Citation: Lorber M, Shapiro P, Bottimor D, Schwartz S, Peck C, Meng D. 1999. A risk assessment tool for the metal finishing industry. Pages 31-19 in, Proceedings: The AESF/EPA Conference for Environmental Excellence. Held Jan 24-27, 1999, at Lake Buena Vista, FL. Published by, AESF, 12644 Research Parkway, Orlando, FL 32826-3298.

# A Risk Assessment Tool for the Metal Finishing Industry

Matthew Lorber[1], Paul Shapiro[1], David Bottimore[2], Stephen Schwartz[2], Charles Peck[2], De-Mei Meng[2]

[1]Office of Research and Development, EPA, Washington, DC 20460; [2]Versar, Inc., 6850 Versar Center, Springfield, VA, 22151

## Introduction

The EPA Common Sense Initiative (CSI) Metal Finishing Sector's **National Metal Finishing Environmental Research and Development Plan** identified developing procedures and tools to characterize risks to workers and neighbors of facilities as a principal need for this sector. A first response by EPA to address this need was the publication of a primer on risk assessment specific to this industry: Characterizing Risk at Metal Finishing Facilities (Brown, 1998). This primer described the approach taken at EPA to evaluate exposure and human health risks to contaminants in the environment, and how that approach can be applied to the metal finishing industry. Very generally and briefly, the risk assessment paradigm is comprised of four components: 1) hazard identification - the determination of the human health hazard posed by exposure to a particular contaminant, 2) dose-response assessment - the quantitative description of the human health response given a particular dose regime for a contaminant, 3) exposure assessment - the description, including quantification, of the exposure of a human to a contaminant, and 4) risk characterization - the compilation of information from the first three steps of the paradigm to make quantitative or qualitative statements regarding potential health risk. EPA's next step is reported on in this paper - to actually develop a user-friendly computer tool which allows an individual to evaluate the potential exposures and health risks to workers and nearby residents from emissions from individual metal finishing facilities.

## Overall Objectives and Scope

With the publication of the risk assessment primer as noted above, the focus at EPA shifted to the development of a computer software tool based on concepts outlined in the primer that could be used to evaluate potential exposures and risks on a site-specific basis. The following objectives were developed by EPA's Office of Research and Development and endorsed by stakeholders (i.e., EPA, industry representatives, environmental groups, etc.) at a March, 1998, meeting of the CSI Metal Finishing Subcommittee, Joint Risk Characterization and Research and Technology workgroup:

> To develop a screening methodology that will enable characterizations of risks to workers and neighbors from emissions of single or multiple chemicals from metal finishing operations. In the future, field monitoring may be used to

supplement and/or field test the methodology.

To develop a simple computer tool that will enable anyone without assistance to perform a screening characterization of the risks to workers and neighbors at metal finishing facilities.

The key phrases relating to objectives here were "screening methodology" (or screening characterization) and "enable anyone without assistance". Some discussion of what is meant by a "screening methodology" is in order. First, the results derived from it are conservative in nature. If an exposure is found to result in an unacceptably high health risk with a screening model, then the appropriate first response is to refine the parameter input and/or evaluate the problem with different and perhaps more complex models. Another response might be to consider monitoring to confirm results of the model. Screening models are rarely, if at all, used as the sole justification in regulatory decision making at EPA. The second key characteristic of screening models is that they are, technically speaking, relatively simple and easy to parameterize for a variety of circumstances. In this site-specific metal finishing facility screening tool, relatively simple models are used to characterize the source emissions and to predict the concentrations of contaminants to which individuals are exposed.

With screening and universal usage as guiding principles, the development of this tool has focused on:

1) *a user-friendly interface which allows users to describe the metal finishing facility and exposure circumstances they wish to evaluate.* This combination of source and receptor definitions is commonly referred to as a "scenario". Users will have the capability of defining their unique scenario through a series of parameter input screens, and then saving their scenario definitions for future retrieval.

2) *a complete set of default parameter values for source characterization, contaminant fate and transport, and exposure circumstances.* For certain scenarios, the user will be required to input a minimum amount of information. For example, if the user wishes to evaluate residential exposures, they will be required to input the distance from the facility to the residence; it doesn't make sense that this and similar parameters have default values. All other parameters, such as source emission rates, exposure characteristics, and other parameters, will have preset values which the user can accept or choose to vary. Providing default values places a high degree of responsibility on the shoulders of the users of this tool to understand the implications of their acceptance of defaults. In developing them, we have sought to assign values that are, first and foremost, defensible. For default characterizations of source emissions, we have attempted to develop default values which best characterize current technologies and the fugitive emissions over open baths associated with these technologies (these emissions are the source of indoor exposures) and then the best available data on performance of pollution control devices in order to quantify the release of these contaminants to the outdoor environment (emissions from stacks after pollution control are the source terms for nearby residential inhalation exposures). In contrast to source characterization, and in keeping with the objective of being conservative as a screening tool, we have assigned human behavior (ie., exposure factor) default values which are characterized as "high end" (EPA, 1992a). "High end" is a term currently used for characterizing exposures that are expected to occur within the $90^{th}$ to $100^{th}$ percentile for an exposed population. Where data are unavailable to best characterize this high end exposure pattern, judgement by the model developers was used to establish default values. Therefore, should an exposure estimated with this tool be unacceptably high with the default exposure parameters offered, an assessor should evaluate the appropriateness of these default values for the specific site he is evaluating.

3) *tested and accepted EPA screening models for fate and transport of contaminants from source release to exposed individuals.* For dispersion of contaminants released to the outdoor environment, we have chosen the SCREEN3 model (EPA, 1995). This is a Gaussian plume model, incorporating source-related, receptor-related, and meteorological factors to estimate ambient concentrations where residential exposures occur. For the indoor environment (i.e., occupational exposure), the standard box model, incorporating process emissions, indoor dimensions and wind movement, is used to estimate indoor air concentrations.

The scope of this effort was defined by the phrases, " single or multiple chemicals from metal finishing operations" and "risks to workers and neighbors". As the project has developed, the scope narrowed with regard to exposure pathways, metal finishing line processes considered, and contaminants modeled. The inhalation pathway is the only pathway which will be considered at this time. Inhalation exposures for plating workers based on indoor air concentrations, and residential exposures based on predicted outdoor air concentrations, will be modeled. Other exposures might occur from release of treated and untreated wastes into receiving water bodies. These exposures include water ingestion or dermal exposure (swimming, showering) and fish consumption. Other residential exposures may occur due to deposition of airborne contaminants onto soils (soil exposures such as soil ingestion and dermal exposure) and vegetation (home gardening, agricultural food production). Exposures that result from disposal of sludge from this industry might also be considered at a later date. A total of 15 metal finishing line operations and 22 contaminants will be modeled. Details on the line processes and contaminants can be found in the companion paper to this one, Characterizing Site-Specific Source Emissions for EPA's Risk Assessment Tool for the Metal Finishing Industry (Schwartz and Lorber, this conference).

## Approaches for Source Characterization, Fate and Transport, and Exposure and Health Risk

### *1. Source Characterization*

Users will have three principal options for characterizing sources in this screening methodology:

a) Ambient Concentrations Only: The user can choose to bypass all source characterization and input only the concentration of the contaminant in ambient air. Such concentrations might be those found from indoor or outdoor ambient monitoring, those associated with a regulatory level, such as an OSHA Permissible Exposure Limit (PEL), or from another source. When conducting an assessment based on a concentration, the user will still have to describe the conditions of exposure in his scenario (inhalation rate per hour, hours per day inhalation, etc.).

b) Source Emissions from Publicly Available Data Bases: The Toxic Releases Inventory, commonly known as TRI, includes reporting of emissions from about 600 facilities in 1996 characterized by Standard Industrial Classification code 3471, which are facilities in the business of electroplating, plating, polishing, anodizing, and coloring. As part of this screening methodology, we will provide a default data base which includes release information from TRI and related data bases in a form appropriate for use in this screening methodology. In this data base, the facilities will be identified by name and address, and the stack emission data will be in a form usable with the SCREEN3 air dispersion model. These data are only appropriate for evaluating residential exposures, not plating facility worker exposures. Also, we will only take emissions data from TRI and related data bases for contaminants which are included in this first version of the screening tool. When using these emissions provided in the data base accompanying this screening tool, users will still have to input appropriate data into the SCREEN3 air dispersion model (such as stack height, exit velocities, distance of the

receptor from the facility, wind speeds, etc.) to model the dispersion and transport of contaminants from the stack to the receptor.

c) Generic Default Line Processes: Source emissions for plating facility worker and outdoor residential exposures can be characterized starting from one of the default line process definitions. Details on the line processes considered and modeled are provided in the companion paper to this one, Characterizing Site-Specific Source Emissions for EPA's Risk Assessment Tool for the Metal Finishing Industry (Schwartz and Lorber, this conference).

d) User-Defined Line Processes: Based on the default line processes, more sophisticated users will also be able to craft a line process by adding or deleting subprocesses that are part of one of the default line processes.

*2. Fate and Transport*

Fate and transport models are used to estimate the ambient air concentrations to which workers and nearby residents are exposed. Separate models are used for indoor and outdoor air concentrations:

a) Indoor Air: Workers are assumed to be exposed to both high concentrations of the contaminants found above plating baths as well as ambient concentrations more typical of the indoor environment. The companion paper to this describes the generation of the higher concentrations above the plating baths.

Ambient indoor air concentrations, $C_{ia}$, can be assigned values in either of two ways in this screening approach. One way is for indoor air concentration to be modeled as a simple fraction of the average uncontrolled concentration of a given contaminant above the plating baths. For example, the user could assume that the ambient indoor air concentration is one hundredth the uncontrolled concentration above the plating bath. Uncontrolled concentrations above baths are supplied as user defaults in this model. Also available to the user will be default concentrations above baths where emission controls such as polymer balls or fume suppressants are used. Obviously, these concentrations are lower than those where no emission controls are used. The second option is to model indoor air concentration using a box model approach. This simple approach can be visualized as follows: air above the floor level is uniformly mixed and all fugitive emissions from open baths in the process line become uniformly mixed within the indoor air volume. With this visual, the indoor air concentration, $C_{ia}$, is calculated as:

$$C_{ia} = \frac{FLUX}{VR}$$

where FLUX is defined as the total fugitive emission rate of a contaminant from all emission points, in units of mass/time, and VR is the ventilation rate in volume/time. The VR can be estimated from direct air flow measurements or equipment ratings. Alternatively, if ventilation is known in terms of air changes per hour, the ventilation rate is calculated as air changes per hour times the room volume.

Both of these options to estimate indoor air concentration - the use of a constant multiplier or the box model approach - assume that uniform mixing of the fugitive emissions from baths occurs in the workspace. In actuality, uniform mixing is unlikely to occur. Realistically, the concentration of fugitives will be higher near the source and decline from distance from it. Ideally, an assessor would use a "personal air concentration" for estimating inhalation risk. This represents the contaminant concentration in the air a person actually inhaled and is measured using a personal air monitor.

Default uncontrolled emission rates are supplied for all sub-processes within a metal finishing process line in this model. The user has the capability of editing all such emissions. The default assumption for all sub-processes is that 1% of uncontrolled emissions are fugitive

emissions into the work space; 99% of emissions are assumed to be captured and emitted from a stack outside the facility (with further reductions if additional pollution controls exist). These initial assumptions are engineering judgments subject to change. It would be possible to backcalculate a fraction lost using the box model approach and appropriate data. These data would include an appropriate working place air concentration of a given contaminant (through ambient or personal monitoring), total uncontrolled emissions of that contaminant, and the ventilation rate for the working environment. Then, using the box model above, the FLUX is calculated as the product of the measured air concentration times the ventilation rate. The FLUX is equal to total uncontrolled emissions times the fraction lost, so that a fraction lost is then calculated as FLUX divided by the total uncontrolled emissions.

As a simple test to this box model, we used the default $Cr^{+6}$ uncontrolled emission rate from a hard chromium plating bath into a work space with a VR of 4 air changes per hour in a working space whose volume is $1*10^6$ $ft^3$ (200 ft wide x 200 ft long by 25 ft high, e.g). Therefore, the ventilation rate is $4*10^6$ $ft^3$/hr in units appropriate for the box model. Using the box model, we found that the indoor air concentration was about 0.0004 times the uncontrolled concentration of $Cr^{+6}$. In the context of the model, the user would get the same indoor air concentration if supplying 0.0004 as the multiplier, or using the box model to calculate indoor air concentrations and supplying the ventilation rate as used in this example.

b) Outdoor air: The SCREEN3 model is used to predict maximum hourly and long-term average ambient air concentrations at the site where exposures occur. SCREEN3 is a screening level model which uses a steady-state Gaussian plume equation to estimate ambient pollutant concentrations from point sources. This model was developed by U.S. EPA, Office of Air Quality Planning and Standards, and incorporates source-related information to predict downwind concentrations (EPA, 1995). The model requires facility-specific stack, meteorology, receptor, and terrain information. The main input parameters are emission rate, stack height, stack inside diameter, stack gas exit temperature, stack gas exit velocity, and land use classification. The user can choose full meteorological conditions for a worst case scenario, specify a single stability class, or specify both a stability class and a wind speed. SCREEN3 can calculate the downwash effect, if the building dimensions are provided. The model estimates 1-hour maximum concentrations at a given distance from the source. For risk assessment purposes, the annual concentration can be calculated by multiplying the 1-hour maximum concentration by a conversion factor. The default value for this conversion factor is 0.08 (EPA, 1992b).

*3. Exposure and Health Risk*

The basic science of conducting exposure and risk assessment, as it might be applied to this industry, was covered in depth in Brown (1998). A brief overview is presented here; readers are encouraged to obtain this reference for more information to learn about the basic science of conducting risk assessments at EPA, and how that science is applied to the metal finishing industry.

As noted in the introduction, "risk assessment" as used here is best described by a paradigm including hazard identification, dose-response, exposure assessment, and risk characterization. Covered in sections above are critical components in exposure assessment: characterizing the source emissions, modeling the fate of contaminants from source to receptor, and therefore being able to predict concentrations of contaminants in air to which receptors (workers, neighbors) are exposed. The next task of this effort is to evaluate the health impact of this exposure.

One way EPA evaluates potential health impact from exposure to contaminants in the air is through the use of a benchmark concentration.

These concentrations are developed through a careful consensus procedure that considers available toxicity data, extrapolations from animal studies to humans, target organs, pathways of exposure, uncertainty, and other factors. Predicted or measured concentrations are compared to these benchmarks. In general, it is preferable to use measured air concentrations than modeled concentrations. For worker exposures, personal air monitoring is the best way to ascertain the concentrations to which workers are exposed.

One common benchmark for inhalation exposures used by EPA is known as the "Reference Concentration", or RfC. RfCs are developed for chronic and sub-chronic non-cancer effects. In general, the chronic RfC is an estimate (with uncertainty spanning perhaps an order of magnitude) of a daily inhalation exposure of the human population (including sensitive subgroups) that is likely to be without an appreciable risk of deleterious non-cancer effects during a lifetime. The subchronic RfC is defined similarly as the chronic RfC, except the risk pertains to a portion of a lifetime rather than a full lifetime.

The chronic RfC for hexavalent chromium mists and dissolved aerosols is $8.6*10^{-6}$ mg/m$^3$. Justification for this value can be found in EPA's Integrated Risk Information System, or IRIS (which can accessed via internet at, www.epa.gov/iris/). This RfC was only recently put onto the IRIS database by EPA and was not available during the development of Brown (1998). The critical effect for which this was developed was nasal septum atrophy. It was based on the study of Lindberg and Hedenstierna (1983), which had an occupational exposure scenario comprised of an 8-hour day, a breathing rate of 10 m$^3$/day, and a 5-day work week. The derivation of the RfC adjusted this occupational exposure to reflect a continuous environmental exposure for the same total intake. Also, its derivation included an uncertainty factor of 90 (i.e., the adjusted concentration derived from the literature study was divided by 90) which considered the extrapolation from a subchronic to a chronic exposure (factor of 3), extrapolation from a lowest observed adverse effect level (LOAEL) to a no observed adverse effect level (NOAEL; factor of 3) and to account for interhuman variation (a factor of 10; from IRIS).

Inhalation benchmark concentrations other than the RfC are available, and these will also be retrieved for the contaminants considered in this risk assessment tool. The Risk Based Concentrations (RBCs) published by EPA Region 3 are based on the dose-response toxicity values in IRIS and HEAST. The Minimal Risk Levels (MRLs) published by Agency for Toxic Substances and Disease Registry (ATSDR) are based on noncancer health effects. Risk-screening environmental indicators published by EPA OPPT for Toxics Release Inventory (TRI) chemicals are based on information from existing EPA models and databases. International Toxicity Estimates for Risk (ITER) database published by TERA, a nonprofit organization, are based on information from EPA, ATSDR, and Health Canada. Other air toxic guideline concentrations were published by various states and compiled in EPA's National Air Toxics Information Clearing House (NATICH) database. For exposures related to occupational settings, it may be appropriate to consider NIOSH Permissible Exposure Limits (PELs) or Threshold Limit Values (TLVs) established by the American Conference of Governmental Industrial Hygienists.

Outputs from assessments conducted will include all predicted and available benchmark concentrations for comparison. Hazard Quotients, or HQs, will also be calculated and displayed for non-cancer effects. An HQ, quite simply, is the ratio of the specific air concentration predicted (or measured, or derived in some manner) divided by the non-cancer RfC. HQs that equal or exceed 1.00 indicate a situation of potential health concern.

Cancer risk is expressed as an estimated upper bound probability of contracting cancer (not necessarily dying of cancer) within a lifetime due to a specific exposure regime. For

the inhalation pathway, EPA has calculated what is termed as a "unit risk" for certain contaminants. A unit risk factor is in units of risk/lifetime exposure concentration, such as $1/(\mu g/m^3)$, so that a multiplication of this unit risk times a given air concentration, in appropriate units, will equal lifetime cancer risk. This cancer risk is specifically defined as the upper bound cancer risk (meaning that the true risk is not likely to be higher and could very well be lower) given a lifetime of exposure at the specified concentration. The "lifetime of exposure" includes assumptions of 20 $m^3$/day inhalation rate, 24 hr/day, 365 days/yr, 70 years exposure duration (equal to a lifetime), and an adult body weight of 70 kg. As described in Brown (1988), it may be desirable to estimate a potential cancer risk given an exposure regime that is different than this lifetime assumption. This can be done with the following equation:

$$R = unit\ risk * C_a * ADJ_{inh} * ADJ_{hpd} * ADJ_{dpy} * ADJ_{ed} * ADJ_{bw}$$

where:

$R$ = cancer risk, equal to the probably of incurring cancer within a lifetime;

*unit risk* = contaminant-specific cancer potency factor associated with a lifetime of exposure, $1/(mg/m^3)$;

$C_a$ = air concentration, $mg/m^3$

$ADJ_{inh}$ = inhalation rate adjustment factor, equal to INH/20, where INH equals the daily inhalation rate, $m^3$/day;

$ADJ_{hpd}$ = hours per day adjust factor, equal to ET/24, where ET is the amount of hours exposed per day to contaminant, hr/day;

$ADJ_{dpy}$ = days per year adjustment factor, equal to EF/365, where EF is the annual exposure frequency, days/yr;

$ADJ_{ed}$ = exposure duration adjustment factor, equal to ED/70, where ED is the number of years of exposure, yr;

$ADJ_{bw}$ = body weight adjustment factor, which can equal $(70/BW)^{2/3}$, $(70/BW)^{3/4}$, or equal to 1.0 implying no adjustment factor warranted

The body weight adjustment factor considers any adjustment the risk assessor chooses to make to the original body weight assumption in the development of the unit risk factor. For most unit risk factors, the original data on cancer was based on animal to human extrapolations, so that there was an animal-to-human body surface area adjustment requirement, which was calculated as the ratio of animal and human body weights raised to a specific power. Originally, this power was assumed to be 2/3. In recent years, reconsideration of this factor has led it to be reassigned a value of 3/4. For some contaminants, and chromium is one of them, the unit risk factor was based on human data and not animal data, so no body weight adjustment is ever required in the above equation. In that case, the $ADJ_{bw}$ is assigned a value of 1.0.

For some contaminants, unit risk factors have not been calculated, but the upper-limit incremental cancer risk due to inhalation can still be estimated as a function of dose and a cancer slope factor:

$$R = 1 - e^{-q_1^* LADD} \approx q_1^* LADD$$

when $q_1^* LADD < 10^{-3}$ and where $q_1^*$ is the 95% upper confidence limit of the linearized cancer slope factor of the dose-response function (expressed in inverse units of the dose quantity, such as kg-day/mg) and LADD is the lifetime average daily dose (which needs to be in units appropriate to cancel those of $q_1^*$d, mg/kg-day). This formulation is only appropriate if it can be assumed that an inhalation dose is equivalent to the dose (most often an ingested dose) for which the $q_1^*$ was developed. The LADD is calculated simply as:

$$LADD = \frac{Ca * INH * EF * ED}{BW * AT}$$

*where:*

*LADD* = lifetime average daily dose, mg/kg-day;

*Ca* = air concentration, mg/m$^3$;

*INH* = inhalation rate, m$^3$/day;

*EF* = exposure frequency, days/yr

*ED* = exposure duration, yr;

*BW* = body weight, kg;

*AT* = averaging time, which for cancer effects is assumed to be a lifetime, yr;

For evaluating the impacts of exposure to multiple chemicals, EPA typically assumes risks should be added across chemicals for carcinogens. However, for systemic toxicants, risks should be added across chemicals only when they target the same organ. Also, risks should be added across pathways when it is reasonable to expect an individual to experience exposure by a given set of pathways. For purposes here, this translates to adding inhalation cancer risks for different contaminants, and the hazard quotients calculated for different contaminants only when they target the same organ. These types of cumulative risks will be displayed in this tool when possible and appropriate.

For this risk assessment tool, default exposure parameters will be provided for four types of receptors: a "plating worker", a "non-plating worker", an "adult resident", and a "child resident". The difference between a plating worker and a non-plating worker is that a plating worker is assumed to be exposed to uncontrolled emissions above the plating baths 5% of his working day, whereas a non-plating worker is assumed to work in the plating shop but be exposed only to ambient indoor air concentrations. The ambient air concentration to which a plating worker is exposed to is calculated as a weighted average of the uncontrolled air concentrations (5%) above plating baths and the indoor ambient air (95%) concentrations. This assumption of a 5% exposure time was assigned based on engineering judgement, and is subject to change. Other exposure factors for both types of workers include: 8-hr work days, 250 work days/yr, 30 years on the job, a daily work-day inhalation rate of 10 m$^3$/day, 70 years lifetime, and 70 kg body weight. The adult and child resident are exposed to the same outdoor air concentration predicted by the SCREEN3 model. The differences in their exposures are expressed in years of exposure - 30 yrs for adult and 5 years for child (they obviously can be assumed to live longer near the facility, but at some point, their exposures are no longer childhood exposures), daily inhalation rates - 20 m$^3$/day for adults and 10 m$^3$/day for child, and body weights, 70 kg for adult, and 16 kg for children.

## Next Steps

The procedures and quantities presented in this paper will be reviewed, and changes will likely be made prior to finalization of the risk assessment tool. Also, other pathways of exposure may be considered in future versions of the risk assessment. This will depend on decisions to be made on expansion of this tool to other plating lines and other liquid or solid emissions from metal finishing facilities. As noted above, other pathways for the nearby resident that result from air emissions might also be included, such as soil-related impacts.

## References

Brown, D.J. 1998. Characterizing Risk at Metal Finishing Facilities. Meeting the Needs of all Stakeholders. Office of Research and Development. EPA/600/R-97/111, May 1998.

Lindberg, E; Hedenstierna, G. (1983) Chrome plating: Symptoms, finding in the upper airways and effects on lung function. Arch Environ Health 38:367-374.

United States Environmental Protection Agency. 1995. The SCREEN3 Model Users Guide. Office of Air Quality Planning and Standards, Research Triangle Park, NC. EPA-454/D-95-004. September, 1995.

United States Environmental Protection Agency. 1992a. Guidelines for Exposure Assessment. Office of Health and Environmental Assessment. EPA/600-Z-92/001. Published in Federal Register, May 29, 1992, p. 22888-22938.

United States Environmental Protection Agency. 1992b. A Tiered Modeling Approach for Assessing the Risks Due to Sources of Hazardous Air Pollutants. Office of Air Quality Planning and Standards, Research Triangle Park, NC. EPA-450/4-92-001.