Occupational Cancer Research Centre

Lesson Learned from the Ontario Uranium Miners …. *still?*

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22-Jan-2016

Towards a cancer-free workplace

Disclosure

Presenter: Minh T Do

I have no conflicts of interest to disclose.

The views and opinions expressed are those of the author and do not necessarily reflect the official policy or position of the OCRC.

Acknowledgements

Loraine Marrett, James Purdham, Wendy Lou, and Jennifer Payne

and

Garthika Navaranjan, Colin Berriault, Paul Villeneuve,

Paul Demers

Funding Support: CIHR, WSIB, and CNSC

Outline

- Ontario Uranium Miners
- Lesson Learned
- Lesson to be learned
  - External radiation (Gamma) example
- Future directions

Who are the Ontario Uranium Miners?

- Generally Males
- Age at first exposure (~ 28 yrs)
- Duration of employment (3 yrs)

Source:
Permission from Elliot Lake Nuclear and Mining Museum

Denison Mines (SMDR# 000107)

ONTARIO MINISTRY OF NATURAL RESOURCES, DIVISION OF MINES
SOURCE MINERAL DEPOSIT RECORD

MAIN COMMODITY: U | DEPOSIT NAME: Denison | DOCUMENT NO.: SMDR 000107 | PAGE 4 OF 4

PRODUCTION RECORD BY YEARS: (For metal deposits give units of each metal produced, value of each metal, total value of metals recovered, tons of ore milled, average recovery grade and average recovery value if available, operating cost per ton milled, yearly operating profit before write offs, net yearly profit, dividends. Where possible obtain this information from reports of the company or the DOM statistical files.)

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1958	1,861,799	5101	2.46		4,239,761	4,212,677	42,042,514			42,042,514
1959	2,046,250	5672	2.56		4,916,108	4,925,655	49,552,089			
1960	2,013,846	5787	2.70		4,911,761	3,060,505	32,047,137			32,047,137
1957-60	6,534,806			2.35	15,421,577					
1961	2,033,483	5827	2.85		5,379,168	4,065,631	39,732,485			39,732,485
1962	1,828,993	5680	2.88		4,844,259	4,069,482	39,791,162			39,791,162
1963	1,586,600	4444	3.34		5,078,760	4,395,215	36,344,601			36,344,601
1964	1,275,384	3573	3.14		3,950,364	6,193,920	27,031,841			27,031,841
1965	889,391	2624	2.93		2,561,164	3,570,996	16,319,154			16,319,154
1966	981,709		2.86		2,748,602	2,967,496	14,478,759			14,478,759
1967	1,219,461	3416	3.07		3,549,000	3,001,495	14,630,230	117,472	986,182	15,616,412
1968	1,315,650	3858	3.07		3,843,000	2,959,379	16,902,494	92,205	749,184	17,651,678
1969	1,237,229	3525	3.43		4,002,949		19,546,766	35,890	352,624	19,899,390
1970	1,178,392	3497	3.15		3,628,163	2,975,333				
1961-70	13,546,292			2.92	39,585,429					
1971	1,387,000	4140	3.20		4,256,000					
1972	1,454,000	4300	2.87		3,914,220					
1973	1,432,000	4287	2.57		3,424,000					
1974	1,290,000	3970	2.33		2,807,000					
1971-74	5,563,000			2.58	14,401,220					

Ontario Uranium Mines

ONTARIO URANIUM MINING REGIONS

ELLIOT LAKE URANIUM MINES

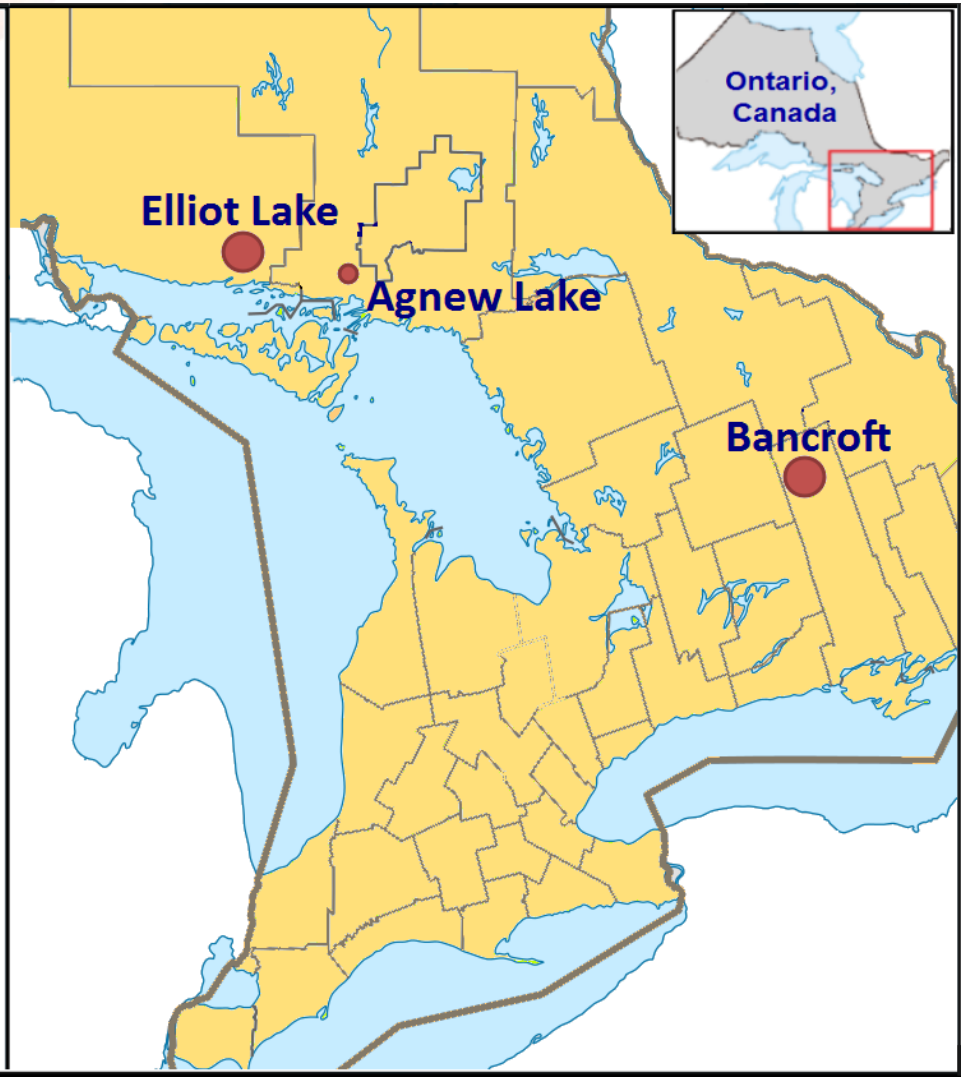
- Buckles
- Denison
- Can-Met
- Lacnor (Nordic Lake)
- Milliken
- Nordic
- Panel
- Pronto
- Quirke I (Old Quirke)
- Quirke II (New Quirke)
- Stanleigh
- Stanrock

AGNEW LAKE URANIUM MINE

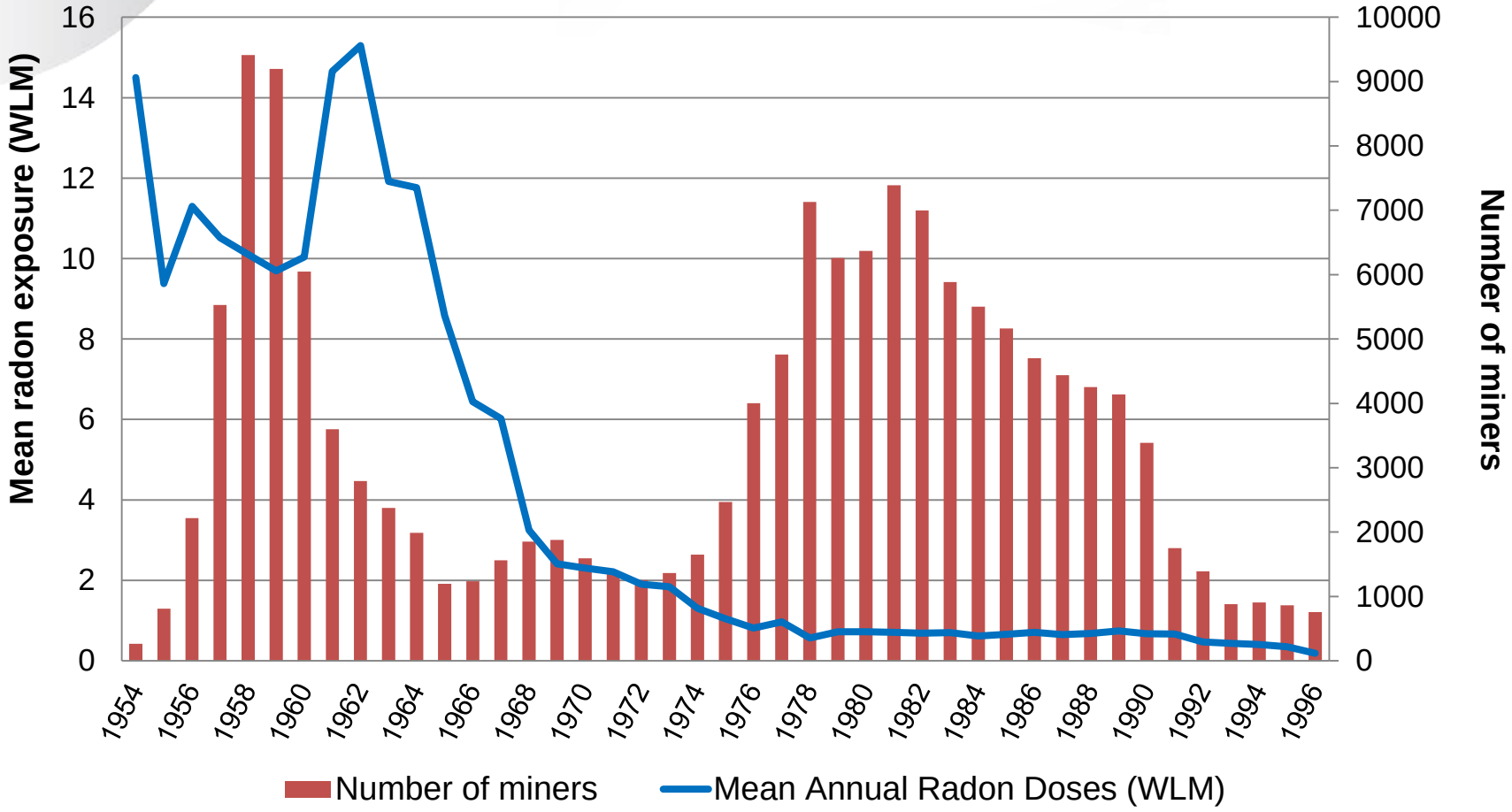
- Agnew Lake

BANCROFT URANIUM MINES

- Bicroft
- Blue Rock
- Canadian Dyno
- Cavendish
- Greyhawk
- Nu-Age
- Madawaska (Faraday)
- Tory-Hill

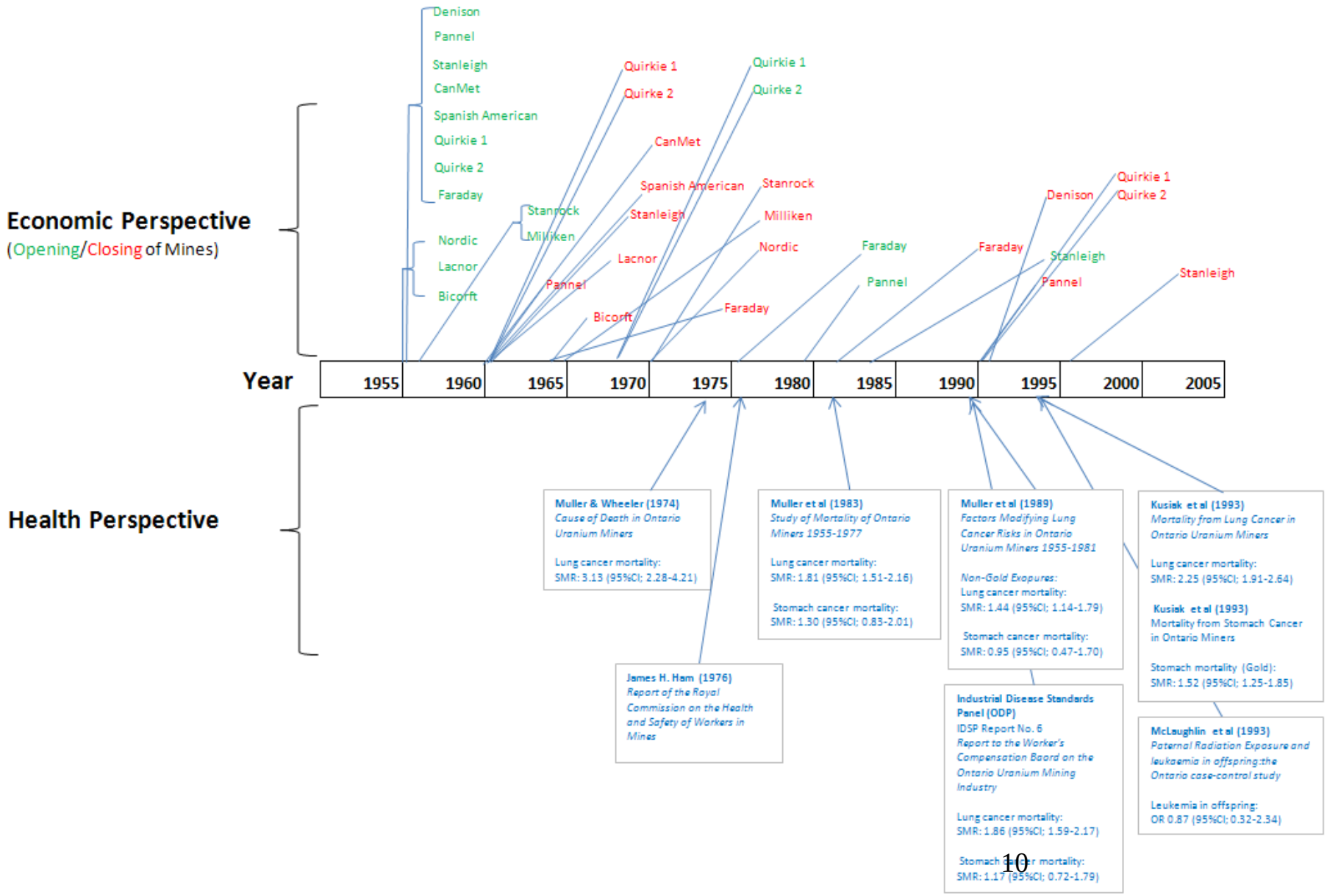


Average Annual Radon Exposure for Ontario Uranium Miners 1954-1996



Lessons Learned

Chronological Activities of Uranium Mining in Ontario

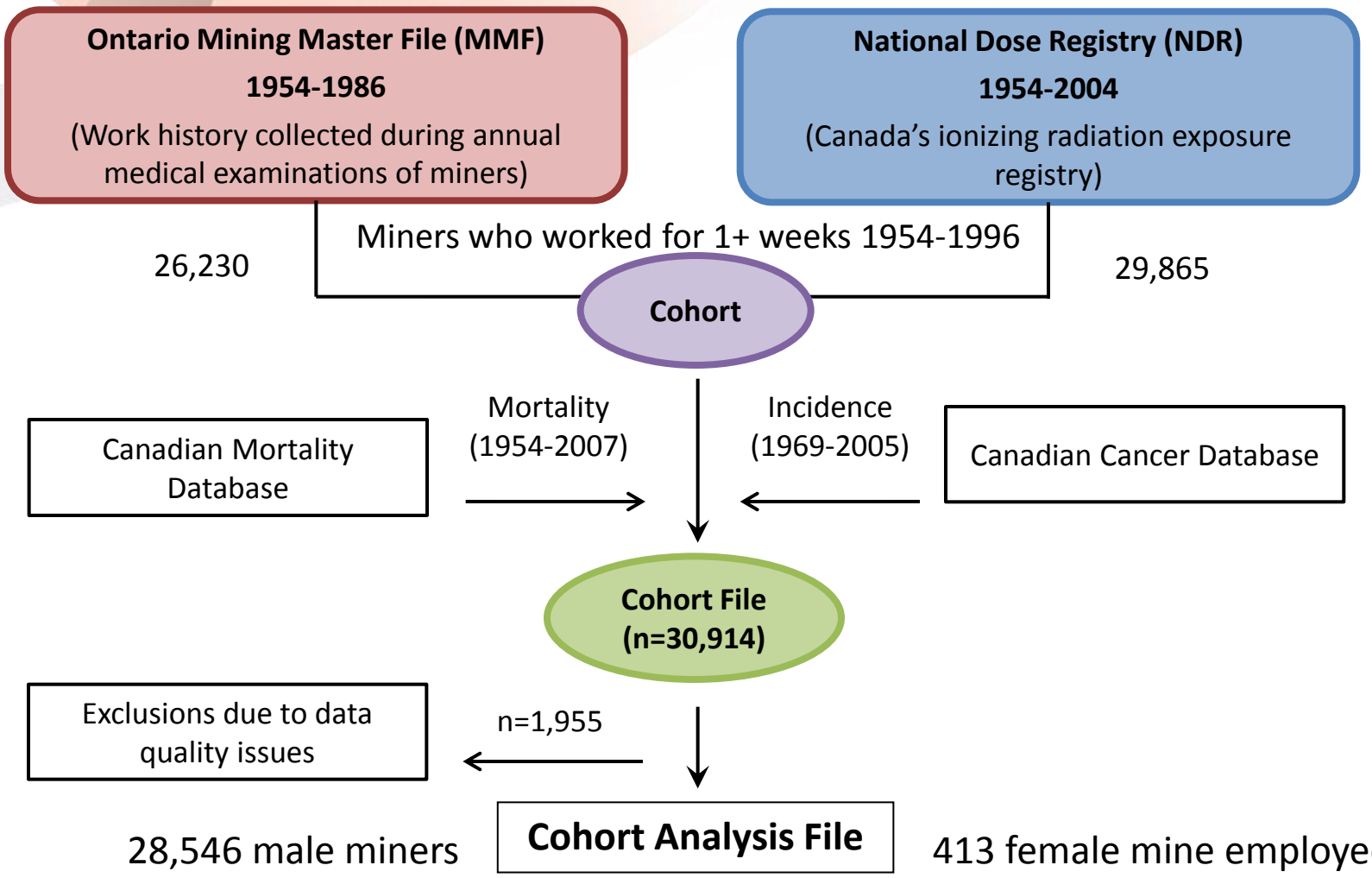


Overview of Previous Ontario Uranium Miner Cohort Studies

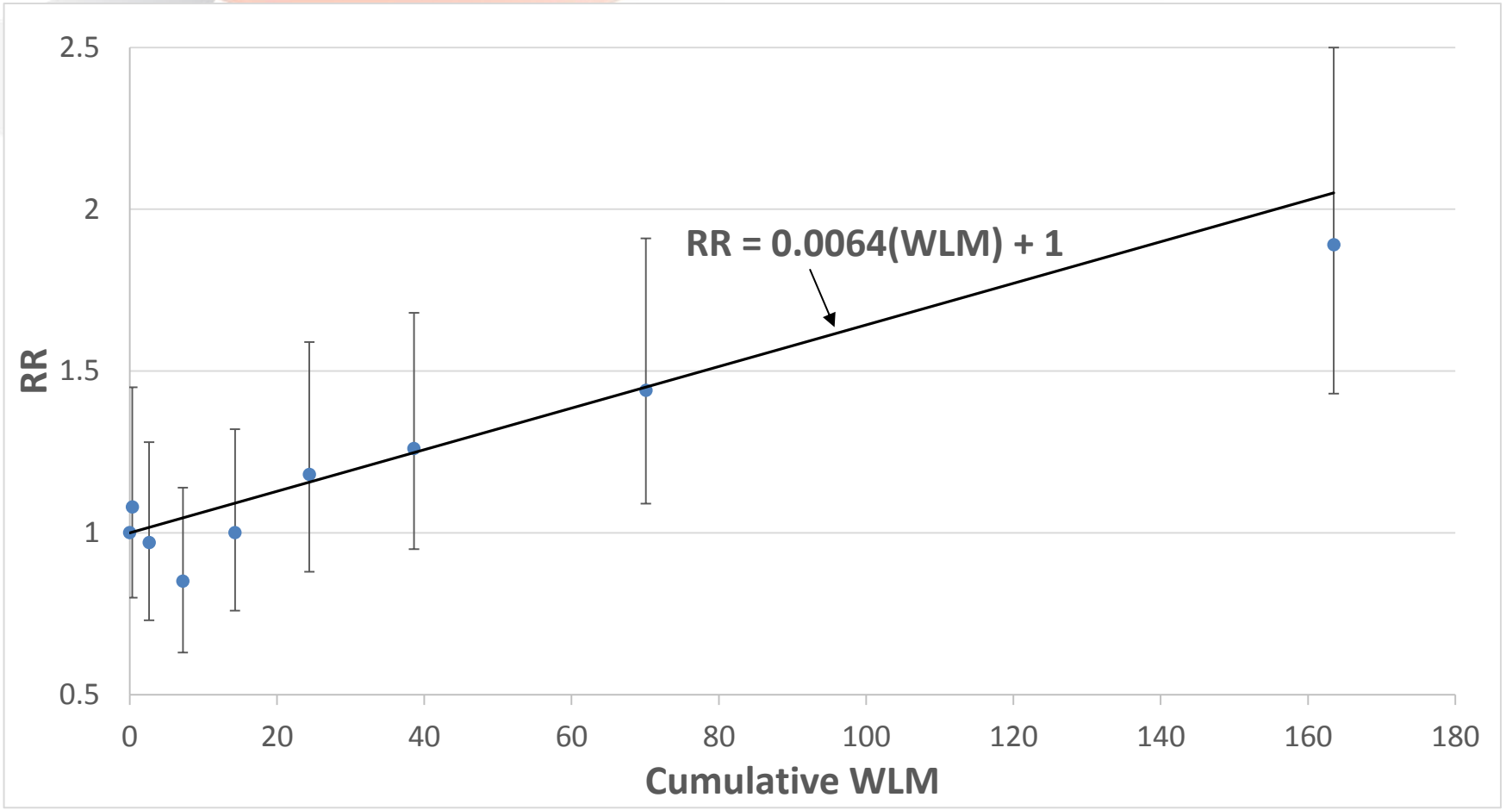
Study Reference	Follow-up period	Cohort size*	Lung cancer SMR	95% CI	Record Linkage
Muller et al., 1974	1955-1973	8,649	3.13	2.75-4.16	National
Ham, 1976	1955-1974	~18,000	1.80	1.43-2.23	Provincial
Muller et al., 1983	1955-1977	15,984	1.81	1.50-2.14	National
Muller et al. 1989	1955-1981	14,877	1.70	1.46-1.97	National
Kusiak et al., 1993	1955-1986	21,346	1.71	1.52-1.91	National
Do, et al., 2009	1954-2004	30,914	NA	NA	Provincial

SMR = Standardized Mortality Ratio, CI = Confidence Interval
*Cohort sizes differ due to varying inclusion criteria and follow-up periods
** Only stomach cancer examined

Ontario Uranium Miners Cohort
Most recent update (funded by CNSC)



Lung Cancer Incidence by Cumulative RDP Exposure: 1969-2005, 5-year lag



* Based on model using 1291 incident lung cancers

Inverse Dose-Rate Effect

Lifetime Cumulative WLM		Duration of Exposure (years)			
		<3	3-<5	5-<10	> 10
WLM: <5	Cases	293	37	13	0
	RR	1.00	1.16 (0.82-1.64)	0.75 (0.43-1.31)	-
WLM: 5-40	Cases	204	178	78	34
	RR	1.00	1.36 (1.11-1.66)	1.82 (1.40-2.37)	1.34 (0.92-1.95)
WLM: >40	Cases	10	70	181	132
	RR	1.00	1.21 (0.63-2.36)	1.50 (0.79-2.84)	2.46 (1.29-4.68)

Excess relative risk (ERR) of lung cancer mortality by time since last exposure: male miners, 5-year lag

Time since last exposure (years)	Lung cancer deaths	ERR/100 WLM	95% CI
<15	268	1.42	0.93-1.91
15-<25	274	0.87	0.49-1.25
25-<30	200	0.81	0.33-1.28
30-<40	275	0.12	(-0.13)-0.38
≥ 40	213	0.00006	(-0.32)-0.32

- Test for homogeneity of ERR/WLM: $p<0.001$

Main Conclusions

- Increased risk of lung cancer
- Strong evidence of lung cancer-radon dose response
- Inverse dose-rate effect observed
- Radon effects strongest for Squamous & small cell lung cancers

Lessons *to be* Learned

Bradford Hill Criteria
(Effects of Radon)

Criteria	Lung Cancer	Kidney Cancer	Stomach Cancer	Leukemia	CV diseases
Strength	Yes	Varies	Varies	Varies	Varies
Consistency	Yes	Varies	Varies	Varies	Varies
Temporality	Yes	Yes	Yes	Yes	Yes
Biological Gradient	Yes	Varies	Varies	Varies	Varies
Biological Plausibility	Yes	Yes	Yes	Yes	Yes
Others?					

What about …?

- Radon exposure and risk of cancers other than lung?
- Radon exposure and risk of non-cancer outcomes?
- Lung cancer risk at low exposure/exposure rates of radon?
- Health effects of other radiological exposures in uranium miners (e.g., gamma radiation)?

Gamma Example

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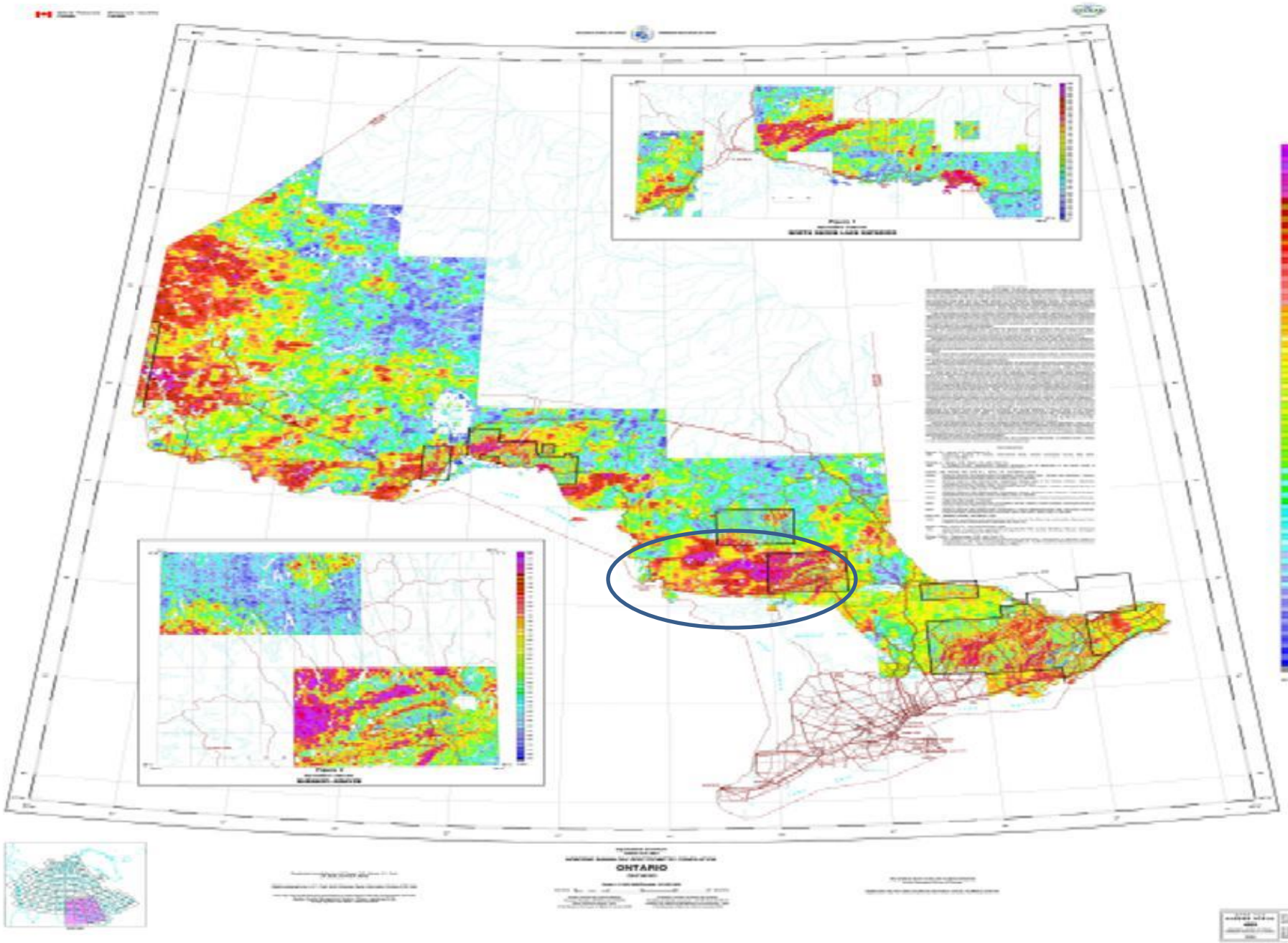

ONTARIO

Background

- Ionizing Radiation
  - Radon (alpha emitters)
  - **Gamma radiation ?**
    - Dosimetry available starting 1981
    - Gamma doses prior to 1981?

Objective

- To develop a statistical method for estimating historical exposures to gamma radiation prior to 1981;
- To estimate risks associated gamma exposure

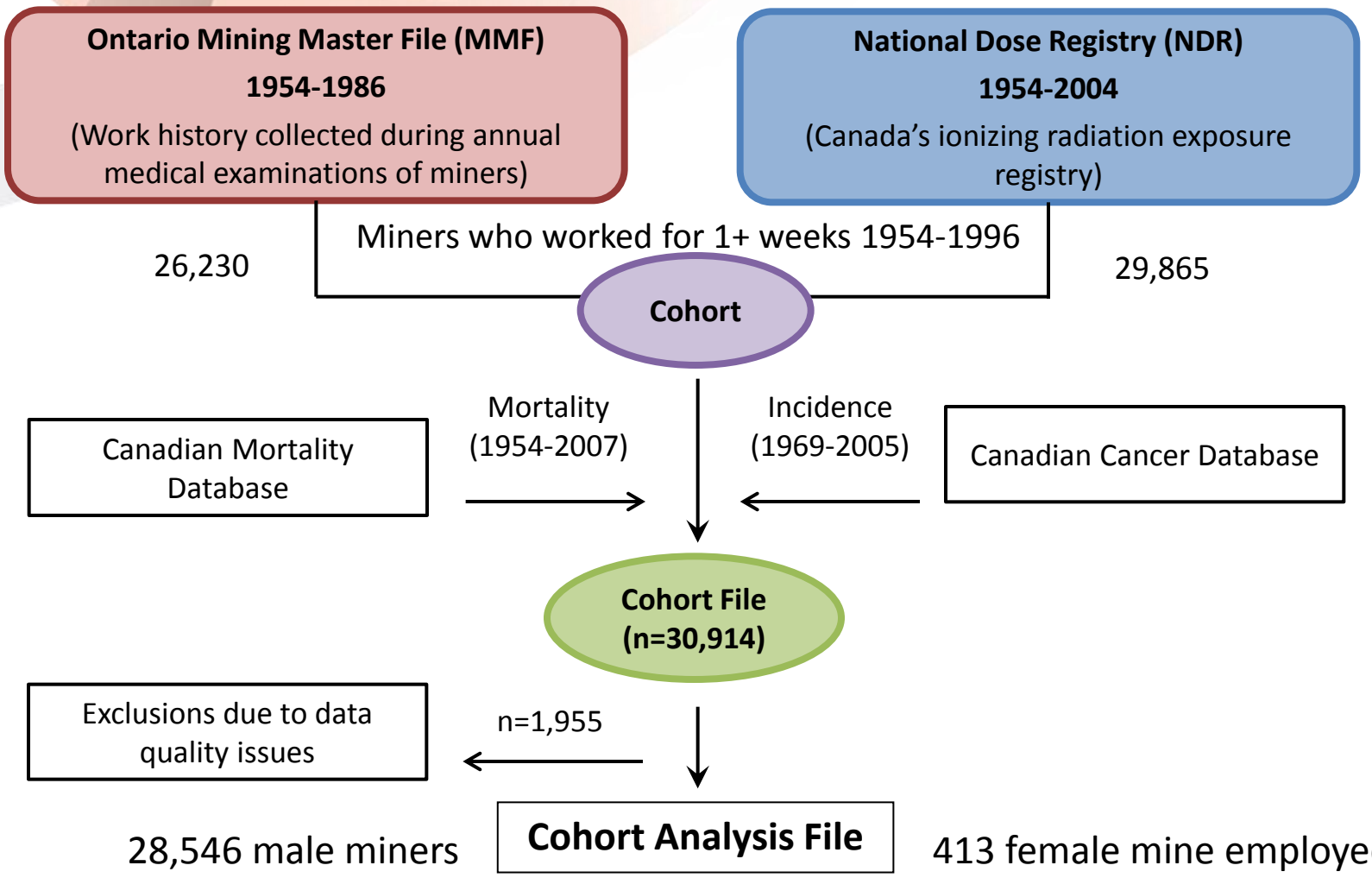
Overview of Approach

Dose = Mine Characteristics

+ Work History

Photo used with permission from the Elliot Lake Nuclear & Mining Museum

Ontario Uranium Miners Cohort
Most recent update (funded by CNSC)



Please Note: Some slides were removed due to pending publications

Discussion/Summary

- Main predictors of gamma exposure:
  - Ore grade
  - Duration of employment
  - Dose rate
- Reasonable model performance regardless of Standard or Robust approach
- Gamma radiation not affected by mine ventilation practices

Potential Limitations

- Performance poorer for smaller mines
- Radon is affected by ventilation practices (poorer ventilation prior to 1970)
- Ecological measures but they were calibrated to badge measurements

Cohort of workers employed at Denison Mines in Ontario Canada

Characteristics of cohort	Characteristics
Cohort Size	12,953
Person years of follow-up (mortality)	431,655
Age (years) at first Employment (n(%))	
<22 years	3,248 (25)
22-<27	3,630 (28)
27 - <34	3,145 (24)
34+	2,930 (23)
Mean (SD)	28 (8.4)

Cardiovascular Disease mortality by cumulative exposure to gamma radiation among Denison Uranium miners

Exposure Lag	Cumulative Gamma Dose (mSv)	Person Years	Cases	RR* (95%CI)
No Lag	0-1.5	111,554	92	1.00 (Referent)
	>1.5-3.5	102,150	254	0.93 (0.77-1.13)
	>3.5-10	113,028	304	0.95 (0.79-1.14)
	>10	104,923	242	0.98 (0.81-1.19)
5 Year Lag	0-1.5	159,319	208	1.00 (Referent)
	>1.5-3.5	88,317	252	0.95 (0.79-1.15)
	>3.5-10	97,508	298	0.96 (0.8-1.15)
	>10	86,512	234	1.01 (0.84-1.22)

Notes: *Adjusted for attained age, period

Leukemia mortality by cumulative exposure to gamma radiation among Denison Uranium miners

Exposure Lag	Cumulative Gamma Dose (mSv)	Person Years	Cases	RR* (95%CI)
No Lag	0 - 4	238,606	11	1.00 (Referent)
	>4.0 - 14	110,748	8	1.39 (0.56-3.47)
	>14	82,302	9	2.43 (1.00-5.92)
2 Year Lag	0 - 4	251,013	11	1.00 (Referent)
	>4.0 - 14	104,375	8	1.46 (0.59-3.64)
	>14	76,267	9	2.58 (1.06-6.3)

Notes: *Adjusted for attained age, period

Future Directions

Characteristics of the Ontario Uranium Miners Cohort

- Large cohort and long period of follow-up
  - > 1M person-years of observation
  - Allow for long latency
- Contains work history for dose reconstruction and other activities
- Linkable to outcome data
  - Cancer, non-cancer
  - Amendable to pooling with other cohorts

Q&A

- Why should we still continue to study this cohort given that we don’t mine uranium here anymore?
  - We might
  - Uranium ore deposits to be mined
  - Increased exploration activities
  - Need to learn as much as we can about the effects of ionizing radiation on the long-term health.

What about …? … Q & Ps.

Q1. Lung cancer risk at low exposure/exposure rates of radon.

P1. Insufficient power

Q2. Radon exposure and risk of cancers other than lung?

P2. Insufficient power

Q3. Radon exposure and risk of non-cancer outcomes?

P3. Insufficient power

Q4. Health effects of other radiological exposures in uranium miners (e.g., gamma radiation)?

P4. Insufficient power

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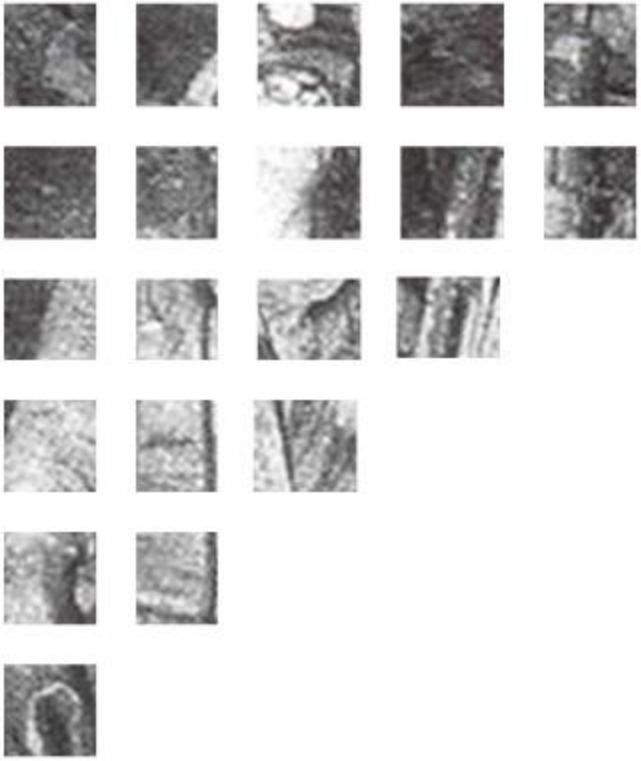

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Ontario Uranium Miners 1954-2007