Fluid consumption, sweat rates and hydration status of thermally-stressed underground miners and the implications for heat illness and shortened shifts.

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Abstract:

There are a number of well-documented physiological problems associated with loss of total body water (dehydration) in humans. Miners working in hot conditions can have very high sweat rates and suffer significant loss of body weight during the course of their working shift. Data has been collected on the hydration status of miners from several metal mines. Sweat rates and fluid consumption rates have also been measured. The results show that miners in hot conditions sweat, on average, at about 0.8 litres per hour with a range of 2.4 to 12.5 litres per shift. However, in coal mines, many workers reportedly drink only 1 to 3 litres per shift, which will result in significant dehydration if working under thermal stress, and an increase in the risk of heat illness. Approximately 40% of metal miners (including surface mill workers) report to work in a hypohydrated state (mild to serious dehydration). There is some evidence that workforce education without a formal dehydration policy is not likely to be effective. A study into when heat illness was occurring during the shift (1st, 2nd, 3rd or 4th quarters) shows that the onset of heat illness is not directly related to the duration of heat exposure. This, along with the poor hydration status of workers at the start of the shift indicates that education at all levels (workers, supervisors, management) about the need to report to work well-hydrated, and then to drink sufficient fluids during the shift (including provision of palatable, potable water on the job), would substantially reduce heat illness in mine workers. Hydration is not the only risk factor in developing heat illness; nor should management of hydration be used in lieu of maintaining adequate environmental conditions in the workplace or reducing the physical work rate where practical. However, a reduction in shift length, without addressing other risk factors, is an ineffective method of reducing heat illness.

Introduction:

Excessive heat stress is known to result in hyperthermia (an elevated deep body core temperature), which in turn is known to increase the risk of heat illness. Heat illness is characterised by fatigue, headaches, dizziness, nausea, vomiting, cramps and potentially even more severe symptoms such as syncope (fainting) and, in extreme cases, stroke. Risk factors for developing heat illness according to the ILO[1] are: small body mass (< 50 kg), poor physical fitness, lack of heat acclimatisation, obesity, some legal and illegal drugs and a variety of medical conditions. Gender, ethnicity and age are not strongly linked in themselves to heat illness, providing the other risk factors are not present.

In addition to damage to worker health, excessive heat stress is also known to affect:

- *Safety*: heat is known to affect concentration, hand-to-eye coordination, mental acuity, and other neurological functions[2] and is therefore a known contributing factor to accidents. It is probably significantly under-recognised as a contributing factor to many industrial accidents in mines.
- *Productivity*: in thermally stressful environments, work must be carried out at a slower pace to avoid overheating the body. Heat stress therefore results in reduced output.
- *Morale*: where work must be conducted day after day under significant levels of thermal stress, morale falls. Among other problems, this results in an increase in absenteeism and turnover of staff, with its problems of loss of skills, lack of care, etc. Workers are also less amenable to workplace change when they believe that one of the key issues in the workplace, the heat stress, is not being taken seriously by management. Therefore, chronic levels of heat stress frequently result in frustration and poor workforce attitudes.
- *Cost*: due to the lower productivity, safety, health and morale, operating costs increase where the workforce is under significant thermal stress.

Humans are approximately 2/3rds water. Water is therefore critical to human health. The thirst sensation which triggers drinking starts at about 1 to 2% dehydration. Moderately severe dehydration occurs between 2% and 6% with very severe dehydration occurring between 7% and 15% and death following at somewhere between 15% and 20%.[3]

Some studies[4] have shown:

- Dehydration of 1 to 2% of body weight results in a 6 to 7% reduction in physical work rate.
- Dehydration of 3 to 4% of body weight results in a 22% to 50% reduction in work rate, for “moderate” and “hot” environments respectively.
- Mental performance (mental function, visuomotor skills and arithmetic tests) begins to decrease at 2% dehydration and thereafter is proportional to the degree of further dehydration.

Hence the inference by numerous competent authors[1-8] that working in heat, when accompanied by dehydration, affects safety performance either directly or indirectly.

Dehydration has also been implicated in 50% of all heat stroke cases in South African miners.[9] Therefore the ability of industrial workers to replace fluid lost in sweat is crucial when designing protocols for working in heat, and particularly in the design of protocols for extended shifts.

Dehydration is not always accompanied by hyperthermia. Adolf[5] describes a condition he called “dehydration exhaustion” (which he recognised as distinct to heat exhaustion or muscular fatigue) caused by “peripheral circulatory failure due to low circulating blood volume” (i.e. insufficient circulating blood due to dehydration). He found that men could become incapacitated from dehydration, to the point where “even standing erect is an intolerable strain”, without experiencing “unbearable discomfort from thirst”. Therefore thirst is not a reliable indicator of serious dehydration, which can potentially occur without the individual developing an excessive body temperature. Studies have also shown that well-acclimatised individuals sweat more than unacclimatised individuals in identical circumstances. However, sweat rates are unaffected by dehydration until quite serious levels of dehydration occur.

In most situations, dehydration in industrial workers will be due to loss of body fluid due to sweating. In this regard, there is some disagreement in the literature about acceptable sweat rates for industrial workers. Whilst sweat rates of 1.5 to 2.5 l/h have been demonstrated over short periods (with peaks of 3 l/h),[10,11] acceptable figures for a working shift are generally considered to be lower. ISO 7933[12] and Belding and Hatch[13] advocate a limit of 1.04 and 1.0 l/h respectively for acclimatised persons, although ISO 9886[14] curiously states that “There is no limit applicable concerning the maximum sweat rate: the values…adopted in ISO 7933…must be considered not as maximum values but rather as minimal values that can be exceeded by most subjects in good physical condition”. Nunneley[15] reports that humans can sweat indefinitely at rates of 1.5 to 2.0 l/h, whilst McArdle[16] recommended a limit of 4.5 l over 4 hours. Therefore, most authors believe that a sweat rate of 1 litre per hour is sustainable for at least four hours (i.e. the typical exposure between meal breaks) for healthy, acclimatised workers.

Note that many studies[5,17,18] have shown that workers typically only replace one half of the water they are losing as sweat (a physiological phenomenon called “voluntary dehydration”), unless they are “program drinking”, i.e. stopping typically every 15 minutes to drink 250 ml of water. Waiting an hour or more and then attempting to drink a litre of cold water, when very thermally stressed, is likely to lead to nausea, vomiting or headache.

It has also been found that, once dehydrated by more than about 2 %, it is difficult to rehydrate merely by drinking water.[5,19-21] This emphasises the importance of not becoming dehydrated in the first place.

Hydration status is generally estimated from urinary specific gravity, which is considered to be an important indicator of the absolute hydration status of the body and of relative changes in hydration status over time, although it does not mimic body water loss in a perfectly linear relationship,[22] and may be in error where the subject is experiencing diuresis due to alcohol or caffeine intake, or is taking vitamin supplements or some drugs.

Pure water has a specific gravity of 1.000 (dimensionless), whilst the maximum concentrating capacity of the renal system (kidneys) is about 1.050. In this study, a dehydrated state was considered to be a specific gravity > 1.030, based on the criterion used by the Australian Pathology Association. A euhydrated (properly hydrated) state was considered to be 0.015, based on work by Donoghue et al[23] and the fact that 1.015 is one standard deviation below the average start-of-shift value found for workers in the original Mount Isa underground study.

A value of 1.022 was an arbitrary value selected approximately half-way between a euhydrated (1.015) and dehydrated (1.030) state. This was to provide a suitable “buffer” to ensure that workers who are “nearly” clinically dehydrated are not exposed to heat stress until rehydrated.

In summary, the following guidelines were used as the basis of comparison between all the mines tested:

Urinary s.g.	1.000 to 1.015	Good

1.016 to 1.022	Fair
1.023 to 1.030	Poor (should not work in thermally stressful situations)
> 1.030	Clinically dehydrated.

Methods:

The hydration status of miners was measured as part of a workforce education program at a number of mines in Queensland and NSW. These tests were conducted prior to the shift starting, at mid-shift, or at the end of the shift, depending on when the talk was given.

At the Mount Isa operation, a detailed program of testing was conducted on those mine workers most exposed to heat stress. This included measuring hydration status before, during and at the end of each shift for each worker. Fluid consumption for each worker was also measured during the shift.

Moreover, at the Mount Isa operation, a comparison was made between workers granted a “six hour shift” (under a previous protocol) and those developing heat illness.

Urinary specific gravity was measured using a handheld, optical refractometer (Atago Uricon-NE).

Fluid consumption was estimated by allocating a separate 4-litre water bottle to each worker participating in the study. The cup on each water bottle had a capacity of 400 ml. Each worker was visited approximately every 60 to 90 minutes and the water consumption estimated from the cups drunk and checked against water levels in the bottle.

Records of heat illness were also reviewed for all cases at Mount Isa from July 1997 to April 1999. The time at which each worker presented at the 24-hour on-site medical centre was recorded (1st, 2nd, 3rd or 4th quartiles in the shift).

Results and Discussion:

Mine A (Mount Isa): Underground base metal operation in NW Qld (workers accommodated locally)

A combined “dehydration and heat illness protocol” (Figure 1) and other management procedures were introduced at this operation immediately prior to and during these studies[24]. These protocols introduced a new heat stress index[25] and a more pro-active approach to the management of heat stress, heat illness and dehydration in the workplace than had previously been the case.

The average urinary specific gravity of a group of 64 Mount Isa underground workers prior to going underground was 1.023 (sd 0.0078, range 1.002-1.035). The distribution of these before-shift results is shown in Table 1.

Table 1 Urinary specific gravity at start of shift for 64 underground miners starting work at Mount Isa, prior to undertaking an education session on working-in-heat.

Mine/Mill	Start/End of shift	Total tested	Good	Fair	Poor, not to work under thermal stress	Clinically dehydrated
Mine	Start	64	16 %	25 %	50 %	9 %

This indicates that, in the absence of education, about 60 % of mine workers in this dry-tropical location were reporting to work unfit to work in thermally stressful conditions.

After-shift dehydration tests were conducted on 413 workers (Jul 97 to Jun 98) who were working in such thermally stressful conditions that they were granted hot jobs (temperatures>32^0 C ET). Of these, 356 (86 %) passed the end of shift dehydration test. This indicates that working in heat, in itself, does not necessarily lead to clinical dehydration.

Of 103 persons developing heat illness at all Isa mines (Jul 97 to Mar 98), only six were granted a “hot job”.[26] This indicates that if the heat stress protocols then in use at Isa (consisting of temperature limits and a six-hour shift when exposure exceeded two hours) were designed to protect workers from heat illness, then these protocols were ineffective. The reason could be the existing heat stress limits were excessive, or the heat stress index then in use was a poor indicator of human heat stress, or that other risk factors were coming into play but were not recognised in the protocols then in use.

Of 426 workers granted a “hot job” at Enterprise mine (Jul 97 to Mar 98), only four developed heat illness.[26] Along with the statistic above, this implied that it was likely that there were other significant factors leading to the heat illness, that were not adequately being taken into account.

Furthermore, in the Enterprise mine, hot jobs fell from 974 in the nine-month period Jul 96 to Mar 97, to 426 in the corresponding period the year later, but incidents of heat illness increased from 7 to 69. Again, this indicated that there was only a poor correlation between the most unbiased estimator the mine had of "heat stress" (the incidence of hot jobs) and heat illness. For heat illness to be reduced substantially, the working-in-heat protocols of the time would need to be substantially modified, requiring a substantial research program. This ultimately led to the submission of two Doctorate theses[28-28] and a number of technical papers.[23-25,28-35]

The fluid consumed during the working shift was monitored and recorded in detail for 39 workers comprising 23 x 12 hour shifts, 3 x 12.5 hour shifts and 13 x 10 hour shifts. These workers had been previously well educated and well informed about the issues of working in heat and the need to consume sufficient water to replace their sweat during their heat exposure. The average fluid consumption per shift was 6.48 litres (over this mix of different shift lengths) with a standard deviation of 2.41 litres and range of 2.40 to 12.50 litres. Moisture content in food was not included in this analysis, but would increase the calculated fluid consumption rates. Urinary specific gravity was measured at the start, mid and end of shift for these workers and there was no statistically significant change between start, mid and end of shift. This indicates that their sweat rates would be similar to their fluid consumption rates.

The average fluid consumption rate during actual exposure hours was 0.8 litres per hour (sd 0.27, range 0.32-1.47). This indicates that underground mine workers were typically sweating at rates broadly in line with ISO 7933. Note, however, that some workers were sweating at rates up to 1.5 litres per hour for their entire shift exposure, typically 9.5 hours for a 12-hour shift.

Records of all heat illness incidents (n=216) at the Mount Isa mines from Jul 97 to Apr 99 were analysed as to the time into the shift at which the individual presented at the 24-hour on-site medical clinic. Presentation times were available for 194 cases. 90 % of these were for workers on 12-hour shifts, 7 % on 10-hour shifts and 3 % on 8-hour shifts. The presentation times in the shift are shown in Table 2:

Table 2 Time in working shift when workers with heat illness reported to on-site medical centre

1st quarter:	12 %
2nd quarter:	30 %
3rd quarter:	27 %
4th quarter:	23 %
After shift end	8 %

This indicates that heat illness was occurring throughout the working shift and was not strongly biased towards the latter part of the shift. This observation is reinforced when it is recognised that some time elapses between the onset of the exposure that gives rise to the heat illness and the actual development of symptoms (typically 30 minutes to 2 hours) and some further time before reporting to the medical centre (up to a further 90 minutes). It is therefore likely that the exposure giving rise to the heat illness was occurring evenly during the shift, and not dependent on the time into the shift. There is no indication from these results that a shorter working shift would significantly reduce the incidence of heat illness.

It is on the basis of these, and other observations, that MIM reviewed its working-in-heat protocols.

Figure 2 shows the results at Mount Isa[36] when the new protocols were introduced simultaneously with the removal of the "6 hour job", which had been in operation for the previous 56 years. Clearly, substantial reductions in heat illness are possible without reducing the shift length, providing a sensible working-in-heat protocol is put in place, along with a substantial and on-going program of management and workforce education.

***Mine B:* Underground base metal operation in NSW (workers accommodated locally)**

Table 3 shows the results for all workers at Mine B. No workforce education had been provided to the workforce prior to the education sessions, held in mid October 1999, at which these dehydration results were obtained. The surface WB temperatures at 1300 hours was 19^0 C WB, i.e. fairly low.

Table 3 Start and end of shift dehydration data for mine and mill workers at Mine B

Mine/Mill	Start/End of shift	Total tested	Good	Fair	Poor, not to work under thermal stress	Clinically dehydrated
Mine	End	8	25%	0%	38%	38%
Mine	End	13	46%	31%	23%	0%
Mill	End	9	0%	22%	78%	0%
Mill	End	4	25%	25%	50%	0%
Mine	Start	12	0%	50%	50%	0%
Mine	Start	19	21%	42%	32%	5%
Mine	Start	16	38%	44%	19%	0%
Mill	Start	5	0%	40%	60%	0%
Totals/Averages		86	22%	35%	38%	5%

Table 4 shows the total proportion of workers who were so poorly hydrated that they should not be allowed to work in thermally stressful conditions (s.g. > 1.022).

Table 4 Mine and mill workers unfit to work in thermally stressful conditions at Mine B

	Mine	Mill	Total sampled
Start of shift	34 %	43 %	47
End of shift	60 %	69 %	21

Note that the proportion of workers failing a “start of shift” test (34 % - 43 %) is broadly in line with that found at Mount Isa.

Also note that both mine and mill workers dehydrated from the beginning to the end of their shift. This is true even in the case of surface mill workers with surface WB temperatures relatively low (19^0 C WB at 1300 hours) [actual workplaces temperatures for the mill workers was not measured]. Note that temperatures measured in the underground workplaces at this mine during these days were much higher (27^0 to 30^0 WB).

If anything, the mill (surface) workers were more poorly hydrated at both the start and end of their working shift compared to underground workers.

Mine C: ***Underground base metal operation in NW Qld (fly in-fly out)***

Table 5 shows the results for all workers receiving workforce education at Mine C. These presentations were given in early December 1999.

Table 5 Start of shift dehydration data for mine workers at Mine C, prior to workforce education

Mine/Mill	Start/End of shift	Total tested	Good	Fair	Poor, not to work under thermal stress	Clinically dehydrated
Mine	Start	23	0%	48%	52%	0%
Mine	Start	24	38%	42%	21%	0%
Mine	Start	19	11%	47%	42%	0%
Mine	Start	25	20%	20%	60%	0%
Totals/Averages		91	18%	38%	44%	0%

As all presentations at this mine were scheduled for the start of shift (a much better arrangement in terms of workforce attentiveness), no end of shift data was collected.

Note that the percentage of workers who failed the start of shift result was 44 %; again, broadly in line with workers at Mount Isa and at Mine B. The ambient surface WB temperatures over the dates of the test were fairly low.

The results for subsequent end of shift testing in late January 2000 of day and night shifts are shown in Table 6. Note, unlike Mount Isa, Mine C did not introduce a formal dehydration testing policy such as indicated in Figure 1, but relied on education only.

Table 6 End of shift dehydration data for mine workers at Mine C, after workforce education, but with no formal dehydration policy

Mine/Mill	Start/End of shift	Total tested	Good	Fair	Poor, not to work under thermal stress	Clinically dehydrated
Mine, Day shift	End	23	0%	48%	52%	0%
Mine, Night shift	End	24	38%	42%	21%	0%
Totals/Averages		47	19%	45%	36%	0%

This somewhat surprisingly indicates that night shift had a better hydration state at the end of their shift than did day shift. As there is only a small change in underground WB temperatures from day to night, the reasons for this result remain unclear.

As this mine did not introduce a formal dehydration policy with their working-in-heat protocols, it appears that, even with a good education program, there was no or only a weak improvement between pre-education and post-education dehydration outcomes.

***<u>Mine D:</u>* Underground base metal operation in NW Qld (fly in-fly out)**

Table 7 shows the results for all workers receiving workforce education at Mine D.

Table7 Start and middle of shift dehydration data for mine workers at Mine D

Mine/Mill	Start/End of shift	Total tested	Good	Fair	Poor, not to work under thermal stress	Clinically dehydrated
Mine	Middle	22	9%	9%	41%	9%
Mine	Start	9	0%	11%	78%	11%
Mine	Start	6	0%	0%	50%	50%
Totals/Averages		37	5%	8%	51%	16%

In the case of Mine D, the presentation given to the underground workers in the middle of their shift was on the surface in their cribroom. It was interesting to observe that over 50 % of the workers who were drinking soft drink were drinking a cola-based product (a strong diuretic, i.e. a drug that promotes dehydration).

Again, 67 % of workers in these tests were unfit to be working in thermally stressful conditions.

Summary and Conclusions

Excessive heat stress affects worker health, safety, production, morale and costs. Both the incidence of heat illness and the contribution of heat stress to workplace accidents are under-recognised in the mining industry.

There is no doubt that a hot workplace is the most significant risk factor in developing heat illness. However, even if the "heat" is removed, injury and even death from heat related illness can still occur, particularly if the work rate is very high. There are numerous documented cases of persons trudging through heavy snow wearing cold-protection clothing and developing heat exhaustion. There is also a documented case of a British soldier who died from a heat related condition in a temperature of only 12^0 C.[37]

In addition, workers can develop severe dehydration and heat illness, even without developing excessive thirst or excessive deep body core temperature.

Without "program drinking", workers typically only replace one half of the fluid they are losing as sweat due to a phenomenon called "voluntary dehydration".

Miners are amongst the most exposed industrial workers in Australia to dehydration and heat stress. There is no documented case of heat stroke in an Australian underground mine worker that the author is aware of, and the risk is exceeding low. For example, Mount Isa worked over ten million manshifts from 1966 to 1996 in conditions exceeding 28^0 C WB[38] (with an upper limit of 32.3^0 ET) without a single recorded case of heat stroke, let alone a fatality. However, heat illness is common, and under-recognised, in the industry. It is also a cause of great frustration and poor morale in the workforce.

Engineering solutions are important and more mines are taking action to reduce the heat exposure on their workers (e.g. the new 25 MW R67 refrigeration plant at Mount Isa, and several other underground operations in Queensland, NSW, Victoria and WA are investigating refrigeration).

One “solution” to the problem of workplace heat stress that is not effective is to reduce the shift length. One of the most significant thermal physiologists of the post-war years[3] stated this as far back as 1964 when he said:

> “It does not seem logical to suggest that if conditions are extreme for an exposure of 8 hours then the duration of exposure should be reduced to 6 hours; it is probable that any acute heat disorder that may develop as a result of an 8-hour exposure will also occur during a 6-hour exposure. Therefore it is preferable to retain the 8-hour duration of exposure and to reduce the average rate of work by an appropriate amount”.

There are a number of very important risk factors for developing heat illness, in addition to the temperature in the workplace. Each of these needs to be addressed in an effective heat stress protocol, along with a substantial program of management and workforce education (with annual refresher training).

One of the most significant of these risk factors is the issue of workforce hydration. Substantial work has been completed in this area and a large proportion of the workforce is not presenting to work sufficiently well hydrated as to be capable of being exposed to heat stress.

Workforce education programs about the issues of dehydration, without some sort of formal dehydration testing program, are unlikely to be fully effective.

Furthermore, sweat rates of about 1 litre per hour are frequently encountered by mine workers, and fluid intakes of this magnitude are required to prevent further dehydration during the shift. This presents challenges to management in terms of ensuring workers have ready access to palatable water on the job, and providing a work routine where short on-the-job breaks are possible every 15 minutes. It is not realistic or healthy for workers to be stopping each hour and then drinking one litre of very cold water.

It also appears from this study that surface mine workers are just as much at risk of dehydration as are underground workers, although the more serious symptoms of heat illness appears to be less prevalent in surface workers, probably due to the relatively less thermally stressful conditions in their workplaces.

Figure 1 Example of dehydration and heat illness protocol used at Mount Isa Mines

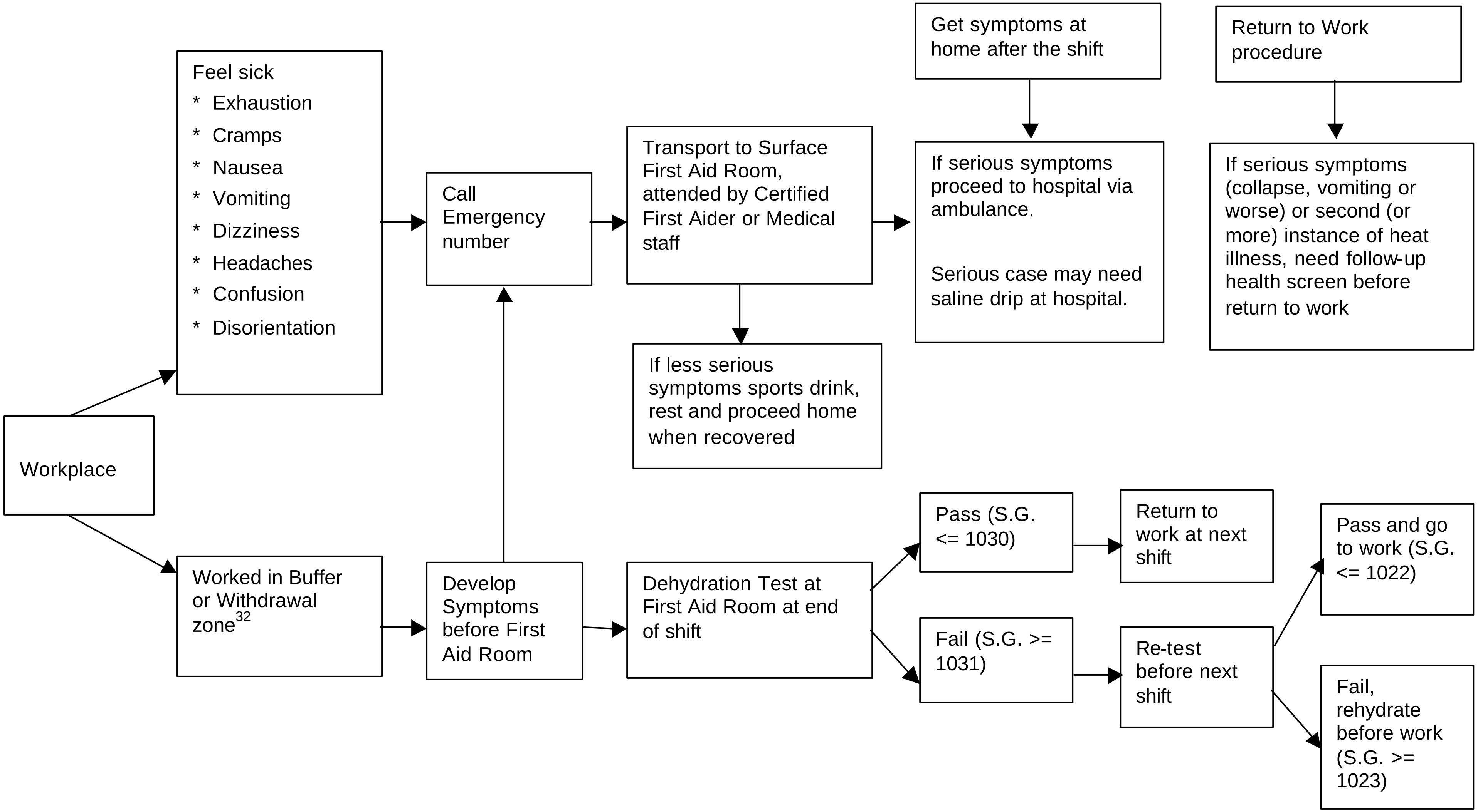
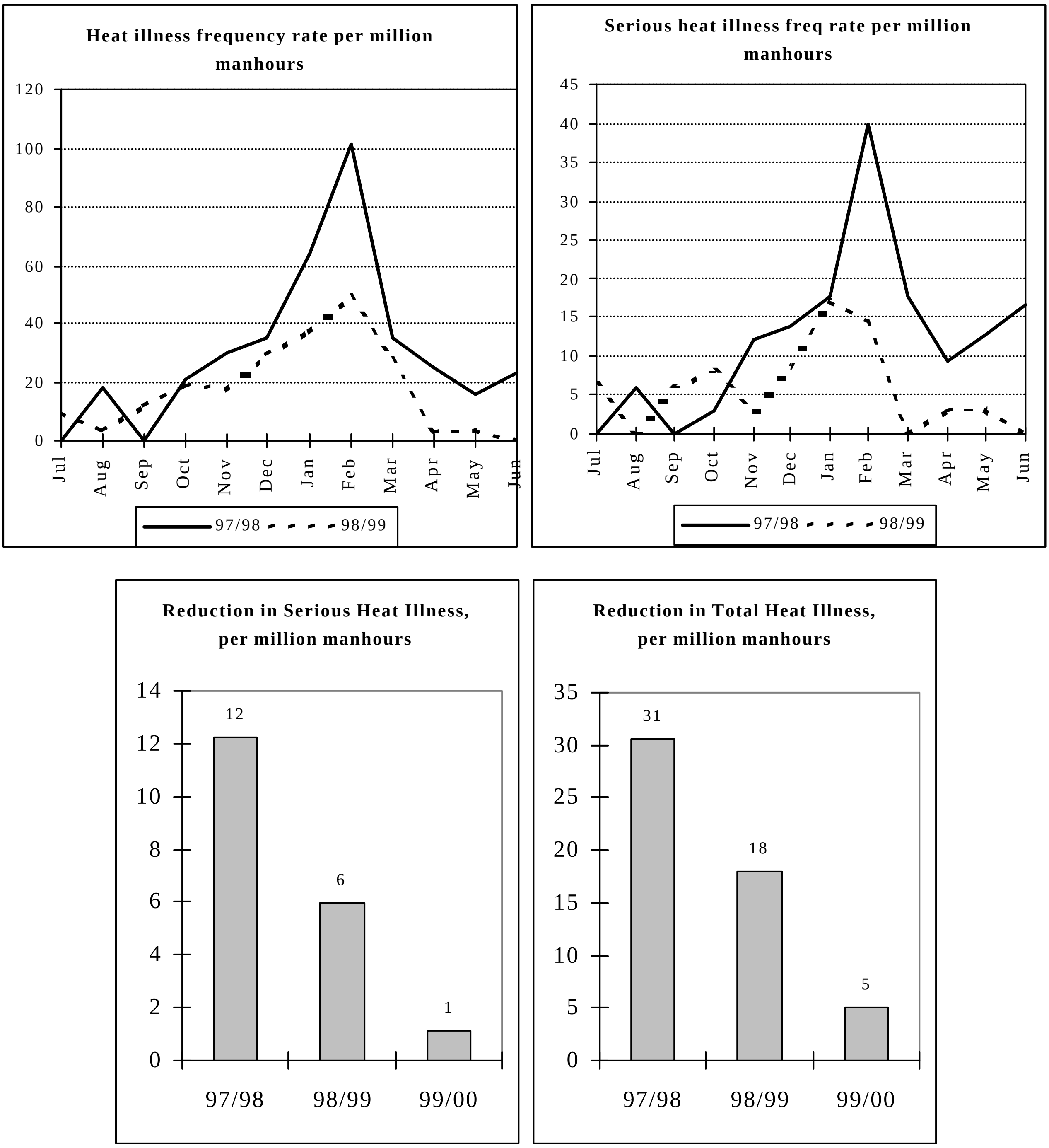


Figure 2 Reduction in heat illness at Mount Isa, before and after changes to working in heat protocols and elimination of six-hour shifts. Serious heat illness is defined arbitrarily as symptoms including vomiting or worse.



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