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Original Article

Assessing the consistency of two models of benzene neurotoxicity risk assessment to create and validate a health risk screening guideline among fuel service workers

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ABSTRACT

Introduction: This research and development study aimed to (1) evaluate the consistency of two models of benzene neurotoxicity risk assessment (NRA) and (2) create and validate a neurotoxicity risk screening manual among fuel service workers (FSW). Data were collected through interviews and urine collection. The neurotoxicity risk screening was divided into two models: qualitative neurotoxicity risk assessment (NRA-1) and quantitative neurotoxicity risk assessment (NRA-2). The two sample groups included inside- and outside the fuel dispenser area were 100 per group, and a neurotoxicity risk screening guide was created and validated using a panel of 15 experts.

Methods: NRA-1 used the following variables in health screening to assess exposure to benzene: frequency of exposure, duration of work (years), number of working hours, number of overtime hours per week, number of trucks providing refueling services per day, and reuse of clothes. NRA-2 used two variables to screen for frequency of exposure: frequency of work (hours per day) and trans,trans-muconic acid (t,t-MA) levels in urine.

Results: NRA-1 showed that 29.0% of the workers had a low risk level, 37.0% moderate, 13.0% high, and 2.0% very high. For NRA-2, 32.0% of the workers had a low risk level, 37.5% moderate, 11.5% high, and 6.0% very high. Both NRAs were statistically significantly consistent ($r = 0.409$, $p < 0.001$). The neurotoxicity risk screening guide was criticized by experts, and it can be concluded that it can be used as a pilot for neurotoxicity screening of FSWs.

Conclusion: The risk assessment was conducted using both qualitative (NRA-1 model) and quantitative (NRA-2 model) methods. The both methods can be applied to easily implement the assessment. The low-cost method can be used to perform the qualitative assessment without testing for metabolites in urine.

Keywords: Benzene, Fuel service workers, Neurotoxicity risk assessment, Medical and public health personnel

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Introduction

Chemicals in fuels have shown that benzene is a substance of particular concern because it is a known carcinogen.[1] There are reports of measurements of benzene in fuel stations that exceed the standards set by the American Conference of Governmental Industrial Hygienists, both in the environment and in the bodies of workers.[2-4] For example, a study of exposure to benzene, toluene, ethyl benzene, and xylene (BTEX) in the urine of fuel station workers found that the workers had benzene (B) exposure exceeding the standard by as much as 29.0%, but toluene (T) was within the standard.[5] Accordingly, fuel station workers are at higher than acceptable health risks.[6]

Benzene can affect workers' health, which is a matter of great concern because 50% of the BTEX that humans inhale throughout their lives will be absorbed into the body.[7] Tunsaringkarn et al.[8] stated that only 14.6% of fuel service workers practice safe behavior while working. The health effects from this group of substances can occur both acutely and chronically in many systems. The main effects are on the nervous system.[7,9-11] Exposure to excessive amounts of benzene can damage the central nervous system (CNS), cause depression,[12] and affect memory, understanding, and behavior.[13] Even at low concentrations, long-term exposure to benzene increases the risk of anemia and leukemia in humans.[14-16]

Health care for risk groups exposed to benzene is usually done by assessing the biomarker of benzene exposure in urine in the form of trans,trans-muconic acid (t,t) MA;[17-18] evaluating changes in biochemical indicators, such as neurochemical biomarkers such as acetylcholinesterase;[19-20] evaluating symptoms in various systems using the modified EUROQUEST questionnaire;[21] and performing neurobehavioral tests and systems.[22]

However, there are still limitations in occupational health operations for informal workers at fuel stations, including a lack of personnel to assess health risks, relatively high prices for toxicology laboratory analysis, and insufficient resources to support occupational health.[23] In Thailand, over the past few years, seven agencies have been authorized to conduct independent laboratory analysis, with only two laboratories located in the eastern region. Importantly, the cost of toxicology laboratory testing based on risk factors is higher than the cost of general analysis; for example, the average cost of t,t-MA analysis is 391.4 baht per sample.[24] Therefore, one option is to use health risk assessment as a method to screen for neurological risks among fuel service workers exposed to benzene.

The assessment of benzene's health risks involves both qualitative and quantitative assessment models, which have been internationally recommended. In Thailand, guidelines for health risk assessment are based on the TIS 2012 standard.[26] Previous studies have assessed occupational health risk models of exposure to benzene, toluene, and xylene at low concentrations, which were semi-quantitative and quantitative assessments, in five manufacturing establishments in China,[27] the health risks of benzene inhalation among gas station workers using the model of the U.S. Environmental Protection Agency (EPA),[28] a biomatrix of health risk assessment of benzene-exposed workers at Thai gasoline stations,[6] and the health risks of volatile organic compounds in high-risk groups in Map Ta Phut Industrial Estate, Rayong Province.[29] For qualitative risk assessment, a health risk assessment model to screen for farmers exposed to pesticides.[30]

There is no study on the creation of a manual for screening the risks of benzene to the nervous system in a risk group. Gas stations contain a variety of chemicals that affect the nervous system, particularly aromatic hydrocarbons such as benzene, toluene, ethylbenzene, and xylene (BTEX group). Studies on several chemicals have found that 29.5% of gas station workers have t,t-MA levels (metabolites of benzene) exceeding the American Conference of Governmental Industrial Hygienists (ACGIH) and Thai standards (more than 500 μg/g Cr).[2,6] The gas station workers also reported 32.5% more neurological symptoms than those who did not previously work there. Toxicology has confirmed a link to the nervous system, which has led to the development of an assessment model. However, other chemicals may also have an effect, such as toluene, but its metabolite levels in urine have been found to be within standard limits.[5] Research studies have only been conducted on the benefits of health monitoring of professionals working at fuel stations in Thailand, who do not have annual health check-ups for risk factors like those in the industrial sector.[3,28] Therefore, our study's objective was to assess the consistency of two models of benzene neurotoxicity risk assessment to create and validate a health risk screening guideline among fuel service workers. The benefits include creating innovations in neurotoxicity risk screening, and the screening manual can be efficiently utilized to reduce costs and mitigate the impact on the nervous system from benzene exposure in the risk group in the future.

Methods

This study used a research and development design. The research operation was divided into three phases: (1) studying personal information, work history, and metabolites of benzene exposure in urine (trans,trans-muconic acid, t,t-MA); (2) assessing the consistency of two models for assessing benzene risk to the nervous system; and (3) creating and validating a manual for screening health risks among fuel service workers (FSWs) for medical and public health personnel and assessing satisfaction with its use. This study was reviewed by the Human Research Committee at Burapha University, with research project code number HS 031/2020, prior to data collection.

The sample was divided into three groups according to the research phase as follows: In Phases 1 and 2, the sample group consisted of individuals who worked in the fuel station area. The sample size was calculated using the unknown population mean estimation formula by substituting the variance (σ) from Eze et al.[31] in the fuel station group, which was equal to 0.36; the 95% confidence (z) value was 1.96, and the error (e) value was 0.05. The sample size was 200 people, divided into the exposure group of 100 people, who worked in the fuel station (inside fuel dispenser areas: I-FDA) and were responsible for providing fuel, and the comparison group of 100 people, who worked in the fuel station but were not directly accountable for providing fuel (outside fuel dispenser areas: O-FDA). The inclusion criteria consisted of working in a fuel station (either I-FDA or O-FDA); being 18–60 years old; being able to read, listen to, and write Thai; and consenting to participate in the research. The exclusion criteria were being unable to work the whole 8 hours or participate in the research activities. The sample consisted of 200 workers in the area of 8 gas stations. This research assessed exposure using the dose of t,t-MA in urine. Therefore, the study selected gas stations of the same size, with a similar number of workers, and offering similar welfare benefits to workers, in an attempt to control for exposure consistency.

In Phase 3, the sample group consisted of 15 experts, including academics and users of NRA guidelines. Academics were university lecturers and doctors with expertise in related fields, including occupational health, industrial hygiene, community and family medicine, toxicology, public health, research statistics, engineering, the environment, and communication technology. Users included representatives from the occupational and environmental diseases division and representatives from occupational and environmental medicine groups of hospitals in the sample area.

Phase 1: Personal information, work history, and t,t-MA in urine. The research instruments and data collection in this study were divided into two parts: an interview form and a urine sample collection device, as follows:

1) The interview form was divided into four parts, totaling 30 questions. The scores were given by selecting the answer and filling in the blanks. The questionnaire consisted of the following: (a) Personal information data, 10 questions, such as gender, age, body mass index, income, marital status, education level, smoking, and alcohol history. (b) Personal hygiene, nine questions, divided into five positive questions, such as washing hands before eating, washing hands before drinking water, changing clothes after work, going out to rest in an area away from the fuel dispenser during breaks, and four negative questions, such as drinking water in the work area,

wearing the same clothes to work the next day, etc. The answer options are actions: yes or no. (c) Six questions about behavior in using personal protective equipment (PPE) and appropriate work clothes, such as safety glasses, face masks, gloves, boots or sneakers, long pants, and long sleeves. The answer options are actions: yes or no. (d) Work history, including five items: work experience (years), number of working hours per day, number of working days per week, overtime work (hours/week), and sleep time per night (hours), among others.

Fifteen symptoms of the nervous system were assessed using an interview form, including dizziness, headache, fatigue/easily tired, stress/irritability, lack of concentration/poor memory, more drowsiness than usual, nausea/vomiting, numbness in the hands/feet, weak arms and legs, hand tremors, loss of smell, or reduced sense of smell. If there was at least one symptom, it was considered abnormal.

To ensure the quality of the interview form, the researcher brought the developed instrument to three experts, consisting of one university lecturer specializing in occupational health and two occupational physicians. After the quality test, the item-objective congruence index (IOC) was calculated for each item. It was found that each question had an IOC value of more than 0.5 for all items. The reliability was checked by finding the Cronbach's alpha coefficient, which was 0.88.

Interview forms were collected per the following steps: (i) After receiving approval from the research ethics committee, the researcher recorded a message and initially coordinated with the fuel station's manager to request cooperation in the study, explain the study's objectives and details about data collection, and request permission to collect data. (ii) The researcher met with the fuel station's manager and FSWs to explain the objectives and request permission to collect data at the time, date, and location provided. (iii) The researcher went to the area to collect research data by interviewing. The researcher explained the questions to the research assistant so they would understand them in the same way. Later, the researcher met with the manager at each fuel station, as scheduled, to begin collecting research data by interviewing the sample at each location. The interview took 10–15 minutes for each person at the office of each fuel station. The interview form was received after the interview was completed.

2) Urine collection, with equipment including a 50-mL polyethylene container, for the purpose of assessing the levels of t,t-MA with data interpretation criteria according to the recommendations of the ACGIH.[2]

For urine sample collection, the researcher distributed urine sample containers to workers during work and instructed them to collect urine samples at the end of the shift; workers collected mid-stream urine samples in a plastic cup, poured half of the urine container into a polyethylene container, and immediately placed it in a cooler box at a temperature below 4°C. When the required amount was collected, it was sent to the laboratory each day for analysis of t,t-MA levels; the analytical laboratory was an ISO/IEC 17025 or ISO 15189 laboratory.

The quantity of the samples was analyzed by using column type C18, mobile phase, containing water/acetonitrile at a ratio of 50:50 v /v, the flow rate of 1.0 mL/min at 37.0 °C, sample solvent by methanol, and ultraviolet detection at 254 nm wavelength, and extracted using the method of Onchoi followed by analysis using High Performance Liquid Chromatography (HPLC). the interpretation of the results based on the ACGIH used a cut-off point (standard normal), which t,t-MA <500.00 μg/g Cr.[32]

Phase 2: Assessment of the consistency of the two models of benzene neurotoxicity risk assessments (NRA). The four steps of health risk assessment were as follows:

Step 1: Hazard identification. The researcher used data collected in Phase 1, including personal information, work history, and t,t-MA in the urine of operators working at fuel stations, including fuel filling, cashiering, and loading fuel (I-FDA), and washing vehicles, repairing vehicles, selling in a convenience store, and selling beverages and food (O-FDA). The details of the chemical data (Safety Data Sheet) for benzene, including the amount of benzene exposure, exposure frequency (EF), and exposure duration (ED), were studied.

Step 2: Dose response. The results from the assessment of abnormal neurological symptoms in the Phase 1 study were grouped into 5 scores to classify health effect rating (HER) or severity rating (SR): 1 (0–2 symptoms), 2 (3–5 symptoms), 3 (6–8 symptoms), 4 (9–11 symptoms), and 5 (12–15 symptoms or more).[33]

Step 3: Exposure assessment, to assess benzene exposure in two models: qualitative exposure assessment using an interview and quantitative exposure assessment by assessing t,t-MA. After that, the exposure rating (ER) was classified by multiplying it with the exposure frequency (EF) as follows:

a) Qualitative exposure assessment. The exposure assessment was derived from the results of the relationship analysis between the independent variables (personal information, work history, personal hygiene, and PPE) and the dependent variable (neurological symptoms). The variables with a statistical relationship of $p < 0.05$ were selected to be used to predict the level of benzene exposure, including (A1) duration of work (years), (A2) overtime worked (hours per week), (A3) number of pickup trucks refueled per day, (B1) wearing short-sleeved shirts while working, and (B2) wearing the same clothes repeatedly or wearing the same clothes for more than 1 day. The above variables are identified as risk factors based on the statistical analysis.

The levels of qualitative ER were calculated as the exposure assessment score (EAS) from risk factors (RF) by summing the scores (A1+A2+A3+B1+B2) multiplied by the exposure frequency (EF) or A4, which is calculated as follows:

Qualitative exposure assessment:

$$EAS = RF \times EF = (A1+A2+A3+B1+B2) \times A4 \qquad (1)$$

b) Quantitative exposure assessment uses the criteria according to the Thai Ministry of Industry's 2012 announcement on chemical risk assessment, using the results of the assessment of t,t-MA compared with the standard value of the biological exposure index (BEI) to obtain the chemical concentration rating (CR). CR was classified into five levels (10% lower than BEI, 10–49%, 50–74%, 75–100%, and >100%). The Biological Exposure Indices (BEIs), as recommended by ACGIH2, define t,t-MA as less than 500 μg/g Cr. Therefore, the range of t,t-MA exposure levels is divided into <50, 50–249, 250–374, 375–500, and >500 μg/g Cr, and was scored as 1, 2, 3, 4, and 5, respectively, then multiplied by the EF. The EF consists of Level 1 (exposure once a year), Level 2 (exposure 2–3 times a year), Level 3 (exposure 2–3 times a month), Level 4 (exposure for 2–4 hours continuously in one shift), and Level 5 (continuous exposure throughout the entire shift). Then, the exposure rating (ER) was obtained. Therefore, when calculating of CR and EF, it will be equal to 5 x 5, the total is equal to 25 points, divided into 5 levels of exposure again: 1–3, 4–6, 10–16, 17–20, 21–25, interpreting the exposure level as 1–5, which is acceptable, low, moderate, high, and very high,[26] to be used in the matrix with Health effect rating (HER).

Quantitative exposure assessment:

$$ER = CR \times EF \qquad (2)$$

Step 4: Risk characterization (RC). This step involves identifying qualitative risk characteristics at five levels: acceptable or insignificant, low, moderate, high, and very high. It is obtained by multiplying the CR by EF to get ER, then multiplying ER by the health effect rating (HER) or the severity level from Step 2 (Levels 1–5), and then comparing the scores in Table 1 to rank the risk level according to the Thai Ministry of Industry's[26] announcement on chemical risk assessment.

$$RC = ER \times HER \qquad (3)$$

Table 1: Levels of risk characterization (RC)

Health effect rating (HER)	Exposure rating (ER)					Exposure Assessment Score (EAS)		
	1	2	3	4	5	Score	Levels	Levels
1	1	2	3	4	5	1-3	Acceptable	0
2	2	4	6	8	10	4-6	Low	1
3	3	6	9	13	15	10-16	Moderate	2
4	4	8	12	16	20	17-20	High	3
5	5	10	15	20	25	21-25	Very high	4

Phase 3: Creating and validating a neurological risk assessment (NRA) manual among FSWs for medical and public health personnel and assessing satisfaction with its use.

To assess the consistency of the qualitative neurological risk assessment (NRA-1) and quantitative neurological risk assessment (NRA-2), the scores of the two models were analyzed for consistency using the kappa test. Then, details of the nervous system risk assessment of benzene were used to create and validate the manual, consisting of Part 1: Academic content of the manual: basic knowledge of occupational chemicals, the body's dose-response to chemicals, chemical toxicity, biomarkers, health surveillance, and principles of health risk assessment; and Part 2: Neurological risk screening and guidelines (NRA-1 and NRA-2).

Satisfaction with the implementation of the NRA screening among FSWs exposed to benzene was assessed for use in the field. The researcher organized a meeting to gather opinions from 15 experts, including academics and those who would use the manual, including university lecturers; workers in occupational health, industrial hygiene, community and family medicine, toxicology, public health, biostatistics, engineering, environment, communication technology; staff from the occupational and environmental diseases division and department of disease control; and representatives from the occupational and environmental medicine of local hospitals.

The manual was assessed using the satisfaction assessment form and focus group discussions as follows:

1) The satisfaction assessment form had 21 items with three options (appropriate, fair, and should be improved). The items assessed novelty, applicability, usability as a guideline for health screening in accordance with the objectives, being created from appropriate and consistent academic principles and concepts, having a reliable process for obtaining the manual, new knowledge in the manual, ease of understanding and usefulness to readers, usefulness to the occupational health sector, the ability of the knowledge in the manual to be exchanged or referenced or disseminated in the profession, usability in real-world health service organizations, completeness of important topics, up-to-date content, clear explanations appropriate for the user group, consistent writing style, appropriate content sequence, reliability, interesting colors or appearance, easy-to-read font size, appropriate illustrations that communicate with the content, easy access when needed or downloadability, organization or ease of reading, and emphasis of essential topics.

2) The focus group was a brainstorming session with set questions to gather opinions from experts, including the appropriateness of the academic content of the manual, the clarity of the language used, and the feasibility of using the manual as a guideline for officials and public health personnel in screening the risks of fuel station workers. The researcher analyzed the content, used consensus to summarize the meeting results, and made adjustments according to the recommendations.

The statistics used in this study were divided into descriptive and inferential statistics. Descriptive statistics included frequencies and percentages. For inferential statistics, the chi-square test was used to analyze the relationship of pairwise variables between 19 independent variables, found that 6 variables were found to have a statistically significant relationship (p <0.05) with health symptoms, namely, work history (4 items) (duration of employment, working hours, overtime work, number of trucks filled with fuel), and risk behavior (2 items) (wearing short-sleeved shirts while working and wearing the same clothes repeatedly or wearing the same outfit for more than 1 day). Therefore, the 6 variables were combined with the neurological symptoms (15 items) and selected variables with a statistically significant relationship (p <0.05) to be used to predict the level of benzene exposure (Exposure rating, ER), with the exposure frequency (EF). In addition, Cohen's kappa coefficient was used to test the consistency of the two NRA screening models. The kappa score range is 0.00, 0.01–0.20, 0.21–0.40, 0.41–0.60, 0.61–0.80, and 0.81–1.00, which can be interpreted as very little, little, fair, moderate, good and very good, respectively.[34]

Results

Phase 1: Personal information, work history, and t,t-MA in urine.

There was a total of 200 workers: 100 inside fuel dispenser areas (I-FDA) and 100 outside fuel dispenser areas (O-FDA). The number of males and females was similar (the ratio of males to females was 1.00:1.27). The mean age was 27.78 years (SD = 5.95). Approximately half (52.5%) were overweight or obese. Of the I-FDA and O-FDA, 53.0% and 74.0% did not smoke, respectively. Regarding the history of alcohol drinking, 49.0% of I-FDA and 42.0% of O-FDA were still drinking. Overall, the majority of the 200 workers at the gas stations did not smoke (63.5%). However, some people did not smoke but could smell cigarette smoke from others (13.0%).

Overall, the workers (n = 200) had an average work experience of 2.44 (S.D. = 4.06) years, average working hours of 9.09 (S.D. = 1.54) per day, an average working period of 6.31 (S.D. = 0.47) days per week, and average overtime work per week of 6.42 (S.D. = 4.87) hours. The workers slept an average of 7.49 (S.D. = 1.38) hours per day. However, 19.0% of them slept less than 5–6 hours. The results from the study of the I-FDA group (n = 100) showed that an average of 32.65 (S.D. = 24.80) refueled pickup trucks and 31.51 (S.D. = 30.43) motorcycles per day per worker.

The results of the relationships between 19 independent variables and neurological symptoms found that six variables (risk factors: RF) related to neurological symptoms were statistically significant (p < 0.05), including the years of work at this fuel station, overtime worked, number of pickup trucks filled per day, number of working hours per day, wearing short-sleeved shirts, and wearing the same clothes or uniforms to work. Therefore, the researcher used all six factors to create an NRA-1 model in the second phase.

Phase 2: Assessment of the consistency of the two models of benzene neurotoxicity risk assessment (NRA).

Two NRA benzene models were developed to find a screening guideline: (1) a qualitative neurological risk assessment (NRA-1) model and (2) a quantitative neurological risk assessment (NRA-2) model[32] (see Table 2).

The results found that the exposure rating (ER) of the workers was 100% continuously exposed to benzene throughout the shift (see Table 3).

The exposure level results according to NRA-1 were obtained by multiplying the ER with the EF according to the score level (score 1–5). The ER was calculated from the grouping results from the EAS or RF (A1+A2+A3+B1+B2), consisting of work history and health behaviors multiplied by the EF (see Table 4)

Table 2: Risk factors for qualitative and quantitative NRA model

NRA-1 model			NRA-2 model	
Part 1 Work history		**Score (points)**	**Part 1 Work history**	**Score (points)**
A1	Duration of working at this fuel station _____ years	< 1 year = 0 ≥ 1 year = 1	Not used	Not used
A2	Working overtime _____ hours per week	<6 hours per week = 0 ≥6 hours per week = 1	Not used	Not used
A3	Number of pickup trucks _____ filled per day	<10 trucks per day = 0 ≥10 trucks per day = 1	Not used	Not used
A4	Working frequency at fuel areas (hours per day) Notes: This section does not need to be combined with other sections.	Rarely 2-3 times a year 2-3 times a month 2-4 hours per shift >4 hours per shift	Use the same as NRA-1 model	Use the same as NRA-1 model
Part 2 Health behavior				
B1	Wearing short-sleeved shirts while working	No = 0 Yes = 1	Not used	Not used
B2	Wearing the same clothes repeatedly or wearing the same outfit for more than 1 day at work	No = 0 Yes = 1	Not used	Not used
	Not used	Not used	**t,t-MA levels compared with BEI values** <10% of BEI 10–49% of BEI 50–74% of BEI 75–100% of BEI >100% of BEI	 1 2 3 4 5
Part 3 Symptoms of the nervous system (Numbers of symptoms)				
C1	0–2 3–5 6–8 9–11 12–15	1 2 3 4 5	0–2 3–5 6–8 9–11 12–15	1 2 3 4 5

Table 3: Number, percentage, exposure frequency (EF) and exposure rating (ER) levels classified by 2 models of exposure levels

Levels	NRA-1 model		NRA-2 model	
	Exposure frequency (EF)	**n, % (Hours working per day)**	**Exposure frequency (EF)**	**n, % (Hours working per day)**
1	Rarely	0 (0.0)	Rarely	0 (0.0)
2	2–3 times a year	0 (0.0)	2–3 times a year	0 (0.0)
3	2–3 times a month	0 (0.0)	2–3 times a month	0 (0.0)
4	2–4 hours per shift	0 (0.0)	2–4 hours per shift	0 (0.0)
5	>4 hours per shift	200 (100.0)	>4 hours per shift	200 (100.0)
Levels	**Exposure rating (ER) of NRA-1 model**		**Exposure rating (ER) of NRA-2 model**	
	ER was obtained by multiplying the Exposure score (ES) or the sum of Risk factors		EF was calculated from ER x EF*	

Levels	NRA-1 model		NRA-2 model	
	Exposure frequency (EF)	n, % (Hours working per day)	Exposure frequency (EF)	n, % (Hours working per day)
	(A1+A2+A3+B1+B2) with the frequency (EF) as shown in Table 3.			
1	acceptable	0 (0.0)	acceptable	0 (0.0)
2	low	8 (4.0)	low	40 (20.0)
3	moderate	102 (51.0)	moderate	52 (26.0)
4	high	75 (37.5)	high	49 (24.5)
5	very high	15 (7.5)	very high	59 (29.5)

Notes: Exposure rating (ER) of Qualitative NRA-1 was obtained by multiplying the Exposure score (ES) or the sum of Risk factors (A1+A2+A3+B1+B2) with the frequency (EF) as shown in Table 3. *For Exposure rating (ER) of Quantitative NRA-2 was calculated from exposure rating, ER x EF follow with Thetkathuek et al.[33]

Table 4: Qualitative neurological risk assessment (NRA-1) model

Exposure rating, EF (A4)	Exposure assessment score (EAS) or Risk factor (RF) A1+A2+A3+B1+B2					Exposure levels		
	≤1	2	3	4	5	Exposure assessment score (EAS)	levels	Exposure rating (ER)
Rarely	1	2	3	4	5	1–3	acceptable	1
2–3 times a year	2	4	6	8	10	4–6	low	2
2–3 times a month	3	6	9	13	15	10–16	moderate	3
2–4 hours per shift	4	8	12	16	20	17–20	high	4
>4 hours per shift	5	10	15	20	25	21–25	very high	5

The exposure level results according to NRA-2 were obtained by multiplying the ER according to the results of the comparison with the five BEI levels and the EF. Details are shown in Table 1 (column NRA-2 model).

The results of the study were obtained by combining scores for abnormal neurological symptoms. It was found that most cases had a Level 2 effect on the nervous system, totaling 49 cases (24.5%) (see Table 5).

The results of the RC study were obtained by multiplying the ER score by the HER score. The RC percentage was classified into five risk levels (RLs): acceptable, low, moderate, high, and very high. The study's results showed that in NRA-1, the largest group was at the moderate level (n = 74 cases; 37.0%), followed by the low level (n = 58 cases; 29%). In NRA-2, the largest group was at the moderate level (n = 75 cases; 37.5%), followed by the low level (n = 64 cases; 32%).

Table 5: Number and percentage of abnormal neurological symptoms

Levels	Neurological symptoms (Symptoms)	n	%
1	0–2	102	51.0
2	3–5	49	24.5
3	6–8	31	15.5
4	9–11	13	6.5
5	12–15	5	2.5

The consistency assessment showed a close consistency between the two NRA models. When the researcher tested the results statistically using Cohen's kappa coefficient, it was found that the two risk assessment formats were moderately consistent (kappa = 0.41, $p < 0.001$; see Table 6).

Table 6: Number and percentage of RC of NRA1 and NRA-2

Risk characterization (RC)			NRA-1		NRA-2		Kappa test	p-value
Score	levels	Levels	n	%	n	%		
1–3	acceptable	0	38	19.0	26	13.0	0.41	<0.001
4–9	low	1	58	29.0	64	32.0		
10–16	moderate	2	74	37.0	75	37.5		
17–20	high	3	26	13.0	23	11.5		
21–25	very high	4	4	2.0	12	6.0		

Phase 3: Creating and validating an NRA manual among FSWs for medical and public health personnel and assessing satisfaction with its use.

The researchers used the NRA-1 and NRA-2 models to create a screening manual for neurological risks, which consists of two parts: the screening manual and the steps of the screening process, as follows:

1. The NRA screening manual for medical and public health personnel (Figure 1) resulted from content quality checks from brainstorming in the form of focus groups of experts and users. The content consisted of two parts: (i) relevant academic content and (ii) a neurological risk screening manual obtained from research and recommendations for use in the assessment. The details are as follows:

Part 1: The manual's academic content includes basic knowledge about occupational chemicals, the body's dose-response to chemicals, chemical toxicity, biological indicators, health surveillance, and principles of health risk assessment.

Part 2: The neurological risk screening form and recommendations for use in health risk assessment consist of a qualitative NRA-1 and a quantitative NRA-2, including examples of assessments based on neurological risk levels.

2. NRA screening included the following steps:

1) The qualitative NRA-1 to screen health risks to the nervous system used a questionnaire consisting of work history, health behaviors, and abnormal neurological symptoms. Those factors entered the obtained data into the risk assessment classified according to the various steps mentioned above. The quantitative NRA-2 assessed the level of exposure using the EF data with the results of the assessment of the level of t,t-MA in urine. The level of effect on the nervous system (HER) was made according to the steps mentioned above.

Figure 1: NRA screening manual among workers at fuel service workers

2) The risk assessment results from Step 1 can screen workers into five risk groups: acceptable, low, moderate, high, and very high. If it is found that the FSWs are at high or very high risk, they should undergo a basic physical and laboratory examination, including advice on reducing exposure to risk factors or self-protection, assessing biochemical indicators, assessing biological indicators, etc.

3) From Step 2, workers who were tested for t,t-MA biomarkers were divided into two evaluation levels: t,t-MA < 500 µg/g Cr and t,t-MA ≥ 500 µg/g Cr, referring to the criteria of the ACGIH (2025) and the Department of Disease Control, Ministry of Public Health (2015). The following actions are recommended: (i) t,t-MA < 500 µg/g Cr: health monitoring should be conducted at least once a year; (ii) t,t-MA ≥ 500 µg/g Cr: advise on reducing exposure to benzene, proper personal hygiene, and proactive monitoring by inspecting the work area to find the source. In addition, after giving advice, t,t-MA exposure should be assessed again in 6 months (Figure 2).

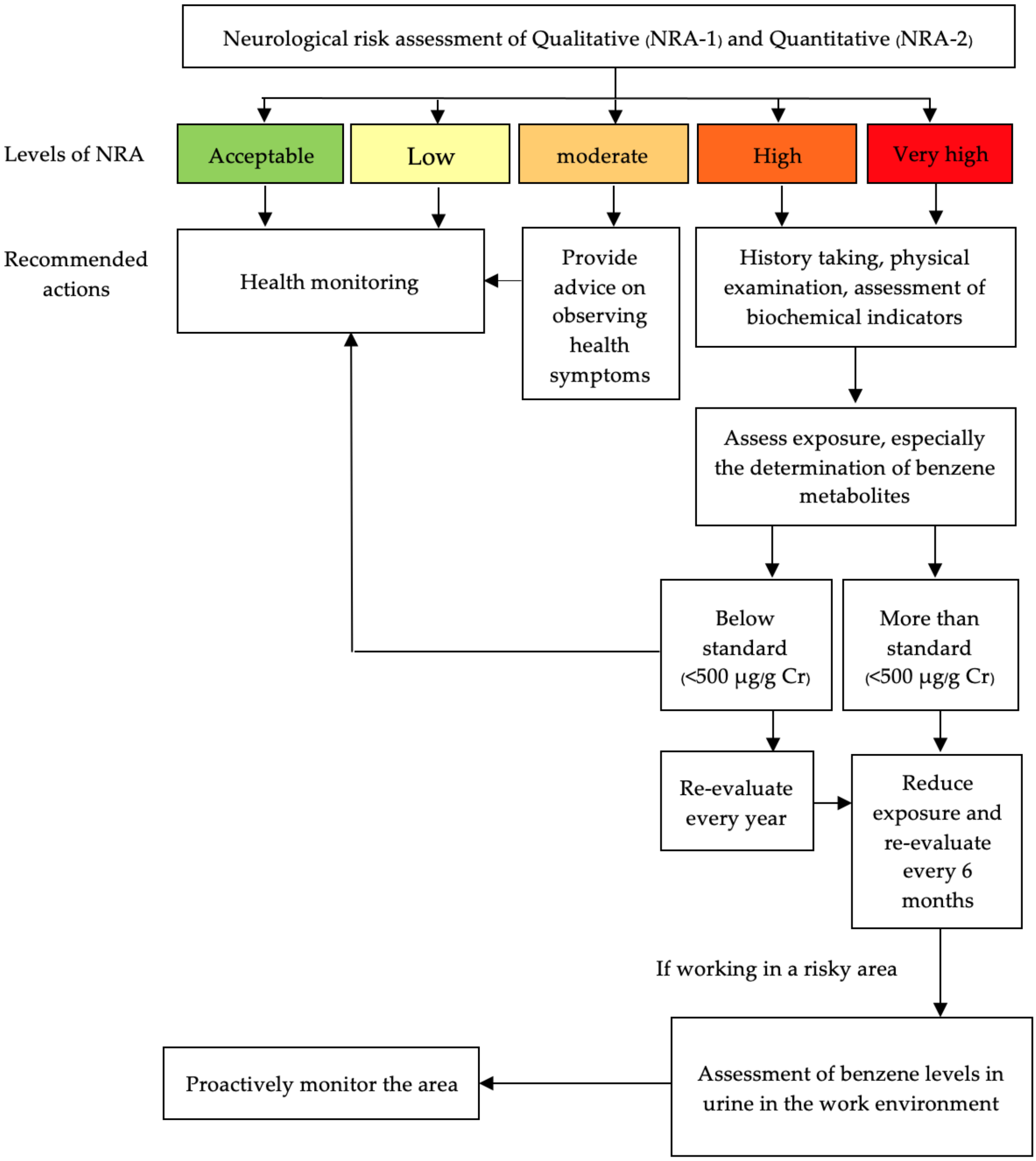

Figure 2: Guidelines for screening for health effects from exposure to benzene

The results on the manual's appropriateness based on the evaluation questionnaire from 15 experts found that all topics were at a good level of appropriateness. For example, they found that the NRA manual was clear and provided appropriate explanations for the user, had a consistent writing style, contained appropriate illustrations and content, was organized and easy to read, and emphasized important points, (see Table 7).

Table 7: Results of NRA of expert satisfaction assessment

Items	Issue	Results (n=15)		
		very appropriate	Enough	improved
1	The NRA manual is innovative.	14 (93.3%)	1 (6.7%)	-
2	The NRA manual can be used.	14 (93.3%)	1 (6.7%)	-
3	The NRA manual can be used as a guideline for health screening in accordance with its objectives.	14 (93.3%)	1 (6.7%)	-
4	The NRA manual is derived from appropriate and consistent academic principles and concepts.	13 (86.7%)	2 (13.3%)	-
5	The acquisition of the NRA manual has a reliable process.	13 (86.7%)	2 (13.3%)	-
6	There is new knowledge in the NRA manual.	11 (73.3%)	4 (26.7%)	-
7	The NRA manual is easy to understand and useful for readers.	12 (80.0%)	2 (13.3%)	1 (6.7%)
8	The NRA manual is useful for the occupational health sector.	14 (93.3%)	1 (6.7%)	-
9	The knowledge in the NRA manual can be exchanged, referenced or disseminated in the profession.	14 (93.3%)	1 (6.7%)	-
10	This NRA manual can be used in real-world health service agencies.	13 (86.7%)	2 (13.3%)	-
11	The NRA manual contains the completeness of important topics.	14 (93.3%)	1 (6.7%)	-
12	The NRA manual is up-to-date in content.	13 (86.7%)	2 (13.3%)	-
13	The NRA manual is clear and provides appropriate explanations for the user group.	15 (100.0%)	-	-
14	The NRA manual has a consistent writing style.	15 (100.0%)	-	-
15	The NRA manual has an appropriate content sequence.	13 (86.7%)	2 (13.3%)	-
16	The NRA manual is reliable.	13 (86.7%)	2 (13.3%)	-
17	The NRA manual is colorful and has an interesting appearance.	10 (66.7%)	5 (33.3%)	-
18	The NRA manual has a font size that is easy to read.	13 (86.7%)	2 (13.3%)	-
19	The NRA manual contains appropriate illustrations and content.	15 (100.0%)	-	-
20	The NRA manual is easily accessible when needed or can be downloaded.	10 (66.7%)	4 (26.6%)	1 (6.7%)
21	The NRA manual is organized, easy to read, or has important points emphasized.	15 (100.0%)	-	-

The researcher synthesized the content analysis of the focus group results to assess the model's potential use in screening risks in the area. The experts expressed their opinions and made suggestions for the NRA manual. The manual's content can be used as a guideline for medical and public health personnel to neurologically screen FSWs in accordance with their objectives. Additionally, it is an innovation that can be applied in the field. However, there was a suggestion that the researcher should create artwork to make the NRA manual more beautiful and enjoyable to read. In terms of benefits, the NRA manual was found to be beneficial to FSWs' health; however, the context of fuel service stations and the Eastern Economic Corridor should be added to make the NRA manual more comprehensive. In addition, the NRA manual should explain how it should be used easily, such as by providing examples of risk assessment methods, and it should be tested before being used in the field and brought back to develop a more complete manual for practical use

Discussion

This study emphasized the importance of benzene on the nervous system. However, neurotoxic effects may be attributed to multiple chemicals in the fuel, such as BTEX.[5] Previously, attention has been paid to this group of compounds. However, benzene has received attention due to its toxicity to multiple systems and its carcinogenicity as well as its skin absorption due to its lipid solubility.[15]

This was a pilot study of the use of an NRA screening form for assessment of FSWs. The NRA screening form underwent a critique process from experts in various related fields, considering its content and the feasibility of its use. The important issues that experts recommended can be divided into academic content and format, such as taking into account the target group clearly when using the assessment form, sequencing the academic content before entering the neurological risk screening to create understanding before use, giving examples of step-by-step use, designing the NRA manual to be interesting to read, the methods because it studied other kinds of fuel station workers who were also exposed to benzene, such as those in food and beverage sales, convenience stores, etc., including variables used in risk assessment. The risk factors were derived from studies examining factors related to health, including work factors, health behaviors, and biological indicators, which encompassed both NRA-1 and NRA-2 models. Due to the variety of factors, it is necessary to use data that covers more exposure opportunities rather than any single factor.

This NRA screening has two recommended models: qualitative NRA-1 and quantitative NRA-2. When testing the consistency of both NRAs' screening, it was found that both NRAs were statistically significant (kappa test = 0.41, $p < 0.001$). Therefore, both NRA models can be used according to the appropriateness of the context in the fuel station. In addition to assessing exposure copyright of the images, etc. The NRA manual was revised based on the suggestions and critiques. Therefore, this NRA screening form is reliable for use and is a guideline that can be applied in practice.

The NRA form followed the Ministry of Thai Industry's guidelines, which included the following criteria: frequency of exposure and severity of neurological symptoms, the primary effects of benzene. Previous health risk assessments have been conducted on FSWs.[3,6,28] For example, Thongsanthia et al. assessed health risk by considering the risk probability based on measurements of BTEX in the work environment.[3] For health severity, symptoms were categorized into mild, moderate, and severe. The study's results showed that fuel workers had a moderate risk level of 7.5%, which was comparable to that of cashiers in fuel stations. However, even though the assessment criteria were the same (exposure opportunities multiplied by severity), this study had different sample groups and

with biological indicators, workers with high and very high risk are recommended to take proactive measures to prevent personal hazards and measure chemicals in the work environment to find their source so that workers can reduce their exposure. The screening form was evaluated by a committee of experts who gave recommendations. It is reliable, but for future development, a study should be conducted with a larger sample of workers to test the screening form's specificity and sensitivity again, including confirmatory factor analysis.

Conclusion

This study's strengths include the development of a screening form for neurological risks that did not previously exist. The risk assessment was conducted using both qualitative (NRA-1 model) and quantitative (NRA-2 model) methods. Both methods can be easily applied to implement the evaluation. The low-cost method can be used to perform the qualitative assessment without testing for metabolites in urine.

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