Review of CT Scan Classifications Performed Under the Coal Mine Workers' Health Scheme

Organization Name

University of Illinois Chicago (UIC)

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Report Date: August 10, 2020

Executive Summary

This review of the classifications of CT scans for occupational pneumoconiosis was performed at the request of Resources Safety and Health Queensland to evaluate the quality of CT scan reporting. We obtained a sample of 100 CT scans that had been taken as follow up for coal miners who had screening CXRs classified as having opacities consistent with pneumoconiosis. These were reviewed independently by an audit team of expert Australia - and US-based B-reader certified radiologists.[*] CT scans were classified using a modified version of the International Classification of HRCT for Occupational and Environmental Respiratory Disease (ICOERD). The scans were scored for technical quality, the presence or absence of small and/or large opacities of pneumoconiosis, and the presence or absence of emphysema. Discordant classifications were resolved by consensus conference of the entire team. The original provider radiologists' reports were reviewed, and the pertinent data abstracted for comparison with the audit team classifications.

Main Findings:

1) Three percent of the of the CT scans were considered uninterpretable or of unacceptable quality by the audit team, as compared to 0% by the original providers.

2) Only 17% of the scans classified as having small opacities consistent with pneumoconiosis by the expert team, were considered to be positive by the original providers. This measure required that the original providers considered pneumoconiosis in their differential diagnosis. The sensitivity increased to 56% if this requirement was relaxed and small opacities of any cause identified by the original providers were included.

3) The original providers failed to identify large opacities in all three of the cases that were determined to have this finding by the expert team.

4) The original providers identified emphysema in 76% of the cases determined to have emphysema by the expert team.

5) A protocol for dual reads of CT scans by radiologists utilising a standardised system, similar to the process employed with plain chest radiography, should be strongly considered. This should be developed by a broad collaboration of experts including organizations such as the ILO, the US National Institute of Occupational Safety and Health, and the colleges of radiology such as RANZCR and the American College of Radiology.

[*] It is important to note that CXRs or CT scans determined to have opacities consistent with pneumoconiosis does not indicate that that miner ultimately had a confirmed diagnosis of pneumoconiosis. An expert occupational and/or respiratory physician can reach a confirmed diagnosis only after the chest imaging, miner's exposure history, and other clinical data have been reviewed and placed into context.

Conclusions: There was considerable discrepancy between the findings of the original readers of CT scans when compared to the findings of the expert team for the identification of small and large opacities consistent with pneumoconiosis. There was better agreement for the finding of emphysema. These results suggest the need to consider specific training and qualification requirements for radiologists classifying CT scans for pneumoconiosis.

Recommendations: Radiologists classifying CT scans for the Coal Mine Workers' Health Scheme should be qualified radiologists with additional training in chest imaging as well as certification as B-readers under the NIOSH/ILO system. A protocol for dual reads of CT scans by radiologists utilising a standardised system, similar to the process employed with plain chest radiography, should be strongly considered.

Contents

Glossary

CT	Computed tomography
CWP	Coal workers' pneumoconiosis
CXR	Chest x-ray
HRCT	High-resolution computed tomography
HSU	Health Surveillance Unit
ICOERD	International Classification of HRCT for Occupational and Environmental Respiratory Diseases
ILO	International Labour Office
NIOSH	National Institute for Occupational Safety and Health
PMF	Progressive massive fibrosis
RSHQ	Resources Safety and Health Queensland
RANZCR	Royal Australian and New Zealand College of Radiologists
UIC	University of Illinois Chicago

Background

In response to the re-identification of coal workers' pneumoconiosis (CWP) in the Queensland coal industry, Monash University and the University of Illinois Chicago (UIC) completed a review of the respiratory component of the Coal Mine Workers' Health Scheme in July 2016. A range of systemic failures were identified, and 18 recommendations were made for improvement. This included additional training for radiologists to classify chest x-rays (CXRs) using the International Labour Office International Classification of Radiographs for Pneumoconioses[1] (ILO Classification) and a guideline for follow-up investigation for workers with abnormal screening results, known as the Clinical Pathways Guideline.

The Clinical Pathways Guideline includes a provision for follow-up investigation by a respiratory physician for coal mine workers with CXRs that had a final ILO classification determination of small opacity profusion ≥ 1/0. This follow up investigation has generally included a high-resolution computed tomography (HRCT) scan.

The testing used in the follow up investigation to rule out or confirm the diagnosis of CWP is a process that is outside of the scope of medical surveillance, and becomes part of an expert diagnostic workup. Therefore, this was beyond the scope of the original review which did not investigate the methods and quality of CT scan reporting. There were however, concerns about the accuracy of the interpretation/classification of findings on these follow up CT scans. Specifically, inaccurate CT scan classification may result in workers who are incorrectly diagnosed as having or not having an occupational lung disease. Given the fact that the CT scan is the most advanced chest imaging technology available, and that it is unlikely that further testing such as lung biopsy with pathologic evaluation would be carried out in these cases, the outcomes of the CT scan may play a significant role in determining a coal mine worker's future, particularly their continued employment.

The primary objective of this study was to determine whether CT scans were reliably acquired and interpreted/classified for pneumoconiosis, a key component of the clinical pathway for diagnosis (See section H of Clinical Pathway Guide in Appendix E). This is to ensure confidence that coal mine workers with abnormal CXR screening results will receive an accurate follow-up evaluation and diagnosis.

Methods

2.1 Study Selection and Management

After obtaining consent, Resources Safety & Health Queensland (RSHQ; formerly the Department of Natural Resources, Mines and Energy) obtained a sample of CT scans performed on coal mine workers whose screening CXRs had a final determination of opacities consistent with pneumoconiosis.[†]

These opacities could be in the form of small opacities with profusion ≥ 1/0 indicating simple pneumoconiosis, or in addition may have large opacities, indicating possible complicated pneumoconiosis or progressive massive fibrosis (PMF). Original CT image files were obtained

[†] Of note, the sample did not include CTs for workers for whom RSHQ had already received notification of confirmed mine dust lung disease.

by audit team staff from RSHQ via secure cloud servers. All CT scan images were de-identified by project staff using ClearCanvas DICOM Viewer software. De-identification included replacing the medical record number, patient name, and birthdate with a unique combination of study ID (e.g., "001") and anonymized name (e.g., "AABB"). The UIC project staff then transmitted the de-identified images to participating reviewers.

2.2 Audit CT Scoring Protocol

A total of five radiologists, all of whom are NIOSH-certified B readers, participated in the audit project (See Appendix A). This audit team was comprised of Australian and US radiologists to draw upon a broad range of expertise and provide sufficient independence for the project. Each CT scan was independently read by one Australian and one US radiologist.

Project investigators developed classification criteria modified from the system developed for the International Classification of HRCT for Occupational and Environmental Respiratory Diseases (ICOERD)[2] (See Appendix B). The principal findings of interest for this study included those findings consistent with a coal mine dust lung disease.[3] These included image quality; presence, shape, and size of small opacities consistent with pneumoconiosis, including both round and irregular opacities; the presence of large opacities consistent with pneumoconiosis; and the presence of emphysema. Image quality was graded as grade 1 – good; grade 2 – acceptable with no technical defect likely to impair classification for pneumoconiosis; grade 3 – acceptable with some technical defect, but still adequate for classification purposes; or grade 4 – unacceptable for classification purposes.

Cases in which the original two audit team radiologists disagreed on the presence of small opacities, large opacities, or emphysema were flagged for further review. These differences were resolved by consensus. ICOERD scores of the separate readers, sum of round and irregular opacities, was reported as an average, rounded up to the next highest number.

2.3 Original Provider Data Abstraction

The original provider reports for each CT scan were provided by RSHQ to project investigators. All original provider reports were reviewed independently by a study pulmonologist (LG) who was not responsible for classifying the audit CT images, and was blinded to the CT classifications of the audit team radiologists. The primary findings of interest from the original provider reports included the presence or absence of small opacities consistent with pneumoconiosis; the presence or absence of large opacities consistent with pneumoconiosis; the presence or absence of emphysema; and differential diagnoses for identified radiologic abnormalities, if given. The original provider data was abstracted (Appendix C), and then linked to the audit readings via unique study identifiers prior to analysis to determine agreement between the audit team and original provider findings.

2.4 Statistical Evaluation

Sensitivity and specificity values were calculated separately for the presence of (1) small opacities consistent with pneumoconiosis, (2) large opacities consistent with pneumoconiosis, and (3) emphysema. We assumed that the audit team of five B reader radiologists plus consensus discussions that included the respiratory physicians was the "gold standard" for presence or absence of disease, and the original radiologist's interpretation was the test under evaluation. In this audit, therefore, sensitivity is a measure of the original provider's ability to identify correctly those who have each feature (small opacities, large opacities, and emphysema). Specificity measures the ability of the original provider to identify correctly those who do not have these features.

Agreement was also calculated between the audit team and original provider reports for those same three outcomes. Kappa statistics and percent agreement were used to determine agreement between the audit radiologists and original providers for each feature. The kappa statistic was developed as a method of calculating agreement between raters taking into consideration agreement due to chance. Kappa values range from 0 to 1, with 1 indicating perfect agreement between raters. A kappa of ≤ 0.2 indicates poor agreement, > 0.2 – 0.4 indicates fair agreement, > 0.4 – 0.6 indicates moderate agreement, > 0.6 – 0.8 indicates substantial agreement, and > 0.8 – 1 almost perfect agreement.

Project staff reviewed the agreement statistics and comments from the audit team and original providers to characterize trends in HRCT classification seen among both groups and highlight systematic patterns that explain the disagreement observed.

Results

This review included 100 CT scans of Queensland coal miners taken between September 2015 and February 2019. The miners in this review received a CT scan as a result of a final determination of a screening CXR that had opacities consistent with pneumoconiosis under the Coal Mine Workers' Health Scheme. Again, it should be noted that the finding of opacities consistent with pneumoconiosis on CXR does not indicate a confirmed diagnosis of pneumoconiosis.

3.1 Image Quality

Most images (n=97) were considered acceptable for classification purposes. Of these 97 studies, 73 (75%) were given a grade of 1 by both the Australian and US radiologists and 14 (14%) were given a score of either 1 or 2 by either expert team radiologist. For those with any quality defect noted (grade 2 and 3), the most common technical defects included motion artifact, thick slice reconstruction, and non-contiguous thin slices (see Table 1).

The audit team found the quality of three CT scans to be unacceptable for classification purposes, citing respiratory motion, low lung volumes, and non-contiguous lung slices as reasons for this grading (see Appendix D). The original provider reports for these three CT scans did not note the quality issues associated with these scans. Their classification of these three images was negative for small opacities, large opacities, or emphysema. The audit team did not classify these images due to the finding of insufficient image quality. The following results are restricted to a comparison of the findings on the 97 images which were classifiable.

Table 1 – CT quality findings from classifications of 100 CT scans performed by U.S. and Australian radiologists.

CT Quality Finding	Number of CTs
Respiratory or other motion artifact	10
Non-contiguous lung slices	9
Low lung volume	2
Thick lung slices	9
Other	5

3.2 Small Opacities Consistent with Pneumoconiosis

Original providers had a sensitivity of 17% for the detection of small opacities consistent with pneumoconiosis. The original provider's classification was considered positive if they specifically indicated pneumoconiosis was a possible cause of the opacities or listed pneumoconiosis was among their differential diagnoses (see Table 2).

Table 2 – Small opacities consistent with pneumoconiosis. Comparison of audit team findings and original provider findings for the presence of small opacities consistent with pneumoconiosis. Sensitivity and specificity were calculated using the audit team findings as the gold standard. The original provider's findings were classified as positive if they included pneumoconiosis in their differential diagnosis.

Small Opacities Consistent with Pneumoconiosis		Audit Team Findings	
		Positive	Negative
Original Provider Findings	Positive	3	1
	Negative	15	78
Sensitivity (95% CI) =		16.7%	(3.6%, 41.4%)
Specificity (95% CI) =		98.7%	(93.2, 100.0%)

The sensitivity improved to 56% when the original provider indicated the presence of any abnormality that could be considered small opacities, regardless of the whether pneumoconiosis was mentioned as a possibility in the report, (see Table 3).

Table 3 – Small opacities. Comparison of audit team findings and original provider findings for the presence of small opacities consistent with pneumoconiosis. Sensitivity and specificity were calculated using the audit team findings as the gold standard. In this case, if the original provider mentioned any abnormality that could be considered small opacities, regardless of their differential diagnosis, the test result was considered to be positive.

Small Opacities (all)		Audit Team Findings	
		Positive	Negative
Original Provider Findings	Positive	10	6
	Negative	8	73
Sensitivity (95% CI) =		55.6%	(30.8%, 78.5%)
Specificity (95% CI) =		92.4%	(84.2%, 97.2%)

The agreement between audit team radiologists and original providers narrowly exceeded the threshold for poor agreement, indicating fair agreement (κ = 0.22) on the presence or absence of small opacities consistent with pneumoconiosis (See Table 4).

Table 4 – Large Opacities. Agreement for the presence/absence of small and large opacities consistent with pneumoconiosis and emphysema, between the RSHQ audit team radiologists and the original providers for Queensland coal miners (n = 97), as measured by simple percent agreement and kappa scores.

Feature	Simple Percent Agreement	Kappa score (95% Confidence Interval)
Small Opacities	83.5	0.22 (-0.01, 0.45)
Large Opacities	96.9	N/A*
Emphysema	94.8	0.81 (0.65, 0.97)

*Kappa statistic not available for this feature as it was not identified in any original provider report.

Closer examination of the data revealed that the audit team radiologists identified the presence of small opacities consistent with pneumoconiosis in 18 CT scans (19%). Of these 18 CT scans, the original providers described a finding of abnormalities in 10 cases, in three of these cases they noted the possibility of small opacities consistent with pneumoconiosis. They did not mention the possibility of small opacities consistent with pneumoconiosis in remaining seven of these 10 cases rather they provided alternate diagnoses.

In eight of 18 cases where the expert panel classified the image as having opacities consistent with pneumoconiosis, the original provider provided no description of any significant abnormality. Of note, half of these eight cases had relatively low profusion abnormalities (ICOERD scores of 1-2), a level of profusion where there may be disagreement among expert readers. (See Table 5).

Table 5 – Eight cases classified as small opacities consistent with pneumoconiosis by the expert panel and negative by the original provider along with ICOERD scores.

CT Number	Expert Panel		Original Provider
	Small Opacities Present Panel	ICOERD Score	Small Opacities Present
011	Yes	2	No
016	Yes	1	No
021	Yes	4	No
025	Yes	2	No
037	Yes	4	No
054	Yes	6	No
090	Yes	3	No
091	Yes	1	No

The original providers did not include the possibility of coal workers' pneumoconiosis in their differential diagnoses in seven of the 10 cases, only noting it as a possible diagnosis in the remaining three cases. In the cases in which small opacities were identified by the original provider, (see Table 6) they provided a differential diagnoses that did not include pneumoconiosis. These diagnoses included sarcoidosis, non-specific interstitial pneumonitis, and granulomatous disease.

Table 6 – Differential diagnoses by original providers of small opacities not thought to be consistent with pneumoconiosis, in which the audit team indicated a finding of small opacities consistent with pneumoconiosis, along with ICOERD scores.

CT Number	Original Provider Reports				
	Small Opacities Present	ICOERD Score	Small Opacities Consistent with Pneumoconiosis	Differential Diagnosis for Small Opacities	Comments
003	Yes	14	No	Sarcoidosis	Perilymphatic nodules.
013	Yes	4	No	Sarcoidosis	Subtle nodularity of bronchovascular bundles, nodularity of left major fissure, areas of confluence of small nodules.
035	Yes	7	No	Non-specific interstitial pneumonitis (NSIP)	11x8 mm nodule. Calcified peripheral nodules.
039	Yes	2	No	Pleural-based lymph nodes	Calcified granuloma in right middle lobe. Nodule in left upper zone. Nodules attributed to previous granulomatous disease.
041	Yes	4	No	Primary interstitial pneumonitis either NSIP or usual interstitial pneumonia (UIP)	Groundglass opacification. Possible honeycombing.
066	Yes	8	No		Several tiny calcified granulomas.
092	Yes	9	No		Multiple small scattered calcified lung granulomas.

Conversely, the original providers identified small opacities in six of the 79 cases that were classified as negative by the audit team. Review of original provider comments indicated the opacities were felt to be consistent with pneumoconiosis in only one of these six cases.

3.3 Large Opacities Consistent with Pneumoconiosis

As with small opacities, the sensitivity and specificity for the identification of large opacities were calculated utilising the assumption that audit team findings represented the gold standard. The test was considered positive if the original provider found large opacities that they described as consistent with pneumoconiosis.

The audit team identified large opacities consistent with pneumoconiosis in three cases. The original providers did not indicate large opacities in any of the 97 CT scans considered in the analysis, or a sensitivity of zero percent (see Table 7).

Table 7 – Large opacities. Comparison of audit team findings and original provider findings for the presence of large opacities. Sensitivity and specificity were calculated using the audit team findings as the gold standard. The original provider was considered to have made a positive diagnosis only if they noted pneumoconiosis in the differential diagnosis.

Large Opacities		Audit Team Findings	
		Positive	Negative
Original Provider Findings	Positive	0	0
	Negative	3	94
Sensitivity (95% CI) =		0.0%	(0.0%, 70.8%)
Specificity (95% CI) =		100.0%	(96.2%, 100.0%)

In all three of these cases in which large opacities were found by the audit team, the original providers did indicate the presence of small opacities, but noted that these opacities could be consistent with pneumoconiosis in only one of these three CT scans. Kappa statistics could not be computed for this feature due to the infrequency of positive findings.

3.4 Emphysema

The audit team identified emphysema in 17 cases (17.5%) and the original provider reports indicated emphysema in 14 cases (14.4%). The sensitivity for this finding was 76%, suggesting that original providers are likely to correctly identify patients with emphysema in the majority of instances. Specificity was very high (99%), indicating that the original providers were correctly identifying those without emphysema (see Table 8).

Agreement between the audit team and original providers for the presence of emphysema was excellent ($\kappa = 0.81$). There were four cases in which the audit radiologists indicated emphysema was present, and the original provider either did not mention emphysema ($n = 3$) or indicated it was absent ($n = 1$). There was one case in which the original provider noted emphysema and the audit team did not note emphysema.

Table 8 – Emphysema. Comparison of audit team findings and original provider findings for the presence of emphysema. Sensitivity and specificity were calculated using the audit team findings as the gold standard. Test positive or negative indicates the findings of the original provider.

Emphysema		Audit Team Findings	
		Positive	Negative
Original Provider Findings	Positive	13	1
	Negative	4	79

Sensitivity (95% CI) = 76.5% (50.1%, 93.2%)

Specificity (95% CI) = 100.0% (93.3%, 99.97%)

3.5 History Given to Original Provider

The original reports were also reviewed to see if there was any indication that the radiologist interpreting the CT scan knew of the work history of coal mining. Of note 15/100 reports did not have any indication that the work history was provided. The other 85 did. Only one of the 15 cases where the history may not have been provided was felt to be positive by the expert panel and negative by that provider. Therefore the absence of an appropriate history is not likely to be the cause of differences in interpretation between the original providers and the expert panel.

Discussion

Overall, the performance of original provider radiologists compared to the audit team of expert radiologists was less than desired. The sensitivity for the identification for small opacities was unacceptably low, however it is important to note that there can be significant disagreement even among expert readers (See below discussion of discordance among the expert panel). The sensitivity for large opacities was unacceptably low, and in this case there was no discordance among the expert panel. There was good performance observed in the evaluation of emphysema. There was no temporal trend, either improvement or worsening, in the number of cases found to be discordant over the time course of the study.

Image quality

The careful evaluation of image quality is very important for the classification of CT scans. While quality problems were uncommon in this review and most images were deemed acceptable for classification purposes, there were three scans (3%) which were felt by the expert audit team to be unclassifiable. The problems with technical quality were likely related to the use of older scanners with fewer detectors, and lower scanning speeds, which limit the ability to prevent motion artifact. Radiologists classifying CT scans should be reminded not to classify these types of low-quality images and request repeat studies that meet quality criteria.

Small Opacities

The sensitivity of the original providers for the detection of small opacities consistent with pneumoconiosis was only 17%, indicating that they did not correctly identify disease in 83% of cases. A major issue was the attribution of the presence of small opacities to diseases other than pneumoconiosis. If the small opacities are present and compatible with pneumoconiosis they should be so classified.

The low sensitivity for the finding of small opacities by the original providers was not limited to the misattribution of the potential causes for the identified small opacities. When we evaluated the sensitivity by considering a finding of small opacities regardless of the attributed cause by the original provider, the sensitivity was still only 56%. This indicates that, in cases in which the audit team found small opacities consistent with pneumoconiosis, the original providers did not find any small opacities, regardless of cause. This low sensitivity could also be explained in part by reader variability in low profusion scans (see discussion of disagreement among experts below). However this disagreement was largely in the direction of experts noting opacities and when the original providers did not, and was randomly distributed as was noted among experts.

The low kappa statistic indicates poor agreement between audit team and original providers. This finding indicates the need for further training and standardization of how CTs should be classified for the presence or absence of pneumoconiosis.

Discordance among experts for small opacities.

There was some disagreement among the expert panel regarding the presence of small opacities. These were resolved by consensus discussion.

Several images had been classified as positive because of the finding of ground glass opacities. These were classified as consistent with pneumoconiosis due to the recent experience with artificial stone pneumoconiosis which may exhibit this abnormality. It was decided by consensus that these findings should be characterized specifically as ground glass opacities, and not round opacities of pneumoconiosis. It was also decided that apical scarring should not be classified as consistent with pneumoconiosis. Of note the vast majority of cases where there was disagreement among experts had low profusion ICOERD scores of 1-2. This highlights the need for standard CT images to improve consistency in CT classification quality, especially for low profusion disease. Standard images could be used to define a threshold for profusions above which the image would be classified as positive for pneumoconiosis, similar to the ILO classification system for chest radiographs,

Large Opacities

The audit team identified three cases with large opacities. The original provider reports for these cases did not mention large opacities or, in one case provided an alternative diagnosis without including pneumoconiosis in the differential. This is of significant concern, as the finding of large opacities or PMF indicates the presence of quite severe disease, as well as the important clinical and legal implications of this diagnosis.

Emphysema

Emphysema contributes substantially to the morbidity among coal mine workers, yet it is a manifestation of CMDLD that is often overlooked. Therefore, great emphasis should be placed on identifying this condition during radiographic surveillance. In this review, emphysema was classified with good sensitivity and excellent specificity. Also, there was very good agreement between the audit team and original providers. Most radiologists have considerable experience in identifying emphysema due to its high prevalence in the general population. Of note, the type of emphysema was not always mentioned in the original provider reports, so we have not discussed those findings.

Conclusions and Recommendations

The current review of CT scans performed for the evaluation of coal mine dust lung disease demonstrated substantial discordance between original radiologists' report and the expert panel's classifications of the same images. This was most evident in the detection of opacities consistent with pneumoconiosis, in which original providers detected small opacities and characterised them as potentially due to pneumoconiosis in only 17% of cases classified as having small opacities consistent with pneumoconiosis by the review team. Some of the cases not identified were of low profusion and therefore disagreement may have been due in part to inter-reader variability. The original providers did not identify large opacities consistent with pneumoconiosis in any of the three cases classified as such by the review team. It is the opinion of the expert panel that there are areas amenable to significant improvement.

The classification of chest CT scans for pneumoconiosis, an uncommon disease in the general population, requires expertise and training beyond what is typical for most practising radiologists. The expert panel agrees with the position statement issued by Royal Australian and New Zealand College of Radiologists (RANZCR)[4] "Imaging of Occupational Lung Disease" that this would best be accomplished by limiting the classification of these images to radiologists who have additional training in thoracic radiology, and who report cases of occupational and non-occupational interstitial disease in their routine practice. Such radiologists should also be involved in ongoing training and work closely with respiratory and occupational physicians. In addition to these recommendations, the review committee also believes these radiologists should have completed additional steps to understand chest imaging for pneumoconiosis. Formal certification for evaluation of CXRs for pneumoconiosis, such as the US NIOSH B-reader certification, is an important background for evaluating CT scans for pneumoconiosis, as the classification systems for CT and CXR are based on similar principles. Given that there are sufficient numbers of B-reader certified radiologists in Australia, and more specifically Queensland, it is likely that this recommendation could be readily enacted.

Classification of CT scans is subjective and challenging, especially in cases of low profusion pneumoconiosis. The ICOERD system is a useful tool, but it does not provide standard images to calibrate the classification of the profusion of opacities. This type of resource along with appropriate training and testing procedures would be an extremely useful tool for physicians engaged in the classification of HRCT for pneumoconiosis. The development of standard images would likely be a task for the ILO in collaboration with other international expert organizations.

We believe a system of dual classification of CT scans should also be considered to reduce the effects of inter-reader variability. This could be performed in the same fashion as the dual classification of CXRs, in which two readers classify the image and, if there is disagreement, a third classification is obtained. Agreement could be judged in a manner similar to that performed in this review: presence or absence of small and large opacities consistent with pneumoconiosis, and presence or absence of emphysema. As these issues aren't applicable to just Queensland alone, it is recommended that the development of an acceptable dual classification and adjudication protocol should be developed by a broad collaboration of experts including organizations such as the ILO, the US National Institute of Occupational Safety and Health, and the colleges of radiology such as RANZCR and the American College of Radiology.

Additional attention should be directed to the quality of the CT scanners and imaging protocols. The RANZCR position statement on the Imaging of Occupational Lung Disease also provides useful guidelines[4] which could be used for HRCT imaging standards under the Coal Mine Workers' Health Scheme.

The expert panel would like to make it clear that the gold standard in this evaluation was the classification of the expert panel in a series of cases with a history of an abnormal screening CXR. The cases used in this review were not those of miners for whom the RSHQ had been notified of confirmed disease. Clearly many radiologists have been involved in the evaluation of the 169 confirmed mine dust lung disease cases to date and were thus able to identify abnormalities of pneumoconiosis.

It should also be noted that at this point in time HRCT is not utilized for routine medical surveillance for dust exposed workers. Rather, it is a diagnostic test employed to evaluate abnormal screening plain chest radiography.

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Appendix A: Biosketches of Expert Team Radiologists

Jonathan H. Chung

Dr. Chung specializes in cardiopulmonary imaging. Dr. Chung analyses and interprets chest radiographs and CT scans for thoracic diseases. He also has an expertise in interstitial lung disease, occupational lung disease, nontuberculous mycobacterial pneumonia and diseases of the large and small airways and is a certified B reader. Through his research, Dr. Chung is studying how imaging can play a more significant role in patients with chronic lung diseases, specifically, interstitial lung disease, pulmonary fibrosis, occupational lung disease and nontuberculous mycobacterial pneumonia. He has authored over 140 peer-reviewed articles that have been published in scientific journals, and co-authored five book chapters and five books that focus on chest diagnostics. In addition to his clinical work and research efforts, Dr. Chung also dedicates himself to educating medical students, residents, and fellows, performing numerous one-on-one teaching sessions, and mentoring younger physicians. His devotion to education has been recognized several times, including when he received the Radiological Society of North America Honored Educator Award in 2013 and the Marc Tetalman Award in 2016.

Kathleen DePonte

Kathleen A. DePonte, M.D. is a board-certified diagnostic radiologist and NIOSH-certified B-reader currently in private practice as a partner with Mountain Empire Radiology, P.C. She completed her residency in diagnostic radiology at Wake Forest University. As president of Diagnostic Imaging Associates, P.C, she specializes in imaging of pneumoconiosis and occupational lung diseases. She serves as a consultant for multiple clinics including Washington and Lee Black Lung Clinic. As a panel surveillance reader for NIOSH she served on the ACR/NIOSH task force for the development of the new digital NIOSH B-reader certification examination. Dr. DePonte also serves as a member of the Adjunct Clinical Faculty at DeBusk College of Osteopathic Medicine.

Catherine Jones

Dr. Catherine Jones, MBBS BSc FRCR FRANZCR, is a chest radiologist, working in Brisbane and providing chest imaging reporting for workers across Queensland and Australia. After completing her medical degree at the University of Queensland, she trained in radiology in the UK, and undertook a chest imaging fellowship in Vancouver Canada. For the last three years she has provided B reader reporting services to the Queensland coal mine surveillance program, as well as across the range of industries with silica exposure.

Catherine is an executive member of the Australian and New Zealand Society of Thoracic Radiology and has been a vocal advocate for robust occupational lung disease screening in both the mining and silica industries.

Katrina Newbigin

A medical graduate from the University of Queensland, Dr. Newbigin trained as a radiologist at the Royal Brisbane Hospital. Subsequently she completed a Chest Imaging fellowship in Ottawa, Canada in 2014. Returning to work at the Wesley Hospital Brisbane, she developed an interest in occupational disease and became one of the first Australian radiologists to obtain her NIOSH B reader certification. As a radiologist, Katrina has advocated for improved screening of coal mineral dust lung disease and silicosis in Australia. Since 2015 she has been a representative on several expert medical panels advising on improving chest x-ray screening pathways for coal mineral dust lung disease and silicosis, particularly in Queensland. Dr. Newbigin ongoing research uses case series analysis to understand the occupational histories of workers diagnosed with coal worker's pneumoconiosis or silicosis. She hopes this research will help maintain awareness of occupational diseases in Australia and the need for ongoing vigilance to prevent further cases occurring.

Robert Tallaksen

Robert J. Tallaksen, MD, is a graduate of the University of North Carolina School of Medicine. He trained in Diagnostic Radiology at the U.S. Naval Hospital in Bethesda, MD, and did further fellowship training in Thoracic Radiology at the Armed Forces Institute of Pathology in Washington, DC. After completing his military service, he worked for several years in private practice. He joined the faculty of the West Virginia University School of Medicine in 2001 as Chief of Cardiothoracic Radiology. He is a Senior Consultant to the Respiratory Health Division of NIOSH/CDC.

Appendix B: CT Scan Data Collection Form

Image identifiers

Study ID ______________________

Date of CT ______________________ (yyyy-mm-dd format)

Anonymized Name ______________________

Image resolution and quality

Slice thickness in mm ______________________ (unit = mm)

Position of image
- ☐ Prone
- ☐ Supine

Please provide the image quality grading.
- ◯ Grade 1: Good
- ◯ Grade 2: Acceptable - with no technical defect likely to impair classification for pneumoconiosis
- ◯ Grade 3: Acceptable - with some technical defect but still adequate for classification purposes
- ◯ Unacceptable for classification purposes

Please specify the image quality issues.
- ☐ Thorax incompletely imaged
- ☐ Other - specify

(only applicable if Image Quality grade is not "1: Good")

Please describe the "other" image quality issues here: ______________________ (Only applicable if "other" selected)

Well-defined rounded opacities

Is the image positive for well-defined rounded opacities?
- ◯ Yes
- ◯ No

"Positive" is defined as having a category of 1 or higher, based on the ICOERD definitions, in at least one zone. If the image does not meet this criteria, select "No".

Please select the predominant size of the well-defined rounded opacities.
- ◯ P ≤ 1.5mm
- ◯ Q =1.5-3mm
- ◯ R ≥ 3-10mm

(only applicable/visible if "yes" selected for rounded opacities)

Right side: Zones / Profusion / Grade

	Grade 0	Grade 1	Grade 2	Grade 3
Upper (U)	◯	◯	◯	◯
Mid (M)	◯	◯	◯	◯
Lower (L)	◯	◯	◯	◯

Left side: Zones / Profusion / Grade

	Grade 0	Grade 1	Grade 2	Grade 3
Upper (U)	○	○	○	○
Mid (M)	○	○	○	○
Lower (L)	○	○	○	○

Sum grade __________________________
(Calculated field)

Irregular and/or linear opacities

Is the image positive for irregular and/or linear opacities?

○ Yes
○ No

"Positive" is defined as having a category of 1 or higher, based on the ICOERD definitions, in at least one zone. If the image does not meet this criteria, select "No".

Right side: Zones / Profusion / Grade

	Grade 0	Grade 1	Grade 2	Grade 3
Upper (U)	○	○	○	○
Mid (M)	○	○	○	○
Lower (L)	○	○	○	○

Left side: Zones / Profusion / Grade

	Grade 0	Grade 1	Grade 2	Grade 3
Upper (U)	○	○	○	○
Mid (M)	○	○	○	○
Lower (L)	○	○	○	○

Sum grade __________________________
(Calculated field)

Large opacities

Is the image positive for large opacities?

○ Yes
○ No
(only applicable/visible if "yes" selected for one of above opacities categories)

Please select the category of the large opacities.

○ A
○ B
○ C
(only applicable/visible if "yes" selected for large opacities)

Emphysema

Is the image positive for emphysema? "Positive" is defined as having a category of 1 or higher, based on the ICOERD definitions, in at least one zone. If the image does not meet this criteria, select "No".	◯ Yes ◯ No

Additional comments

Please enter any additional comments here:

Date of reading ______________________________

Appendix C: Original Provider Report Data Abstraction Tool

CT Audit - Original Provider Reports

Image identifiers

Study ID ______________________________

Anonymized Name ______________________________

CT Date ______________________________

CT findings

Does the report indicate that the study is positive for the presence of SMALL opacities (round or irregular)?	◯ Yes ◯ No ◯ Not mentioned
Were regular and/or irregular small opacities clearly indicated? Check all that apply.	☐ Regular small opacities ☐ Irregular small opacities ☐ Neither were clearly indicated
Did the reader characterize the small opacities as suggestive of or consistent with pneumoconiosis?	◯ Yes ◯ No
Enter free text of differential diagnosis, if any	______________________________
Does the report indicate that the study is positive for the presence of LARGE opacities?	◯ Yes ◯ No ◯ Not mentioned
Did the reader characterize the large opacity or opacities as suggestive of or consistent with pneumoconiosis?	◯ Yes ◯ No
Enter free text of differential diagnosis, if any	______________________________
Does the report indicate the patient has emphysema?	◯ Yes (Emphysema present) ◯ No (Emphysema not present) ◯ Not mentioned
Emphysema type, if indicated	______________________________
Comments	____________________________________

Appendix D: Tabular Audit Team Data

Dataset containing abstracted original provider reports and audit team classifications will be submitted to Resources Safety & Health Queensland.

CMWHS Clinical Pathways Guideline

Purpose

The Coal Mine Workers' Health Scheme (CMWHS) Clinical Pathways Guideline (the Guideline) documents the recommended process for follow-up investigation and referral to appropriate medical specialists of workers with abnormal results on screening tests. The Guideline will assist in reaching a diagnosis on potential cases of coal mine dust lung disease (CMDLD) in a reasonable time frame, reducing worker anxiety and providing more consistent outcomes.

Background

Monash University in collaboration with the University of Illinois at Chicago completed an independent review of the respiratory component of the CMWHS in 2016. The review was commissioned by the Queensland Government after new cases of coal workers' pneumoconiosis (CWP) were identified. One of the review's recommendations was that a clinical pathway for follow-up investigation and referral should be developed and incorporated into the CMWHS. The CMWHS provides compulsory pre-employment, periodic and retirement medical examinations of coal mine workers employed in Queensland.

The Guidelines were developed by the CMDLD Collaborative Group, a group of health specialists from the Australasian Faculty of Occupational and Environmental Medicine, the Thoracic Society of Australia and New Zealand, the Australian and New Zealand Society of Occupational Medicine and the Royal Australian and New Zealand College of Radiologists. The group is supported by Professor Robert Cohen MD of the University of Illinois at Chicago, Queensland Health and the Department of Natural Resources, Mines and Energy (DNRME).

The Guidelines have been endorsed by Queensland's Chief Health Officer, the Royal Australasian College of Physicians and its Australasian Faculty of Occupational and Environmental Medicine.

Implementation

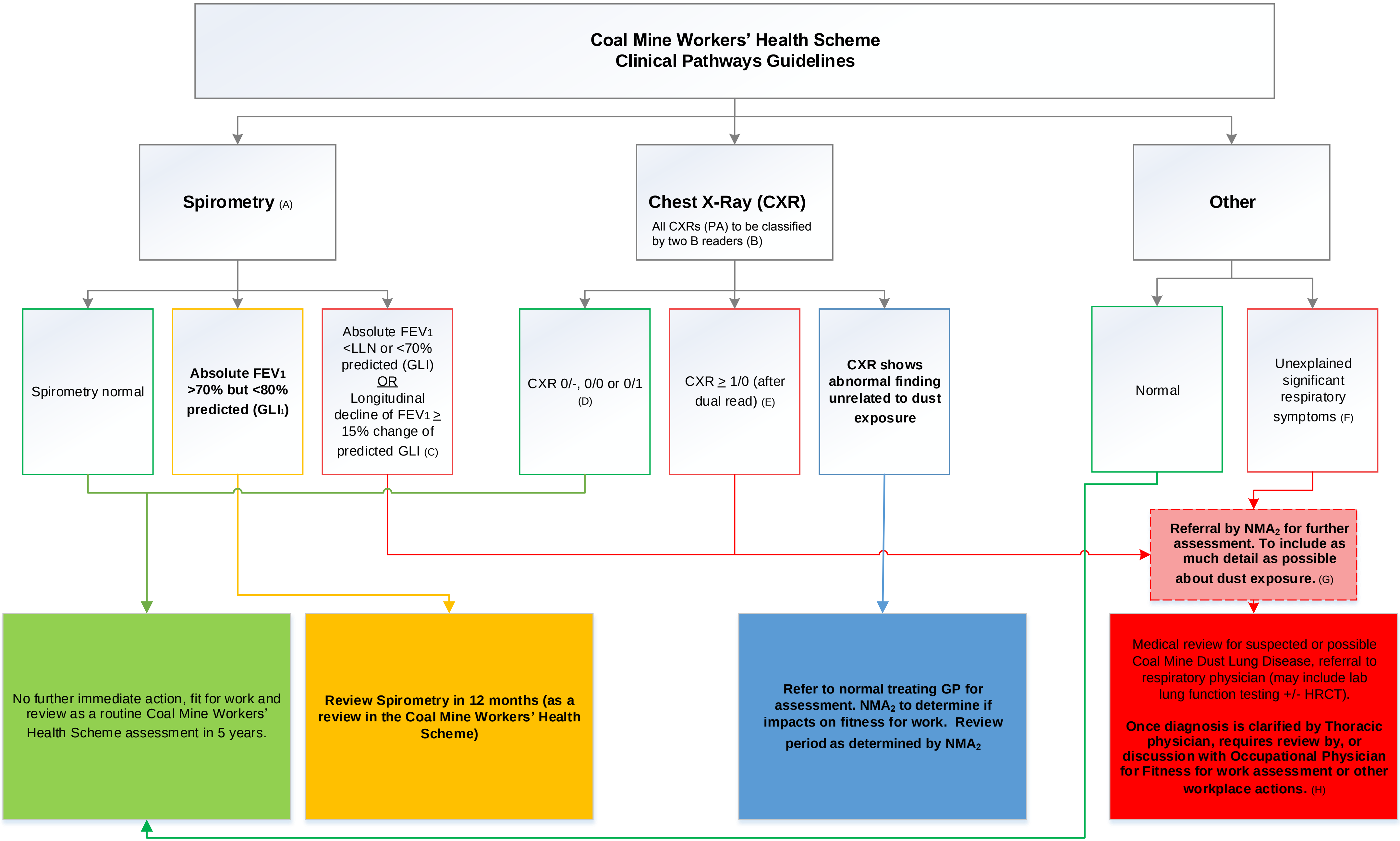
DNRME expects that Nominated Medical Advisers, other doctors and medical providers that are registered with the department to offer health services to Queensland's coal mine workers will implement the Guidelines when assessing coal mine workers, unless there is a valid medical reason for an alternate course of action.

Please note that the Thoracic Society of Australia and New Zealand has developed *Standards for the Delivery of Spirometry for Coal Mine Workers*. While this standard provides a general method for the interpretation of spirometry, the Clinical Pathways Guideline is to be applied by the doctor with responsibility for interpreting the spirometry results and deciding on the referral pathway.

The Guidelines should be used in association with the health assessment requirements of the Coal Mining Safety and Health Regulation 2017, the associated health assessment form and other conditions of registration.

As provided for in the Regulation, if a coal mine worker is not satisfied with a health assessment outcome that reports that they are unable to carry out their tasks at the mine without creating an unacceptable level of risk, they are able to submit to their employer a further health assessment from another doctor of their choice.

The employer will then request that the original Nominated Medical Adviser reviews the further assessment and provides the employer and the worker with a report on their review. If there are conflicting heath assessment reports, the worker or the employer can seek DNRME to arrange for an independent review of the conflicting assessments and the review report by a relevant specialist. This review may include another health assessment or medical examination to resolve the conflict in the reports.



1. Global Lung Function Initiative
2. Nominated Medical Advisor

Supporting Documentation for Coal Mine Workers' Health Scheme Clinical Pathway Guidelines

A: High quality spirometry is essential (including quality assurance processes for the equipment and training)

B: All CXRs (PA) are classified by two B-readers, with additional readers available for adjudication. A total of up to 5 readers may be required.

Please Note: The CMDLD Collaborative Group recommends the following transitional arrangements in jurisdictions that do not immediately adopt the use of B-readers: until 31/01/2019, this task may also be performed by registered radiologists whose names appear on the register of clinical radiologists for CWP screening, maintained by the Royal Australian and New Zealand College of Radiologists.

C:

- The "threshold" for FEV_1 and impairment is defined by the comparison of absolute measurements to reference values, or longitudinal studies that show excessive declines in FEV_1. The threshold is met if:
  - The absolute value is less than the Lower Limit of Normal (L.L.N) or less than 70% predicted, from Global Lung function Initiative (GLI) reference values – whichever is lower – assuming that age, height and race are entered correctly.
    - *Please Note: The decision to use <70% FEV1 as a cut-off was reached because choosing a higher cut-off value (such as <80%) would have resulted in a greater number of false positive results. Such false positives would, for example, have included workers without CWP, but with mild dysfunction due to other respiratory conditions*
    - *Please Note: It is planned that FEV1 level will be reviewed within 2 years*
- A longitudinal decline of ≥ 15% of reference over any period of time(GLI)Abnormalities are an indicator of 'suspected CWP' and a trigger for referral and medical review (as CXR pathway)
- Abnormal Pre-employment lung function needs an individualised approach
- If COPD is suspected, then a suitable FFW assessment ie required (similar to 1/0).
- These guidelines are suitable for assessing former coal mine workers.

D:

- All patients with a 0/0, 0/- or 0/1 CXRs are classified as negative. Results are to be recorded in the patient's file, with no other radiology, including HRCT, required at this stage.
- Patients with a 0/0, 0/- or 0/1 are deemed fit for work and should not be removed from the workplace.

E:

- A 1/0 or greater read is not confirmed until it has been read using the dual reader protocol, with adjudications if needed, in order to obtain a final determination.
  - *Please Note: In the current Queensland CMWHS system of X-ray dual reading, whereby the CXR is read in Australia and also in the USA. An urgent turn-around can be requested on the US read in the event of a potential positive read.*
- A 1/0 or greater final determination is deemed 'suspected CWP' and then triggers referral for medical review

F: If a worker has a negative CXR but reports significant, unexplained respiratory symptoms this should also trigger a medical review.

G:

- The Group recommends the following case **definition of CWP:**
  - When considering CWP a 'significant or substantial' exposure to coal mine dust should be an essential element together with a change in CXR (or other imaging equivalent):
    - Coal mine dust exposure must be considered and the effectiveness of exposure controls
    - A significant or substantial exposure was considered, as a guide, to be at least 10 years in an appropriate exposure group or S.E.G
    - Lesser time periods of exposure may be considered in circumstances of significantly greater exposures.

H:

- Medical review can include:
  - Medical Evaluation by NMA (doctor responsible for health surveillance) and/or occupational physician (OP) and/or respiratory physician.
  - Obtaining information about the worker's occupational dust exposure and any other relevant exposures
  - HRCT may be indicated in many cases, especially low profusion CWP and cases where it is difficult to obtain a high quality image. The HRCT, if performed, should be conducted according to the specified protocol and read by a radiologist from the CWP register.

- Spirometry and advanced lung function testing.
- The diagnosis needs to be established and the worker’s fitness for work determined.

- Ongoing surveillance including symptom evaluation by questionnaires, spirometry and CXR at clinically appropriate intervals.
- The NMA (doctor responsible for health surveillance), OP and/or respiratory physician are to consider and assess dust exposures.