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Assemblyman Reed Gusciora, Stephanie Harris, Coalition for Peace Action, and New Jersey Peace Action, Plaintiffs, v. James E. McGreevey, Governor of the State of New Jersey (in his official capacity) and Peter C. Harvey, Attorney General of the State of New Jersey (in his official capacity), Defendants.	SUPERIOR COURT LAW DIVISION MERCER COUNTY Docket No. MER-L-2691-04 CIVIL ACTION

ANDREW W. APPEL, being of full age, hereby certifies:

1. I am a Professor of Computer Science at Princeton University, and a resident of Princeton Township, Mercer County, New Jersey. I received a bachelor’s degree in physics, *summa cum laude,* from Princeton University in 1981, and a Ph.D. in computer science from Carnegie Mellon University in 1985. I have been on the faculty of

Princeton University since 1986. I attach my C.V. to this report as exhibit A.

2. Among my areas of expertise are computer security, software engineering and design, programming languages, computer architecture, operating systems, and other areas. My primary research over the past decade is in software security: on what basis can we decide whether to trust the correct and safe operation of computers and computer programs.

3. I have studied the technological issues connected to the use of voting machines, and also the social and political context in which these machines are used. In addition, in the fall semester of 2004, I taught an undergraduate course at Princeton University on these topics. My research and teaching includes the study of a wide variety of voting technologies, including paper ballots, optical-scan ballots, punch-card ballots, direct-recording electronic machines, and other technologies including internet voting protocols. With each technology I study questions such as, “what protocols and safeguards are used with this technology, how effective are the safeguards, and what was the historical context that led to the introduction of these safeguards?”

4. In two previous reports submitted to this Court (attached as exhibits B and C) I have explained why it is practically impossible to verify the correct and nonfraudulent operation of Direct-Recording Electronic (DRE) voting machines just based on an examination of the hardware and software of the machine, or based on pre-election "test runs." Software is inherently complex. It is possible to write software that cheats on vote-counting in such a way as to fool even the most dedicated certification agencies. It also commonly occurs in general commercial software that software engineers make unintentional mistakes, creating bugs that are be vulnerable to abuse by the users of the software. In a voting machine, such software bugs in could allow election workers or voters to cheat in elections. In those reports, I also concluded that the certification and testing processes used in NJ are not sufficient to detect software flaws or manipulations.

5. In my prior two reports to this Court, I stated that I believe that a voter-verified paper ballot can serve as an effective external check on the behavior of DRE machines (or optical-scan vote counters). My understanding is that pursuant to a 2005 New Jersey law,

all DREs used in NJ must produce a voter-verified paper ballot (VVPB) by January 1, 2008.

6. In this report I will discuss the Sequoia Pacific AVC Advantage (DRE) voting machine, in particular its technical architecture and how this bears on the feasibility of upgrading the machine to produce a voter-verified paper record of each vote.

7. For the reasons discussed below, I believe that there is a substantial possibility that the design of the Sequoia Pacific AVC Advantage may make it technically difficult to add an attachment to produce a voter-verified paper ballot. Therefore we cannot assume that just because the State is willing to pay for such an attachment that it will become commercially available for that machine, either from Sequoia or from any other vendor, by January 1, 2008.

8. A DRE machine consists of hardware and software. The hardware is all the physical components such as input devices (buttons or a touch screen) that the voter uses to indicate a vote; output devices (lights or a video display) that the machine uses to confirm the vote to the voter; a computer microprocessor chip, in which the software instructions are programmed to decide how to respond to the input devices; a memory, for holding the

software program and for recording the votes; printers for reporting the vote totals after the polls close; and a cabinet containing all these works.

9. In addition, some DREs have a printer for producing a voter-verified paper ballot, which may or may not be the same printer as the one used for printing close-of-voting totals. In the case of the Sequoia Pacific AVC Advantage, a new external printer would need to be added for voter-verified paper ballots.

10. The software is the computer program, a sequence of instructions that is interpreted by the microprocessor. When this software is installed on a read-only memory chip, as it is on the Sequoia AVC Advantage, it is sometimes called “firmware.”

11. The layman, upon seeing a DRE machine such as the AVC Advantage, might assume that there is some inherent connection between each button, the corresponding indicator light, and a vote total. This is not at all the case. The software can read the state of each button (pressed or not pressed), can write the state of each light (lit or dark), and can add to numbers in its own memory, entirely at the discretion of the software. Correctly written DRE software will read a button (by which the voter selects a candidate), light the

corresponding light (to provide feedback to the voter), and add “1” to the corresponding counter in its memory. But if you load different software into the machine, it could play a video game, light the lights in an aesthetically pleasing pattern, or--most dangerous--simulate the action of a legitimate voting machine, so that the voter believes he has voted for Candidate A, while the software counts a vote for Candidate B.

12. I have read a document labeled as originating from Sequoia Voting Systems, Inc., of Oakland, CA, entitled “AVC ADVANTAGE SECURITY OVERVIEW” (copyright 1997-2004). This document is attached as exhibit D. The document makes many statements of fact that are generally plausible and consistent with other knowledge I have of the machine, with one exception (a hyperbolic statement that is not scientifically supportable that “not a single vote has been lost to equipment malfunction”).

13. According to the AVC ADVANTAGE SECURITY OVERVIEW, the microprocessor (computer chip) used in the Sequoia Pacific AVC Advantage is the Zilog Z80. I am familiar with this microprocessor; it was first produced in 1976, and I wrote computer programs for it starting in about 1977. The Z80 can accommodate a total of 64 kilobytes (65,536 bytes) of memory, which was typical of mid-1970s

microprocessors. Sequoia Pacific has configured this so that half (32k) is program memory (to hold the instructions telling the computer how to operate) and half is data memory (to hold candidate names, ballots, and vote counts). Thirty-two kilobytes is quite a small amount of memory. The document you are reading now has just about 1,000 letters (bytes) per page. So, 32k of memory is approximately 32 pages in this format. In contrast to this 32,768 bytes of program memory, modern desktop or notebook PCs have about 100,000,000 bytes of program memory, or more.

14. As an illustration of how tiny 32k is by modern standards, another voting machine (the Diebold AccuVote-TS, not used in New Jersey) has a control program whose “source code” is approximately 50,000 lines of text (2,400 pages, in the format you are reading now), and which probably requires a program memory of at least half a million bytes. Diebold can afford to do this because the computer chip they use does not have a 32k limit. (Studies have shown that the Diebold software contains bugs that allow voters and election workers to manipulate election results. I mention the machine here mainly for the purpose of showing that typical DRE machines have

substantially more memory than the Sequoia Pacific AVC Advantage.)

15. Thirty-two kilobytes (32k) may be enough space to fit all the software features of a bare-bones voting-machine such as the original AVC Advantage. But, as I will explain, with a very limited capacity to expand the software to accommodate new features, we cannot assume that there will be sufficient capacity on the Z80 to add the control software for a voter-verified paper ballot printer.

16. Since I have not been able to examine Sequoia’s computer software code, which Sequoia keeps as a trade secret, I cannot know whether or not there is sufficient capacity to upgrade the software. However, the risk of insufficient memory capacity to upgrade is much more substantial for a technology like that used in the AVC Advantage than it would be for the newer technologies used in most other DRE voting machines on the market. If I were given the opportunity to examine Sequoia’s source code for the AVC Advantage machines, I would be able to determine whether sufficient space remains within the 32k limit to add additional software to operate a voter-verified paper ballot printer.

17. In Sequoia’s original 1987 voting-machine design (based on a 1976 microprocessor) they managed to fit, in the limited 32k of space, a software program that controls interaction with the pushbuttons and lights, the reading and processing of ballot-definition cartridges, manipulation of candidate names and party affiliations, handling of write-in votes, and printing close-of-voting “cash-register-tape” reports.

18. Since 1987 Sequoia has added new features to its AVC Advantage machines. For example, on the close-of-voting report, more recent versions of the AVC advantage print the letter-number pair for the ballot position of each candidate by that candidate’s vote total. Just as, when you have to pack a 50-page legal brief into a 32-page limit, you can rewrite some prose to make an argument more concise, very likely Sequoia had to tighten up their “software prose” to fit in more features. But this “tightening up” has its limits: to implement more features, eventually one needs more memory space. It is very possible that Sequoia’s 32k bytes of program memory is packed full.

19. To add a feature such as voter-verified paper ballots to the Sequoia AVC Advantage machine would require adding to the software several hundred bytes of instructions, at

the very least. These instructions would direct the microprocessor to print the paper record, and request and handle voter confirmation. If the voter rejects the ballot, the software must have instructions to void that ballot and allow the voter to start over.

20. In the tiny 32k space allotted for program memory, it is very possible that there is just no room left to add more features to the software. If I were able to examine the software, I could determine how much room remains for upgrading the software.

21. If there is no room in software capacity of the Z80 to add the voter-verified paper ballot feature, to satisfy New Jersey law, then Sequoia Pacific could replace the Z80 microprocessor with a more capacious one, or they could add an auxiliary microprocessor to handle the paper-ballot printer.

22. If Sequoia Pacific replaces the Z80, then they would have to redesign the entire machine from scratch: This would not be a mere software upgrade. Sequoia Pacific would have to discard the Z80 computer chip, discard all the software in the machine (which is specific to the Z80), discard the circuit board on which the Z80 chip sits, and redesign all the circuitry and rewrite all the software using a more modern microprocessor with a

greater memory capacity. The only parts of the current AVC Advantage that could be salvaged and re-used would be the cabinet and the panel of buttons and lights.

23. In essence, if it is necessary to replace the Z80 microprocessor in order for the AVC Advantage to produce a voter-verified paper ballot, Sequoia Pacific would have to engineer an entirely new voting system, and house it in the current AVC Advantage shell. This would take years to do.

24. If Sequoia chose to add an auxiliary microprocessor to manage a voter-verified paper ballot printer, then the software for that new microprocessor, the hardware circuits to accommodate the new microprocessor and connect it to the existing Z80, would all need to be designed, implemented, and certified, and it would add substantial complexity to the AVC Advantage voting machine. The process of specification, design, implementation, testing, and certification can be expected to take several years.

25. Additionally, the complexity involved in adding an auxiliary microprocessor is undesirable for several reasons. First, complexity leads to unreliability. Second, an additional microprocessor and its software increase the vulnerability of the machine to fraudulent

manipulation. Third, it makes it more difficult (in, for example, a certification process) to determine whether the machine will work according to its specification.

26. Software and/or hardware modifications to the AVC Advantage would produce a machine that does not work the same way as the old one; thus, the new machine should be recertified. As I discussed in my prior reports to this Court, any modification of software, even a minor one, can (deliberately or inadvertently) introduce bugs that radically alter or corrupt the effect of the program. We observe frequently that “upgrades” to commercial software can render it unreliable or vulnerable to exploitation by hackers. A modification as significant as the addition of a voter-verified paper ballot generator to the control program of a voting machine would require reexamination by the state’s certification process, that is, recertification.

27. For these reasons, I am not surprised to learn that Sequoia Pacific has not made commercially available a voter verified paper ballot component that is compatible with the AVC Advantage. Upgrading computer programs to add new features, when program memory capacity is severely limited, is often difficult or impossible.

28. If Sequoia chooses not to provide this upgrade, it will be infeasible for another company to do so. To upgrade the voting machine software, another company would face all the difficult engineering problems that Sequoia would face. In addition, the other company would need access to the source code and design documents for the machine. This source code is, as I understand it, a trade secret of Sequoia, and available to other companies only at Sequoia's discretion.[1]

29. I am also familiar with the Sequoia AVC Edge voting machine, used in one county in New Jersey. This machine has a microprocessor dating from the 1980s (in contrast to the AVC Advantage's Z80 which dates from 1976); the Edge's microprocessor can accommodate a program memory much larger than the Z80 can. It is, a priori, much more feasible to add a voter-verified paper ballot printer to the AVC Edge. It is my understanding that Sequoia

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[1] One could imagine another company attempting to recover the software by reverse-engineering the contents of the ROM chip in the voting machine. This is technologically possible, but it would be expensive and it would lead to unreliable results, based on the possibility of misunderstandings in the reverse engineering process. It would be unwise for any agency to certify, or for New Jersey to accept the certification of, a voting machine upgrade designed on the basis of reverse engineering. Furthermore, it may be the case that New Jersey counties are contractually prohibited from installing upgrades based on reverse engineering.

already offers such an upgrade and that it was used in Nevada in the 2004 election.

30. Sequoia's upgrade for the AVC Edge (used in Nevada) does not properly preserve the secrecy of the ballot. Instead of producing individual printed ballots that are dropped into a box, it produces a continuous "cash-register tape" of ballot paper, one voter at a time, during election day. Because the order in which voters vote is known publicly, it would be possible for anyone with access to the ballot tape to determine which ballot belonged to each voter.

31. I mention the Sequoia Pacific AVC Edge mainly to illustrate that, because the Edge's microprocessor has a much larger memory capacity, there are fewer *software* engineering difficulties in upgrading the machine with a paper ballot printer, and therefore Sequoia was able to offer such an upgrade commercially for that machine.

32. I certify that the foregoing statements are true. I am aware that if any statements are willfully false, I will be subject to punishment.

Dated: March ___, 2006
Princeton, New Jersey

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Andrew W. Appel