drilling and Hydraulic Fracturing

Image retrieved from http://http://www.powerincooperation.com/EN/Pages/drilling-and-completion.html

BACKGROUND

- Recent studies focus on environmental issues and workers' exposure to silica dust
  - Environmental impact studies
    - Groundwater contamination
    - Air pollution
  - National Institute for Occupational Safety and Health (NIOSH) field study, "NIOSH Field Effort to Assess Chemical Exposure Risks to Gas and Oil Workers,"
    - Focused heavily (if not exclusively) on air sampling
    - Found that workers may be exposed to high levels of respirable crystalline silica

BACKGROUND

- Resources for the Future's Center for Energy Economics and Policy has generated a set of "impact pathways" that link shale gas development to their potential ecological impacts.

Activity	Intermediate Impacts					
	Groundwater	**Surface Water**	**Soil Quality**	**Air Quality**	**Habitat Disruption**	**Community Disruption**
Drilling equipment operation at surface	Drilling fluids/cuttings	Drilling fluids/cuttings	Drilling fluids/cuttings	Conventional air pollutants and CO_2		Industrial landscape Light pollution Noise pollution
Drilling of vertical and lateral wellbore	Methane Drilling fluids/cuttings Intrusion of saline-formation water into fresh groundwater	Drilling fluids/cuttings		Methane		
Casing and cementing	Methane Drilling fluids/cuttings Intrusion of saline-formation water into fresh groundwater	Drilling fluids/cuttings	Drilling fluids/cuttings	Methane		

BACKGROUND

- Oil and Gas Act violations are more prevalent among Marcellus Shale hydraulic fracturing wells than among other conventional oil and gas wells (Volz, 2011)
  - Failure to properly store, transport, process, or dispose of a residual waste
  - Failures to adequately construct or maintain impoundments holding gas extraction flowback fluids containing toxic contaminants

BACKGROUND

- Conventional oil and gas well drilling and hydraulic fracturing share much of the same equipment and techniques.

- OSHA's eTool for conventional oil and gas well drilling and servicing.
  - Identifies common hazards and possible solutions to reduce incidents that could lead to injuries or fatalities among workers.

BACKGROUND

- EPA's Mid-Atlantic Region requested disclosure of flowback and produced water - contents and disposal methods

Images retrieved from: http://www.dragonproductsltd.com (left), http://www.marcellus-shale.us/MARCELLUS-AIR-III.htm (right)

BACKGROUND

Fluid Operator, Hydraulic Fracturing Team, Eagle Ford Shale Area. Laredo, Texas. 2012. Image retrieved from http://goldmanpictures.com/blog/?p=613

SPECIFIC AIMS

- Elicit the possible health and safety hazard scenarios at drilling sites that lead to dermal exposure of workers to fracking fluid and flowback water
- Develop a survey instrument to further evaluate scenarios
- Conduct a dermal exposure risk assessment for workers at hydraulic fracturing sites

METHODS

- Conduct preliminary interviews
  - Elicit health and safety hazard scenarios
  - Subjects include regulatory and industry experts
- Create survey instrument
  - Further evaluate scenarios
  - Based on interview responses
- Estimate cancer risk following dermal exposure to carcinogenic agents in flowback water
- Create Marcellus Shale Flowback Constituents Data Set
  - Compile EPA data into spreadsheet ≈ 23,000 entries

METHODS

- Interviews
  - Interviewed a Frac Field Engineer and an Environmental, Safety, and Health Coordinator from Range Resources

Activity	Potential Failures Associated with Activity	Nature of Exposure/Injury	What is done to prevent failure/protect human health & safety?	What could be improved to prevent failure/protect human health & safety?
FRACTURING AND COMPLETION:				
Perforation of well casing/cementing				
Hydraulic fracture initiation				
Introduction of proppant				
Flushing of wellbore				
Storage of fracturing fluids at drill site				

METHODS

- Survey Instrument
  - Developed using interview responses and OSHA's eTool for oil and gas well drilling to identify scenarios that are most hazardous to worker health and safety and most likely to lead to dermal exposure to frac fluid and flowback water
  - Respondents rank attributes of each scenario on a 1-5 scale. Attributes include:
    - Frequency
    - Severity
    - Incentive to ignore failure prevention control measures
    - Likelihood to result in dermal exposure to hydraulic fracturing fluid and/or flowback water

METHODS

- Marcellus Shale Flowback Constituents Data Set
  - Major PA operators
    - Atlas Resources
    - Cabot Gas & Oil Corp.
    - Chesapeake Energy
    - Range Resources- Appalachia
    - SWEPI
    - Talisman Energy USA
  - Currently organizing and running summary statistics on data

METHODS

- Dermal Exposure Risk Estimate

Cancer Risk following Dermal Exposure = DAD x SF_{ABS}

Where:

- DAD = Dermally Absorbed Dose (mg/kg-day)
- SF_{ABS} = Absorbed cancer slope factor $(mg/kg\text{-}day)^{-1}$

METHODS

$$DAD = \frac{DA_{event} \times EV \times ED \times EF \times SA}{BW \times AT}$$

Where:

- DAD = Dermally Absorbed Dose (mg/kg-day)
- DA_{event} = Absorbed dose per event (mg/cm^2-event)
- SA = Skin surface area available for contact (cm^2)
- EV = Event frequency (events/day)
- EF = Exposure frequency (days/year)
- ED = Exposure duration (years)
- BW = Body weight (kg)
- AT = Averaging time (days)

METHODS

$$DA_{event} = 2FA \times K_P \times C_W \sqrt{([6\tau_{event} \times t_{event}] / \pi)}$$

Where:

- DA_{event} = Absorbed dose per event (mg/cm^2-event)
- FA = Fraction absorbed water (dimensionless)
- K_p = Dermal permeability coefficient of compound in water (cm/hr)
- C_w = Chemical concentration in water (mg/cm^3)
- τ_{event} = Lag time per event (hr/event)
- t_{event} = Event duration (hr/event)

METHODS

$$SF_{ABS} = SF_O / ABS_{GI}$$

- Where:
  - SF_{ABS} = Absorbed slope factor
  - SF_O = Oral slope factor $(mg/kg\text{-}day)^{-1}$
  - ABS_{GI} = Fraction of contaminant absorbed in gastrointestinal tract (dimensionless) in the critical toxicity study

METHODS

Sample Dermal Cancer Risk Estimate for Benzene Exposure (30-second event duration/Few drops exposure):

$SF_{ABS} = SF_{O} / ABS_{GI} = 5.5E\text{-}02 / 1 = 5.5E\text{-}02$

If $t_{event} \leq t^{*}$, *then:* $DA_{event} = 2FA \times K_{P} \times C_{W} \sqrt{([6\tau_{event} \times t_{event}] / \pi)}$

$= 2(1) \times 1.5E\text{-}02 \times 1.95E\text{-}03 \sqrt{([6(0.292) \times 8.3E\text{-}03] / \pi)} = 3.98E\text{-}06$

$DAD = (DA_{event} \times EV \times ED \times EF \times SA) / (BW \times AT)$

$= (3.98E\text{-}06 \times 1 \times 10 \times 52 \times 448) / (70 \times [70 \times 365]) = 5.18E\text{-}07$

$\text{Dermal Cancer Risk} = DAD \times SF_{ABS} = 4.68E\text{-}04 \times 5.5E\text{-}02 =$ 2.8E-08

RESULTS

- Preliminary interview:
  - The following worker health and safety hazard scenarios were identified:

- WELL PAD LINER FAILURE - Frac fluid spills due to leak before use, flows off liner
- WELL PAD LINER FAILURE - Liner not watertight/constructed improperly
- PUMP FAILURE - Poor/infrequent inspections
- SURFACE PIPE FAILURE - Poor/infrequent inspections
- SURFACE PIPE FAILURE - Adverse weather events/natural disasters
- SURFACE DETONATION OF PERFORATION CHARGES
- FAILURE TO ESTIMATE/MAINTAIN PROPER PRESSURE AT START OF PRODUCTION FLOW
- COMPLETION FAILURE IN SUBSURFACE (e.g. Liner/Casing Failure) - Poor engineering
- COMPLETION FAILURE IN SUBSURFACE (e.g. Liner/Casing Failure) - Adverse weather events/natural disasters
- FLOWBACK SPILLS - Due to leaks in equipment/piping
- FLOWBACK SPILLS - During loading to transport offsite, flows off well pad liner
- FAILURE OF FLUID IMPOUNDMENT - Holding basin overflows due to excess precipitation
- FAILURE OF FLUID IMPOUNDMENT - Holding basin not watertight
- SAFETY PROCEDURE FAILURE - Poor or improper use of safety equipment and/or PPE

RESULTS

- Survey Instrument
  - Respondents rank the attribute of each health and safety hazard scenario identified through interviews
  - Survey also asks about dermal exposure during routine activities – frequency, amount, duration, etc.
  - Intended respondents include industry experts and regulatory experts

Shale Gas Development (Hydraulic Fracturing) Workplace Hazard Scenarios Survey

Page 2 of 2

5. Please rate the attribute of each scenario on a 1-5 scale (1 being no concern, 5 being highest concern), with regards to worker health and safety.

	Severity	Frequency	Incentive to Ignore Failure Prevention Control Measures	Gaps in Controls/Difficulty in Implementing Failure Prevention Control Measures	Public Concern	Overall Concern with the Scenario	Likelihood to Result in Worker Skin Exposure to Hydraulic Fracturing Fluid and/or Flow-Back Water	Has This Event Ever Happened?
PUMP FAILURE - Poor/infrequent inspections								
SURFACE PIPE FAILURE - Poor/infrequent inspections								
SURFACE PIPE FAILURE - Adverse weather events/natural disasters								
SURFACE DETONATION OF PERFORATION CHARGES								

RESULTS

- Cancer Risk following dermal exposure to flowback

	Event Duration: **30 seconds** Exposure Amount: **Few drops**	Event Duration: **30 seconds** Exposure Amount: **Full hand**	Event Duration: **3 hours** Exposure Amount: **Few drops**	Event Duration: **3 hours** Exposure Amount: **Full hand**
Benzene	3E-09	3E-08	3E-03	3E-02
Bromoform	4E-12	4E-11	7E-11	7E-10
DEHP	2E-10	2E-09	3E-09	3E-07

CONCLUSION

- This project contributes to the research effort needed to fill a void that currently exists in oil and gas worker health and safety
  - May serve to inform worker health and safety regulations and industry practices
- It is possible that worker dermal exposure to hydraulic fracturing fluid and flowback water could occur during the identified scenarios
- The survey instrument will be able to provide more details about dermal exposures and other worker health and safety hazard scenarios
- Dermal exposure to carcinogens in flowback water increases cancer risk
- Regulations to prevent worker exposure to hydraulic fracturing fluid and flowback water should be strictly enforced

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