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Electromagnetic field exposure in power plants: a qualitative assessment of work safety perceptions among employees

Thomas A. M. Stege[a], John F. B. Bolte[a,b], Liesbeth Claassen[a] and Danielle R. M. Timmermans[c]

[a]National Institute for Public Health and the Environment (RIVM), Bilthoven, The Netherlands; [b]Smart Sensor Systems group, Faculty of Technology, Innovation, and Society, The Hague University of Applied Sciences, Delft, The Netherlands; [c]Amsterdam Public Health research institute, Department of Public and Occupational Health, VU University Medical Center, Amsterdam, The Netherlands

ABSTRACT

Electromagnetic fields, or EMF, are ubiquitous in our daily life. Extremely low frequency magnetic fields (ELF MF) are generated by any device using electric current. Especially in workplace situations involving MRI scanners, welding equipment, induction heaters, and power plants, they are known for potentially high field strengths. These high field strengths may lead to adverse health effects if insufficient preventive measures are in place. This study investigates employees' perceptions on work safety regarding EMF exposure. We held 15 semi-structured interviews in three different (non-nuclear) power plants in the Netherlands. We found that power plants in this study made ample use of fences and warning signs where needed, creating a safe working environment. Nevertheless, some workers perceive that there are vague regulations, organizational issues and lack of clarity on the properties of EMF. Participants also indicated that there is some room for improvement with respect to work safety meetings on EMF. Employees want to be informed about EMF and its potential health effects and mitigation methods, but their information need is limited and straightforward. A simple warning system, along with safety information on paper, may be sufficient.

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EMF; Electromagnetic fields; Power plants; Risk communication; Risk perception; Work safety

1. Introduction

Electromagnetic fields (EMF) are ubiquitous in our daily life. In certain working environments, the application of high electric currents leads to extremely low frequency magnetic fields or electric fields (ELF MF or EF) (European Commission 2010), with a frequency range of 1 Hz to 100 kHz. ELF MF exposure can generate an internal electric field or current in the body, which can lead to adverse short-term effects. These effects include nausea, vertigo, dizziness, flashes of light (phosphenes), metallic taste, muscle contractions, tissue overheating, arrhythmia, disruptions in metal implants and pacemakers, and injuries due to flying metal objects. ELF EF exposure to low-frequency electric fields may cause well-defined biological responses, ranging from perception to annoyance, through surface electric-charge effects (ICNIRP (International Commission on Non-Ionizing Radiation Protection), 2010; Health & Safety Executive 2016).

CONTACT Thomas A. M. Stege thomas.stege@rivm.nl National Institute for Public Health and the Environment (RIVM), PO Box 1, 3720 BA Bilthoven, The Netherlands

Typical outdoor sources of exposure are overhead powerlines, high power transmission lines and electric means of transportation, such as trams and trains. Higher doses of ELF MF occur in the workplace (Karpowicz and Gryz 2007), for example with MRI scanners, welding equipment, induction heaters, and in power plants. Some studies claim an increase in the relative risk in leukemia for children living near powerlines (Ahlbom et al. 2000; Kemp et al. 2002; Kheifets, Afifi, and Shimkhada 2006). Although the IARC classifies ELF MF as category 2B "possibly carcinogenic", a causal effect has not been proven, as the mechanism that may lead from exposure to leukemia is yet unknown. There are some scientific indications that workplace ELF MF exposure may lead to long-term effects such as Parkinson's or ALS (Huss et al. 2015), but no causal effect is known here either. Finally, some studies found indications for an association between residential exposure levels of ELF MF and non-specific physical symptoms, such as headache, painful muscles and dizziness (Baliatsas et al. 2015; Bolte et al. 2015); however, the mechanism for a causal effect is yet unknown.

European Directive 2013/35/EU set Exposure Limit Values for EMF, dose levels in the body, and derived the so-called Action Values from these, exposure limits outside the body, to protect workers against effects of EMF exposure. The so-called low Action Values prevent occurrence of sensory effects such as vertigo or phosphenes. The high Action Values are to prevent effects in the peripheral nerve system, such as involuntary muscle contraction. However, Stam (2014) shows that exceedance of both the low and high Action Values for ELF MF may occur in power plants.

The European Directive also considers two main methods of combatting the exceedance of these Action Values. Firstly, safety by design is recommended, with a focus on emission reduction, combined with limitations on access and audiovisual warnings (ICNIRP (International Commission on Non-Ionizing Radiation Protection)), 2010). Literature supports this idea of safety by design, which makes it impossible to work unsafely (Mols et al. 2015). Secondly, the European Directive also assigns the task of workers' education to the employer. This can be seen in the Dutch national law as well, which mandates informing workers on relevant risks periodically. Literature agrees that education on work safety and providing risk information can be effective as a prevention tool (Cezar-Vaz, Bonow, and Cezar-Vaz 2015; Sheyn et al. 2008). Ideally, workers should be aware of the risks involved with their work, aware of possible mitigation methods, and willing to participate in mitigation. Therefore, an efficacious education system both informs workers about risks and mitigation, thereby influencing their risk perception, and incentivizes safe behavior (Cezar-Vaz, Bonow, and Cezar-Vaz 2015).

This study investigates how workers in power plants perceive work safety concerning EMF, in order to determine the appropriate course of action regarding work safety and education. We decided on power plants as a workplace case, since Stam (2014) showed that a high EMF exposure occurs within companies involved in electricity supply, potentially exceeding the Action Values. Our research question is: "How do employees in power plants perceive work safety with regards to EMF?" We will present our findings regarding employees' risk perceptions, as well as recommendations for further work safety development and education.

2. Method

In order to study the perceptions of risk and mitigation by various employees of power plants, we held a series of semi-structured interviews. According to McIntosh and Morse (2015), semi-structured interviews are characterized by a general systematic order, but a tendency to allow deviations from the script when appropriate. The general systematic order allows for a focused development of the conversation, with basic information about work-related risks before methods of instruction and contextual factors. Conversely, deviations from the script were sometimes

necessary whenever unexpected important or interesting topics came up, such as the inclusion of a complete work safety instruction.

2.1. Sampling

We contacted three of the largest suppliers of electricity in the Netherlands, and all of these companies chose to participate in this study. Although the companies were willing to participate, they could only offer a limited number of participants for various reasons, including reorganizations; for example, one of the companies cancelled the final four interviews due to unforeseen circumstances. In the end, the process yielded 15 interviews, with a variety of workers from different layers of the organization. Although this number of 15 is small, it still exceeds the minimum benchmark of 12 recommended by Guest, Bunce, and Johnson (2006).

All 15 participants were male, and ages ranged from 33 to 63 years at the time of the interview (during the summer and fall of 2017), with a (rounded) average of 51 years. This could be perceived as a bias regarding age or gender, but it should be noted that power plants still involve predominantly male-oriented professions, and many of these companies appear to struggle to find young recruits. Therefore, our sample appears to be in line, demographically, with the actual work force in power plants.

In general, the participants working in these companies were educated at a medium or high vocational education level. Of the 15 participants, seven were mostly involved with mechanical engineering, four were mostly involved with electrical engineering, and four did something else, including one occupational hygienist, one risk manager, one education manager, and one ICT specialist.

2.2. Data collection

All participants were asked beforehand whether they had any objections to the recording of the interviews. Participants were informed that they would retain full anonymity and that they could say anything they pleased without repercussions. The participants all agreed to the terms of these interviews.

The interviews began with a number of general questions involving job description, age, level of education, and work satisfaction. Subsequently, we asked participants about the risks that are present in the workplace, and we focused on the question to what extent EMF exposure was considered an important risk compared to other risks. After exploring the perceptions of EMF and other risks, we asked about mitigation, rules and regulations towards EMF, and then about practices concerning risk communication and work safety instruction. We also asked participants which information about EMF they would find important to know, and about various contextual elements that might influence work safety. All participants were given the opportunity to make further additions at the conclusion of each interview. An overview of the interview guideline can be found in Appendix 1. This guideline was thoroughly tested in an earlier study involving PM exposure in roadwork companies (Stege et al. 2019), and it was slightly altered to fit the situation involving EMF in power plants.

2.3. Data analysis

After getting a verbatim transcription for all 15 interviews, we used Atlas.TI version 5.2 for a qualitative analysis involving coding. Coding is the process by which short phrases or keywords are attached to text fragments in order to systematically analyze and interpret these fragments, and to uncover links between these fragments in the data (Merriam 1998). The grounded theory approach states that qualitative analysis is usually accompanied by three types of coding, namely

open, axial and selective coding (Strauss and Corbin 1990). Open coding is the first step, in which the initial interpretation is made; axial coding groups similar codes together within categories; and selective coding identifies the core categories (Strauss and Corbin 1990).

In a process of open coding, the author who performed the interviews defined an initial coding scheme based on the first three interviews. These codes corresponded to some extent with the questions we asked during the interview, but they were categorized further by means of axial and selective coding. For example, we asked for participants' thoughts about EMF, and the actual coding provided details on whether the answer was related to the definition of EMF, sources of EMF, mitigation methods, and so on. This yielded codes such as 'EMF_cause_generator', 'EMF_effect_pacemaker' and 'EMF_mitigation_warningsigns'. We also asked about work safety instruction, which in these companies was called 'toolbox', and participants gave us information about things such as the frequency, contents and methods of instruction. Therefore, this yielded codes such as 'toolbox_frequency', 'toolbox_contents_EMF', and 'toolbox_method_elearning'.

When 12 of the 15 interviews were coded, the first and third authors discussed and refined the coding scheme and each coded the final three interviews separately. There were no significant discrepancies concerning the actual contents of the codes. The total number of codes added up to 157.

3. Results

The results from the interviews are categorized into three main themes: perceptions of exposure to EMF, safety by design, and education. This is in line with the important aspects of work safety mentioned in the introduction, with the first theme corresponding with our research question and the second and third themes corresponding with the two main areas of mitigation.

3.1. Perceptions of exposure to EMF

During the interview, all participants were asked which risks were involved with their work. Various risks were mentioned, including heat, high pressure, electrocution, falling and tripping, toxic substances, particulate matter, mechanical risks and noise. Although all participants were aware of the presence of EMF within their company, less than half of them mentioned EMF as a relevant risk themselves. For example, one participant mentioned several risks other than EMF, and that participant was then asked to tell something about EMF.

> *Electromagnetic fields. Yes, we have those around the transformers. […] We usually stay away from those as much as possible. We do not get involved with them a lot.* [ptcp. 12]

The sources of EMF were often mentioned implicitly, not explicitly. To most participants, it made intuitive sense that EMF exposure is present in power plants. However, some more specific sources were mentioned, including generators, transformers, cables, and communication devices such as transceivers.

The majority of participants mentioned that people with pacemakers and other active implants are at risk of disruptions when exposed to EMF. Other short-term effects of exposure to EMF such as muscle contractions, headaches, nausea and phosphenes were also mentioned. One participant mentioned the possibility of current induction in your body, and one participant talked about sleeping disorders. Two participants pointed out that effects such as muscle contractions might also lead to indirect effects such as tripping or falling, as illustrated by the following quote:

> *If you are working in a certain situation surrounded by dangers, but you are standing on your ladder just fine, having everything under control, and then suddenly you get an involuntary muscle contraction, that could mean that you fall off your ladder.* [ptcp. 6]

Considering the long-term effects, about half of the participants simply had no idea about any long-term effects, although some were aware that these are unknown for the most part. Only one participant referred to a study that showed a link between EMF and childhood leukemia, although he was skeptical about the scientists' conclusions:

> *[I have read about] childhood leukemia. People are living in a neighborhood under transmission towers, and they just say harshly [to them], "it has been proven that more cancer occurs among these children", but they say "whether there is a causal link is not proven". Well, I think that is a big lie, because if you measure it in several areas and it is simply more under the transmission towers, then it is proven in my opinion.* [ptcp. 13]

Nevertheless, all participants who were asked agreed that EMF exposure had not led to any health effects in their company, as illustrated by this quote:

> *Well, EMF… I have never heard of anyone actually being hurt by it.* [ptcp. 8]

In two of the three companies, detailed measurements had recently taken place by third parties, and for the third company it was planned shortly after these interviews. The stakeholders took the task of measuring EMF exposure seriously:

> *Some time ago we heard from the work inspectorate, I think, that we had to pick this up. Well, we bought a meter immediately. […] We visited all units, did the measurements and pasted the stickers.* [ptcp. 8]

One participant showed a more detailed description of the measurements during the interview. The results of these measurements indicated that EMF exposure was indeed below the action values of 1000 microtesla as stated in the European Directive:

> *This is a list of measurements. […] [In this specific situation, with a 50 Hz frequency] I measured a field strength of 86 microtesla. Which is very low, as it is allowed to go up to 1000.* [ptcp. 1]

3.2. Safety by design & mitigation

One participant, the occupational hygienist, gave a detailed overview about the occupational hygiene strategy for EMF within the branch. He referred to the four-step overview of the strategy, filling in each step in the process:

> *It starts like this: address the source, for if you remove the source, there will never be a problem. But that is impossible [with EMF] since the power plant will just shut down. […] The next step in the strategy is: take care of technical measures. A fence is a technical measure. […] Organizational measures include a sticker, an icon, a warning. […] The final safety option is personal protection. That is not possible [with magnetic fields].* [ptcp. 6]

The two mitigation methods mentioned above, fences and warning signs, are also mentioned by most of the other participants. According to several participants, there has been such a strong reduction in EMF exposure due to fences that the risk was completely mitigated, at least for people without pacemakers or active implants. This is illustrated by the following quote:

> *Not anymore, because we have mitigated it. If you look at the working distances to the source, I would think "well, that is not the most exciting thing". I can imagine that it would be different with a different type of installation. […] But we have managed it away in the design.* [ptcp. 4]

Most participants also mentioned the warning signs, and the fact that these people take the warnings seriously is illustrated by this quote:

> *If I see such a pictogram, I will keep my distance.* [ptcp. 10]

Two participants pointed out that fences and other enclosures were sometimes already in use for other types of risk, such as electrocution or noise, thereby mitigating all EMF risk in the process:

> *Often it is also about noise reduction, that it [an enclosure] is already around [the installation].* [ptcp. 3]

3.3. Education

The three companies all maintained periodical work safety meetings. Company A sent employees an email before having a plenary session in which employees could ask questions and had to sign a presence sheet. Company B had implemented all workplace risk instruction within an e-learning format, with a small test at the end of it. Company C had assimilated the work safety meetings with the department meetings, setting apart time within these meetings for several safety issues.

Most of the risk information was either embedded within these work safety meetings or given more informally. However, all companies provided short instruction films and small quizzes both visitors (including the interviewer of this study) and new employees need to watch before entering the premises.

Company A had recently implemented a work safety meeting on EMF, but this meeting was considered too bureaucratic and unpractical:

> *We are really saying here, 'we are going to make a task risk analysis' [in places with high EMF exposure]. Then we say, 'alright, there is a risk, we are going to do [the work] anyway.' Appointing an EMF guard. That just means that you are working and I am watching from two meters distance wearing a transceiver. 'Oh, he looks a bit pale, I am going to take him back.' Should I walk into the area where you are working and pull you away, or should I walk away and get help?* [ptcp. 15]

Company B had a standardized e-learning instruction about EMF, which had been successful but needed some updating:

> *It might be about time to look out for other ways of giving safety and health information […] because I think that it gets a little less attention than before. The novelty is gone, many people have heard it two or three or four times already. And sometimes you just need to apply some new methods to reach the knowledge or attitude or behavioral change.* [ptcp. 6]

Company C did not appear to have any work safety meetings dedicated to EMF; one participant thought that they did, but could not recall any details, and one other participant was adamant that they had not. EMF was mentioned in the instruction film everyone needs to watch before entering the premises, but only in relation to active implants such as pacemakers.

Even though participants did not consider exposure to EMF as an important risk in power plants, the majority of them, regardless of the company they were in, still thought some information is needed, as illustrated by the following quotes:

> *I think it is definitely useful to make a work safety meeting out of it. Inform the people [about EMF].* [ptcp. 13, company A]

> *We have to recognize [EMF]. We have to instruct people about it.* [ptcp. 11, company B]

> *Give information. Show people what it is about, but especially mention whether it causes damage or not. Do not just throw the words [electromagnetic fields] out there.* [ptcp. 3, company C]

The majority of participants, regardless of the company, also said that possible effects of EMF should at least be discussed, as well as possible protective measures. For the most part, this meant that people should know the appropriate minimum distance to keep from several EMF sources. This is illustrated by the following quote:

> *For us it is like this: it is a certain area. It is fenced off. And you should just not come behind it, or too close to it. So then it is done. That is really [all we need to know].* [ptcp. 9]

Participants mentioned some other information needs as well, including information on EMF detection, various sources of EMF, and a definition of EMF. About a quarter of the participants found it important to have a dedicated EMF expert present within the company. Interestingly, this is mostly (but not exclusively) seen in company C, the company without a dedicated EMF work safety meeting.

They need to be able to find the procedure. They need to know where their expert is, so to say, in the area [of EMF]. [ptcp. 4, company C]

[I find it important to know] who is responsible. So whom should you ask if there is a problem [about EMF]? [ptcp. 9, company B]

Many participants were to some extent satisfied with the work safety meetings. One participant pointed out that, no matter what form you choose for the instruction, it will never be ideal, but retention is crucial no matter what you choose:

An e-learning tool is an option. A plenary session is an option. And in both cases I can say with certainty that it will never be one hundred percent perfect. [...] The best option would be that which makes the receiver remember what it is about, and which extracts the most relevant things for him. [ptcp. 11, company B]

Various factors may influence the efficacy of safety instruction, other than the mere presence of risk information. About half of the participants pointed out the need for communication within the company. For example, one participant said that work safety meetings are more effective when employees are given the opportunity to give their opinion on the contents:

I would say: "Well, did everyone read the [instruction]? What do you think about it? Does it still fit with us, or do we need to change [it]? Or do you think that there are things that are irrelevant for us, or illogical?" [ptcp. 7]

4. Discussion

4.1. General discussion

In this study, we investigated the perceptions of employees in power plants concerning work safety with regards to EMF. We found that the employees in power plants that participated in this study perceived EMF not as an important health risk. These power plants use fences and warning signs to mitigate the risks, and employees perceive a high degree of safety by design. Employees in this study agree that being informed about EMF is still important even if the actual risk is low, and they feel that there is room for improvement in the companies involved when it comes to instruction methods.

4.1.1. Safety by design & mitigation

It appears that EMF risks are mitigated to a large degree in power plants in this study. All companies already provide fences, as well as warning signs indicating strong electromagnetic fields, to alleviate any potential for EMF exposure that exceeds legal limits. Since these legal limits have become somewhat less strict in the past few years (Alanko et al. 2014; European Commission 2015), the chance of exceeding the legal limits has decreased further. Even though this does not automatically guarantee the safety of the legal limits, there are also no clear indications that there are adverse effects of EMF present in the companies in this study. Since several participants mentioned that there have been recent measurements as well as additional warning stickers, it is plausible that in these three power plants no sections exist where exposure at accessible places will exceed the Action Values.

4.1.2. Emf perceptions & education

Participants are aware of the existence of EMF as well as the potential presence within their companies. Nevertheless, employees' perceptions regarding effects of EMF are not always accurate. Even though there is a European Directive to protect workers against short-term health effects from exposure to EMF, some employees are unaware that EMF exposure might have short-term adverse effects even in people without implants (Health & Safety Executive 2016).

Most participants do not mention long-term effects, but at least one participant assumes that there are long-term adverse health effects such as cancer, based on the studies involving transmission towers and leukemia (e.g. Kheifets, Afifi, and Shimkhada 2006). It appears that the misconception here, the idea that a causal link between EMF and cancer would be proven, can be explained by a lack of understanding of scientific methods.

One difficulty in designing a system for EMF health risk information is the absence of clarity about long-term effects (Health & Safety Executive 2016). One approach is to include information about potential long-term risks, including neurodegenerative diseases (Huss et al. 2015) and non-specific physical symptoms (Baliatsas et al. 2015; Bolte et al. 2015), while also mentioning that these effects remain unproven and are therefore uncertain. By including these uncertain effects, employers ensure themselves of being thorough in informing their workers of potential risks. If future research turns out to confirm these long-term effects of EMF, employers can then be credited with their expeditious approach of risk communication.

Literature suggests that employees should get sufficient practical instructions, not just theoretical insights (Niewöhner et al. 2004; Petts et al. 2002). However, participants in this study point out that, besides keeping distance and shielding yourself from the source, there is not much to be done about EMF if exposure levels are exceeded. Although the amount of practical instructions to be given in the context of EMF is limited, clear information about these basic preventive measures might already be helpful. For example, companies could give facts and figures about the potential exposure within a certain distance, and tell workers to keep the fences and warning signs in check. Since power plants appear to be well-informed about precise EMF exposure in various locations on their premises, they could even include a 'heat map' of EMF exposure in their risk information system, as recommended by Koehler and Volckens (2011).

4.2. Strengths and limitations

This study gives an overview about the EMF safety systems that are in place in the large power plants in the Netherlands. Of course, the relatively small sample size is a limitation for the generalizability for these results, and we cannot claim that our sample is representative. We cannot be certain that we have a complete overview of relevant issues regarding EMF exposure risk and mitigation. We believe we have nevertheless succeeded in getting a fair cross-section of both the participating companies and the Dutch electricity branch in general (all three major Dutch electricity companies were involved in this study), with sufficient diversity in participants. The generalizability to other countries remains an issue, though; differences in laws and safety culture might lead to an increased EMF exposure, and thereby more adverse effects. We feel this is an important starting point for future research. Finally, the qualitative set-up of this study has led to insights from employees of these power plants regarding EMF exposure, but there as we did not perform any measurements ourselves we have no way of knowing that these insights are accurate.

5. Conclusion

Based on this study, employees in power plants do not appear to perceive EMF as one of the most important risks within their companies, mainly because there is a high degree of mitigation. Participants in this study are aware of the most important mitigation methods, fences and warning signs, and they feel that their workplace has a high degree of safety by design because of this.

While mitigation methods are in place, participants still feel that they should be informed about basic aspects of EMF. We recommend that power plants give at least the most relevant EMF risk information to employees, such as the Action Values from the EU Directive, how to

recognize potential high exposure areas (signs and fences) and the possible health effects, including nausea, vertigo, phosphenes and so on (Health & Safety Executive 2016). Participants in our study often mentioned these subjects when asked for their information needs. It also turned out that they would like more clarity on who would be responsible within the company for EMF-related issues, so we also recommend including this in the risk information.

Education about risk helps as a prevention tool in its own right. Risk information about EMF should aim to alleviate misconceptions that are present, as well as provide more clarity on effects and mitigation methods. Even though periodical work safety meetings are in place in all companies, one of them does not explicitly discuss EMF. All companies should do that. To prevent the meeting from getting bureaucratic, a plenary question-answer session may be a fitting method. In order to reduce (perceived and actual) bureaucracy, we recommend thoroughly investigating whether safety measures are actually necessary to work safely or if they are superfluous, with the caveat that companies should of course comply with legally mandated safety measures.

Finally, it is interesting to note that employees are allowed to provide input for the work safety meetings, at least in one of the companies involved. Work safety experts ask questions about the contents of these meetings to the engineers and other employees, and they can give their opinion on which content might be outdated or irrelevant. We certainly recommend maintaining this practice, as it is a perfect example in line with the idea from Hambach et al. (2011) that employees want to feel listened to.

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Appendix 1. Interview guideline (translated from Dutch)

- Can you tell me something about [company name] and the work you are doing here?
  - How long have you worked here?
    - And how old are you?
  - What education did you follow?
  - Are you satisfied about your work?
- What risks would you say are involved with this work?
  - [if not yet mentioned] Can you tell me something about things in your workplace that might make you ill?
    - Do you struggle with health issues?
      - What is the cause of these issues?
      - To what extent does your work play a role in this?
  - Can EMF (electromagnetic fields) be a risk? [if not yet mentioned]/Can you tell me more about EMF? [if mentioned]
    - [if they have no idea at all, give them a short explanation of what EMF is]
    - To what extent is EMF a relevant health risk?
      - What are the properties of EMF?
      - What does that mean for your health?
  - How does [company name] handle issues regarding EMF exposure?
    - What rules and guidelines are in place?
    - To what extent are these guidelines prioritized?
    - What is your opinion on how these issues related to EMF are handled?
- How do you get safety instructions at work?
  - To what extent is EMF given any attention?
  - Which materials and instruction methods are used?
  - What is your opinion on the current state of affairs regarding safety instruction?

    - What would you like to know about EMF?
        - What would you consider a good method of getting this information?
        - From whom would you like to get this information?
    - Can you think of any ways to prevent work-related risks other than methods of instruction?
- To what extent do you feel that you are in a safe and healthy work environment?
    - To what extent are you aware of methods to mitigate risks?
    - How do you handle this in practice? [If needed, assure them that this is not an inspection and they can give any answer without repercussions]
    - Would you say that [company name] has a good safety culture?
- Would you like to add something we have not discussed before?
    - Do you have any questions for me?