SET PHASERS ON STUN

And Other True Tales of Design, Technology, and Human Error

SECOND EDITION

technologies, technologies in which the actions of a few influence the lives of many, technologies that can bring countless benefits but can also amplify the consequences of human error in ways that were never before possible or never anticipated. Traditional engineering knowledge - - of electronics, chemistry, physics, structures, and materials - - is insufficient in and of itself for the design of technologies which play such a profound role in our lives. The future will require more of designers and their designs as systems become more complex, more intertwined, and even more, not less, dependent on human capabilities and limitations.

I would like to thank the many dozens of individuals who assisted me with the first and second editions by providing useful leads and story ideas. I am also grateful to the many readers who have sent me material on other promising stories; it is my intention to put this information to good use in follow-on volumes.

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Voyne Ray Cox, 33, just "Ray" to his family and numerous friends, winced a little as the bare skin of his stomach and chest pressed down on the icy tabletop positioned beneath the massive Therac-25 cancer radiation therapy machine. The table top wasn't really all that cold, it just seemed that way due to the unseasonably warm weather and the constant air conditioning inside the East Texas Cancer Center here in Tyler. It was Ray's ninth radiation treatment since the surgery for the removal of the tumor on his left shoulder, and he expected the session to be just as uneventful as the previous eight. He should be out of there in no time at all.

Mary Beth, the radiotherapy technician, was being every bit as pleasant as she had been during his other visits. She commenced with the customary greetings and banter and helped him get positioned on the perfect spot on the table. The surgery and radiation treatments had proved to be better than he

had feared, and he was looking forward to getting it all behind him and returning to work in the oil fields east of town. Not one to be fazed by adversity, Ray knew what he had to do, and he was determined to get on with the treatment and get this cancer thing well into the past.

Ray, lying chest-down with the side of his face resting on the table, listened to the familiar instructions about remaining still. He watched Mary Beth from his prone position as she operated the hand-held control console that rotated the table and him to the proper position underneath the machine's gantry. She told him to stay still and then walked out the exit of the treatment room to the small control room outside down the hall. Ray raised his head a little and looked up at the imposing device poised overhead. To Ray, the radiotherapy machine was just a big and attractive-looking piece of gear, all packaged-up nicely in clean and seamless sheets of plastic and metal. But, as it had been explained to him by the physicians and technicians at the center, the million dollar Therac-25 was the state-of-the-art in cancer treatment equipment. Beneath the sleek skin was a complex and downright ominous-looking machine, capable of delivering a beam of high-energy radiation to any point on or in a person's body. There were two keys to treatment success: hitting the cancer cells with pinpoint accuracy and having many separate treatments of relatively lower doses rather than a single treatment of one large dose. Ray Cox knew that he would be back in the treatment room many times over the next few weeks, and any remaining cancer cells from the small tumor that had been removed from his back would eventually be killed. By now, Mary Beth was in the control room, so he put his head back down after deciding it best to just mind his own business and take the opportunity to relax and be still.

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Inside the small control room, Mary Beth began to enter the commands into the computer keyboard to initiate the treatment. She was working with a common Digital Equipment Corporation VT100 terminal which in turn was connected to a PDP-11 computer that controlled the radiotherapy accelerator. The control system would aim the accelerator with pinpoint accuracy and, when ready, briefly fire a radiation beam of prescribed intensity. Ray Cox should not feel a thing.

There was a video camera inside the treatment room, but there was no picture on Mary Beth's television screen in the control room (the video monitor was not plugged in). The voice intercom between the two rooms was also inoperative. Neither of these things were viewed as being particularly significant, as Ray Cox had gone through this before and was now lying on the table right where he should.

The Therac-25 had two modes of operation, something that made it unique in the radiotherapy marketplace. One mode was a high-power "x-ray" mode utilizing the full 25 million electron volt capacity of the machine. It was selected by typing an "x" on the keyboard. This put the machine on maximum power and automatically inserted a thick metal plate just beneath the beam. When passed through the metal plate, the beam was transformed into an x-ray which was used to radiate tumors inside the body. The plate also lowered the intensity of the beam.

The other setting was a relatively low-power "electron beam" mode and was selected by pressing the "e" key. Ray Cox was scheduled to be treated with the "electron beam" mode. He would receive a painless burst of about 200 rads to the spot on his shoulder.

Mary Beth pressed the "x" key, moved on to the next entry on the keyboard, and realized suddenly that she had entered the

wrong letter. She meant to enter an "e" to set the machine for "electron beam" mode but had mistakenly entered an "x" and set the machine on "x-ray" mode. It was a simple enough slip, and one that certainly had no consequence since the treatment had not yet begun. Not one to waste time, Mary Beth quickly pressed the "up" arrow key to select the "edit" functions from the computer display. This enabled her to change the incorrect "x-ray" setting to the correct "electron beam" setting, which she did by pressing the "e" key. The screen now indicated to her that she was in the "electron beam" mode. The error corrected, she quickly pressed the return key on the keyboard to move the cursor to the bottom of the screen to wait for the "beam ready" display indicating that the machine was fully prepared to fire the narrow beam of radiation down onto Ray Cox's back. All of this took place within the span of eight seconds.

She had no idea that no one had ever entered this unusual but not at all unexpected sequence of commands in the thousands of times this particular Therac-25 had been operated. And the engineers for the Canadian manufacturer of the Therac-25, Atomic Energy of Canada, Ltd. (AECL), had not considered it possible for a technician to enter this sequence of commands in less than eight seconds. Accordingly, AECL did not test this unique sequence of inputs during the machine's development a few years before.

Mary Beth thought nothing of her small error or the quick steps she had taken to correct it. But unknown to her, AECL, and Ray Cox, the stage was set for disaster. Her rapid and unique series of inputs had tripped-up the computer. It retracted the thick metal plate used during x-ray mode - - but left the power setting on maximum. Her computer screen showed that the machine was in the necessary "electron beam" mode, but it was actually now in a debased operating setting and poised to deliver a blast of 25,000 rads down onto Ray Cox's

back - - in a proton beam powered by 25 million electron volts!

She looked back down at the computer screen just as the "beam ready" command appeared telling her that the machine was primed and ready to fire. Well-trained in the procedures, she then pressed the "b" key to turn the beam on...

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Ray Cox saw a flash of blue light, heard a frying sound, and felt the invisible lightning bolt of high-energy radiation shoot down from the Therac-25 into his back. It was as if a red-hot fireplace poker had been jammed through to his chest. He jolted reflexively. The pain was excruciating, nothing remotely like the other treatments.

Inside the isolated control room, Mary Beth's computer screen simultaneously displayed "Malfunction 54," indicating that something was not working and that the treatment had not been initiated. Having received no feedback that the machine had fired, she quickly reset the Therac-25 so that she could try it again...

Out on the table, Ray was rolling onto his side, his shoulder feeling on fire. The blue light flashed again, there was a sizzling sound, and Ray, now conditioned and forewarned, began to scream out for it to stop. But, before he could expel the complete force of his terrified shout, the proton beam shot down from above, this time into his neck. His chest muscles constricted, squeezing the air out of his lungs. The pain was as intense as anything he had ever felt, and for a moment he thought he might pass out. He slowly caught his breath and held it in his chest while trying to maintain some level of control.

A few moments later he took a deep cleansing breath, joggled his head once, and called out to Mary Beth.

"Hey, are you pushing the wrong button?"

At nearly the same moment, Mary Beth's computer screen in the control room showed that the Therac-25 was primed and ready once again, and she entered the "b" to fire the high-energy beam. Inexplicably, the machine responded by displaying "Malfunction 54." She had never had any problems with the machine before, and certainly had no idea what was meant by the error code...

Outside on the treatment table, Ray Cox was hit for a third time with another deadly and invisible shot to his shoulders and neck. He might just as well have been standing at the wrong end of a firing range. Fearing for his life and writhing in pain, he jumped from the table and ran to the door, where he bumped into technicians walking down the hall.

Mary Beth eventually came out of the control room and met Ray at the nurses' station, where he explained to her that he had received repeated and painful "electric shocks" while lying on the table. She responded by saying how strange that was and that nothing like that had ever occurred before. She had no idea what might have happened, but that there was no need to be concerned because the machine had malfunctioned and shut down automatically. According to the display, Ray had received only one tenth of his prescribed treatment dose.

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Faced with an inoperative machine and a disrupted schedule, Mary Beth called Fritz Hager, the radiological physicist in charge of the Therac-25 at the center, and asked him to come down to examine the equipment. Lee Schlichtemeier, Ray's radiological oncologist, eventually made his way to the treatment room as well. They found nothing physically wrong with Ray or the machine, but decided to call AECL and discuss the event. After conducting some recommended tests of the

equipment and finding nothing that suggested anything remotely abnormal, they continued use of the machine that same afternoon. There were, after all, other patients in the queue.

Just three weeks later it happened again with another patient, a 66-year old man by the name of Verdon Kidd, undergoing treatment for a growth on his ear. Mary Beth inadvertently typed an "x" instead of an "e" and then corrected her error by entering the "edit" routine and changing the mode to "e." The man was severely "shocked" about eight seconds later. Mary Beth watched in amazement from the control booth as the Therac-25 shut down, apparently without administering the planned treatment. The computer screen registered a "Malfunction 54."

With the second occurrence it became apparent to Fritz Hager that there were serious problems with the control system, problems that occurred when the "edit" function was used to quickly change the setting from "x-ray" mode to "electron beam" mode. Although the machine told the operator it was operating in the "electron beam" mode, it was actually operating in a hybrid proton beam mode and delivering blasts of 25,000 rads with 25 million electron volts - - more than 125 times the prescribed dose. And to make matters worse, Mary Beth had delivered multiple "treatments" to Ray Cox because of the lack of feedback and her conclusion that no treatment had been administered. The blue flash Ray saw before each blast was from Cherenkov radiation, a rare phenomenon seen only when a stream of electrons is accelerated to an extreme velocity.

Hager immediately called AECL, as well as other U.S. users of the Therac-25, and alerted them to the problem. Subsequent investigations lead to the discovery of similar overdoses in clinics in Marietta, Georgia; Ontario, Canada; and Yakima, Washington.

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Around the same time, Ray Cox's doctors began to suspect that he had been subjected to a massive radiation overdose. He was starting to spit up blood, and terrible radiation burns were appearing on his back, shoulder, and neck. Over the next few months the tissues hit by the beams died and sloughed off, leaving massive, gaping lesions in his upper body. Before his death four months later, Ray Cox maintained his good nature and humor, often joking in his east Texas drawl that "Captain Kirk forgot to put the machine on stun."

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