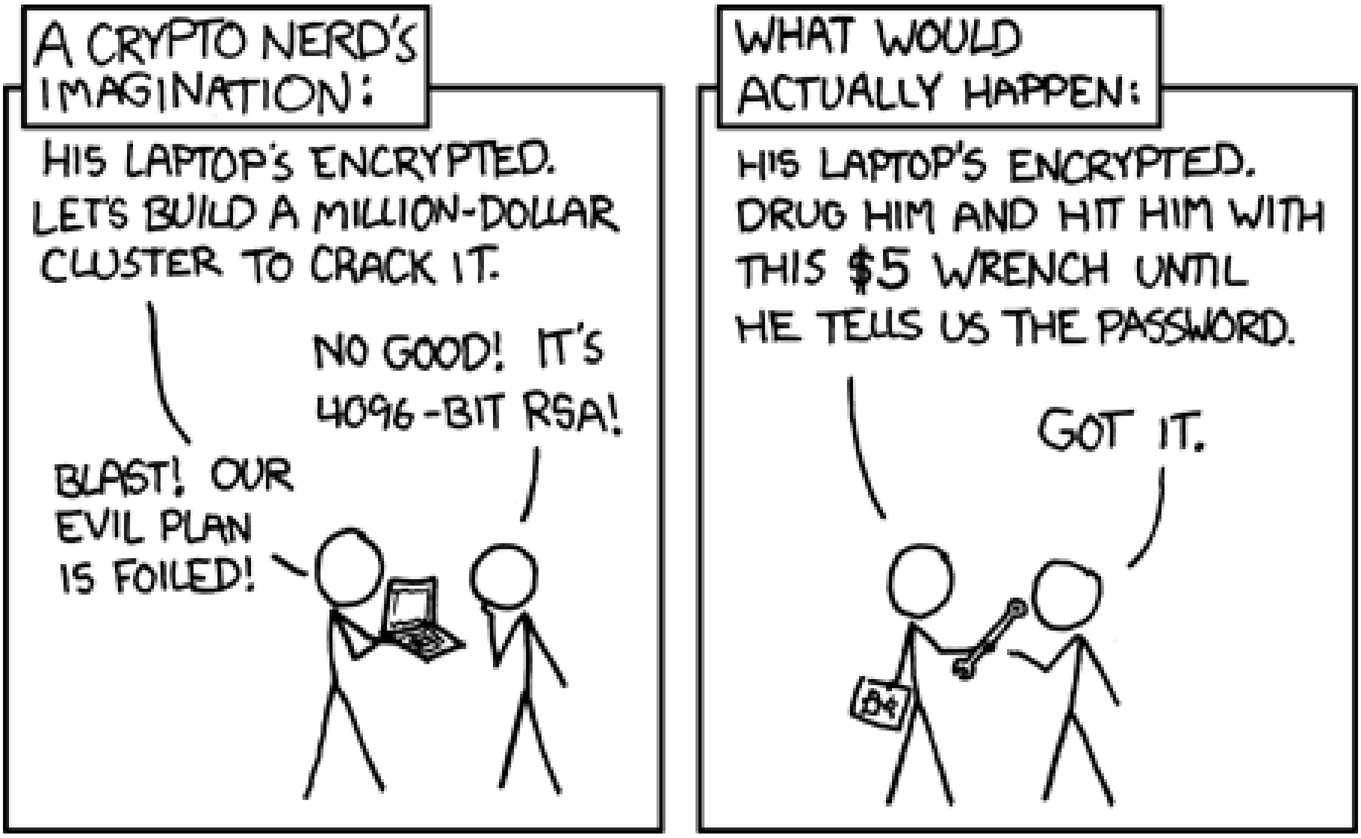
Failures of secret-key cryptography

D. J. Bernstein
University of Illinois at Chicago &
Technische Universiteit Eindhoven



http://xkcd.com/538/

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2002 Shamir: "Cryptography is usually bypassed. I am not aware of any major world-class security system employing cryptography in which the hackers penetrated the system by actually going through the cryptanalysis."

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Let's look at some examples.

Windows code signatures

Flame broke into computers, spied on audio, keystrokes, etc.

2012.06.03 Microsoft: "We recently became aware of a complex piece of targeted malware known as 'Flame' and immediately began examining the issue. . . . We have discovered through our analysis that some components of the malware have been signed by certificates that allow software to appear as if it was produced by Microsoft."

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Was MD5 "homebrew crypto"? No. Standardized, widely used. Worthwhile to attack? Yes.

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http://en.wikipedia.org/wiki/2003_Mission_Accomplished_speech

WEP

WEP introduced in 1997
in 802.11 wireless standard.

2001 Borisov–Goldberg–Wagner:
24-bit “nonce” frequently repeats,
leaking plaintext xor and
allowing very easy forgeries.

2001 Arbaugh–Shankar–Wan:
this also breaks user auth.

2001 Fluhrer–Mantin–Shamir:
WEP builds RC4 key (k, n)
from secret k, “nonce” n;
RC4 outputs leak bytes of k.

Implementations, optimizations of k-recovery attack: 2001 Stubblefield–Ioannidis–Rubin, 2004 KoreK, 2004 Devine, 2005 d'Otreppe, 2006 Klein, 2007 Tews–Weinmann–Pyshkin, 2010 Sepehrdad–Vaudenay–Vuagnoux, 2013 S–Sušil–V–V, . . .

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Fact: WEP blamed for 2007 theft of 45 million credit-card numbers from T. J. Maxx. Subsequent lawsuit settled for $40900000.

Keeloq

Wikipedia: "KeeLoq is or was used in many remote keyless entry systems by such companies as Chrysler, Daewoo, Fiat, GM, Honda, Toyota, Volvo, Volkswagen Group, Clifford, Shurlok, Jaguar, etc."

2007 Indesteege–Keller–Biham–Dunkelman–Preneel "How to steal cars": recover 64-bit KeeLoq key using 2^{16} known plaintexts, only $2^{44.5}$ encryptions.

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1. Setup phase of this attack watches power consumption of Keeloq device. Is this "bypassing" the cryptography?

2. If all the "X is weak" press comes from academics, is it safe to conclude that real attackers aren't breaking X? How often do real attackers issue press releases?

VMWare View

VMWare View is a remote desktop protocol supported by many low-cost terminals.

Recommendation from VMWare, Dell, etc.: switch from “AES-128” to “SALSA20-256” for the “best user experience”. Apparently AES slows down network graphics.

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Closer look at documentation: "AES-128" and "SALSA20-256" are actually "AES-128-GCM" and "Salsa20-256-Round12".

AES-128-GCM includes AES
and message authentication.

No indication that VMWare's
"Salsa20-256-Round12" includes
any message authentication.
Can attacker forge packets?
One *can* easily combine Salsa20
with message authentication,
but *does* VMWare do this?

Salsa20 has speed and security
advantages over AES, but
both Salsa20 and AES are
unauthenticated ciphers.
User needs *authenticated* cipher.

SSL/TLS/HTTPS

Standard AES-CBC encryption
of a packet (p_0, p_1, p_2):
send random v,
$c_0 = \text{AES}_k(p_0 \oplus v)$,
$c_1 = \text{AES}_k(p_1 \oplus c_0)$,
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AES-CBC encryption in SSL:
retrieve last block c_{-1}
from previous ciphertext; send
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$c_1 = \text{AES}_k(p_1 \oplus c_0)$,
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SSL lets attacker choose p_0
as function of c_{-1}! Very bad.

2002 Möller:
To check a guess g for (e.g.) p_{-3},
choose $p_0 = c_{-1} \oplus g \oplus c_{-4}$,
compare c_0 to c_{-3}.

2006 Bard:
malicious code in browser should
be able to carry out this attack,
especially if high-entropy data
is split across blocks.

2011 Duong–Rizzo "BEAST":
fast attack fully implemented,
including controlled variable split.

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CBC by forging *ciphertexts*,
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SSL appends an authenticator,
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This is provably secure.

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This is completely broken
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2013.02 AlFardan–Paterson
"Lucky 13": watch timing more closely; attack still works.

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The software does support one non-CBC option: RC4.
Now widely recommended, used for 50% of SSL traffic.

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2013 AlFardan–Bernstein–Paterson–Poettering–Schuldt, "On the security of RC4 in TLS": Force target cookie into many RC4 sessions. Use RC4 biases to find cookie from ciphertexts.

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But wait: there's more!

2013 AlFardan–Bernstein–Paterson–Poettering–Schuldt: *accurately* computed $\Pr[z_i = j]$ for all $i \in \{1, \ldots, 256\}$, all j; found $\approx$**65536** single-byte biases; used *all* of them in SSL attack via proper Bayesian analysis.

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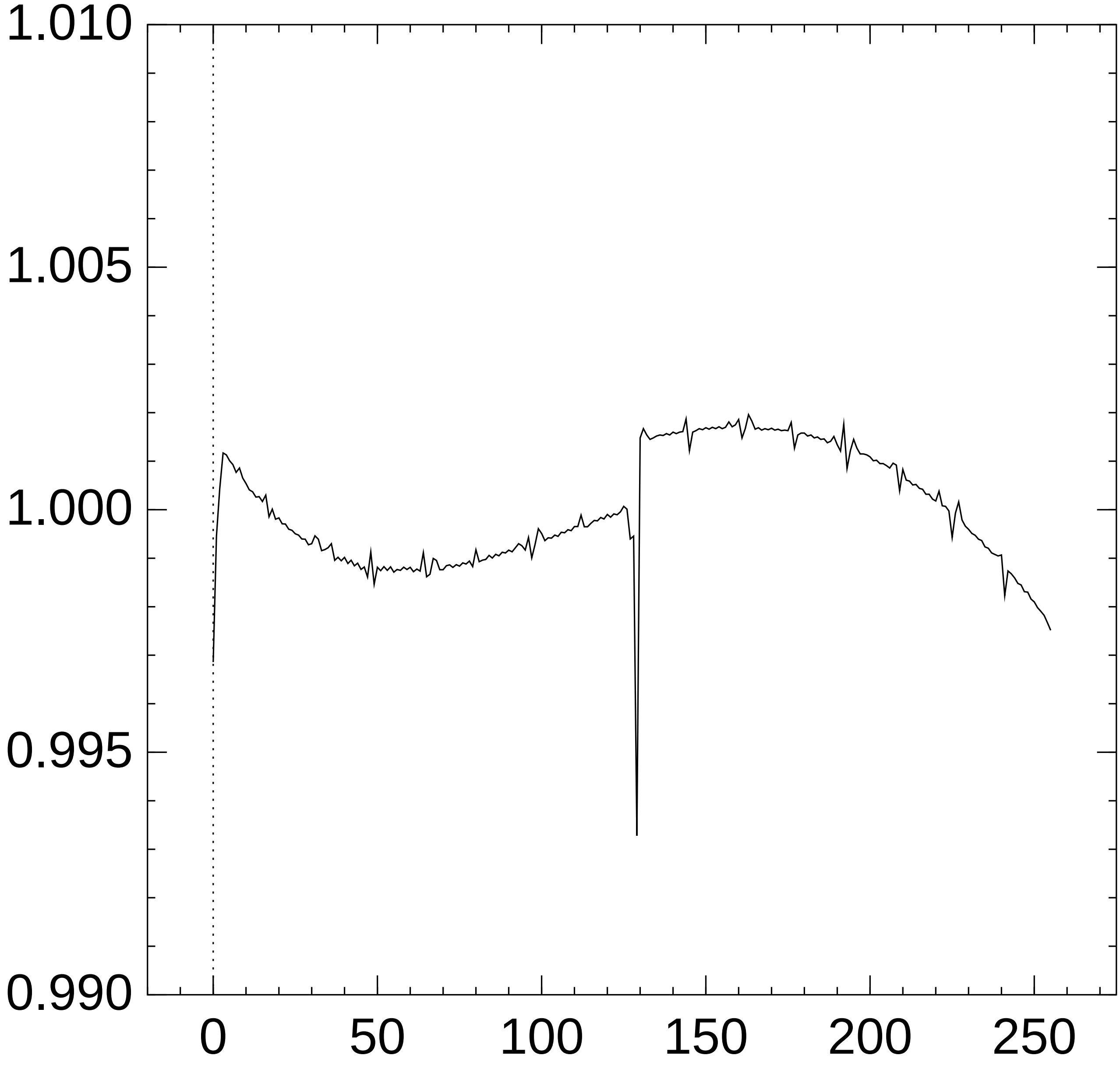
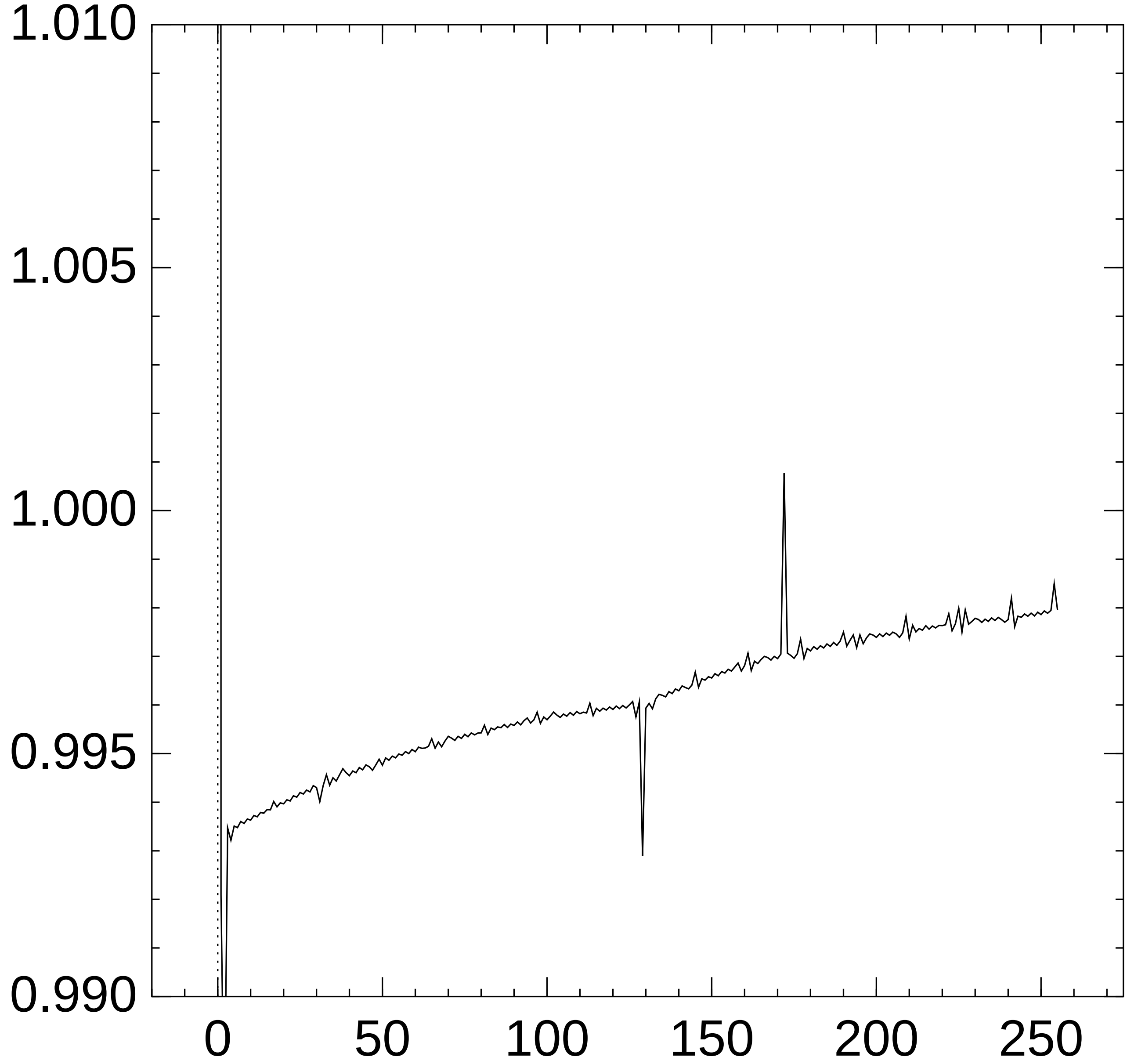
$\approx$256 of these biases were found independently (slightly earlier) by 2013 Watanabe–Isobe–Ohigashi–Morii, 2013 Isobe–Ohigashi–Watanabe–Morii: $z_{32} \to 224$, $z_{48} \to 208$, etc.; $z_3 \to 131$; $z_i \to i$; $z_{256} \not\to 0$.

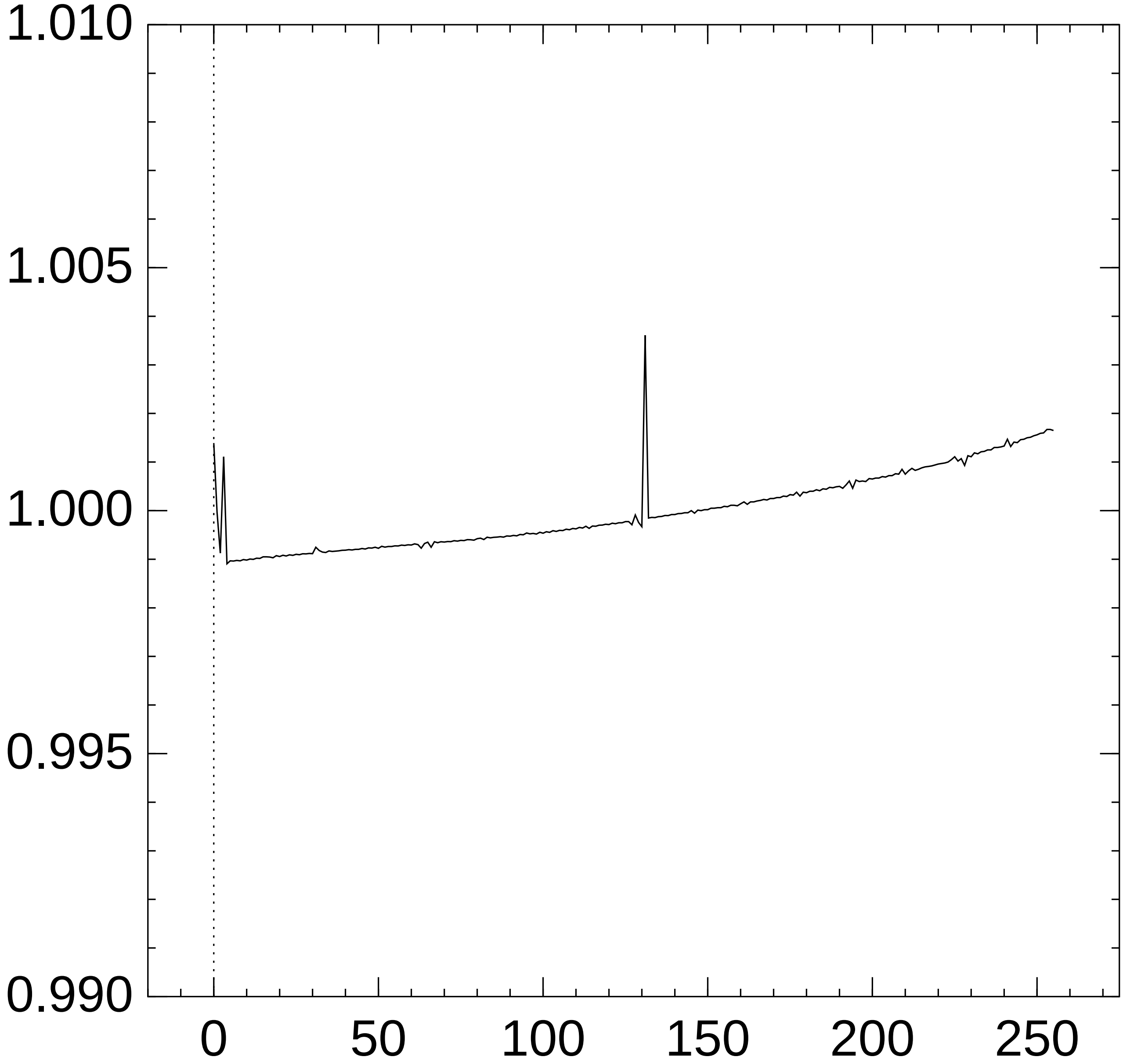
Graph of $256 \Pr[z_1 = x]$:



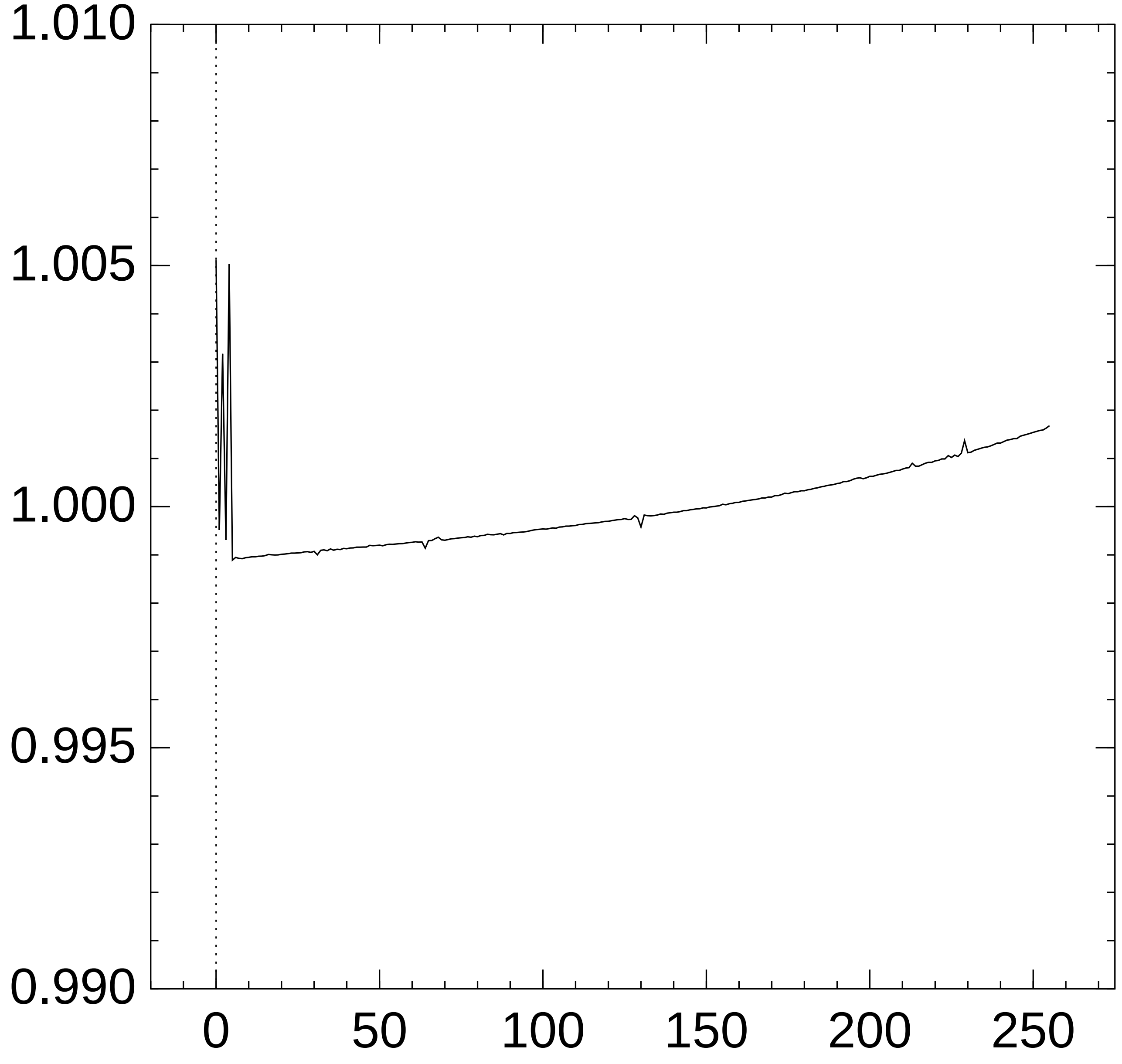
Graph of $256\,\Pr[z_2 = x]$:



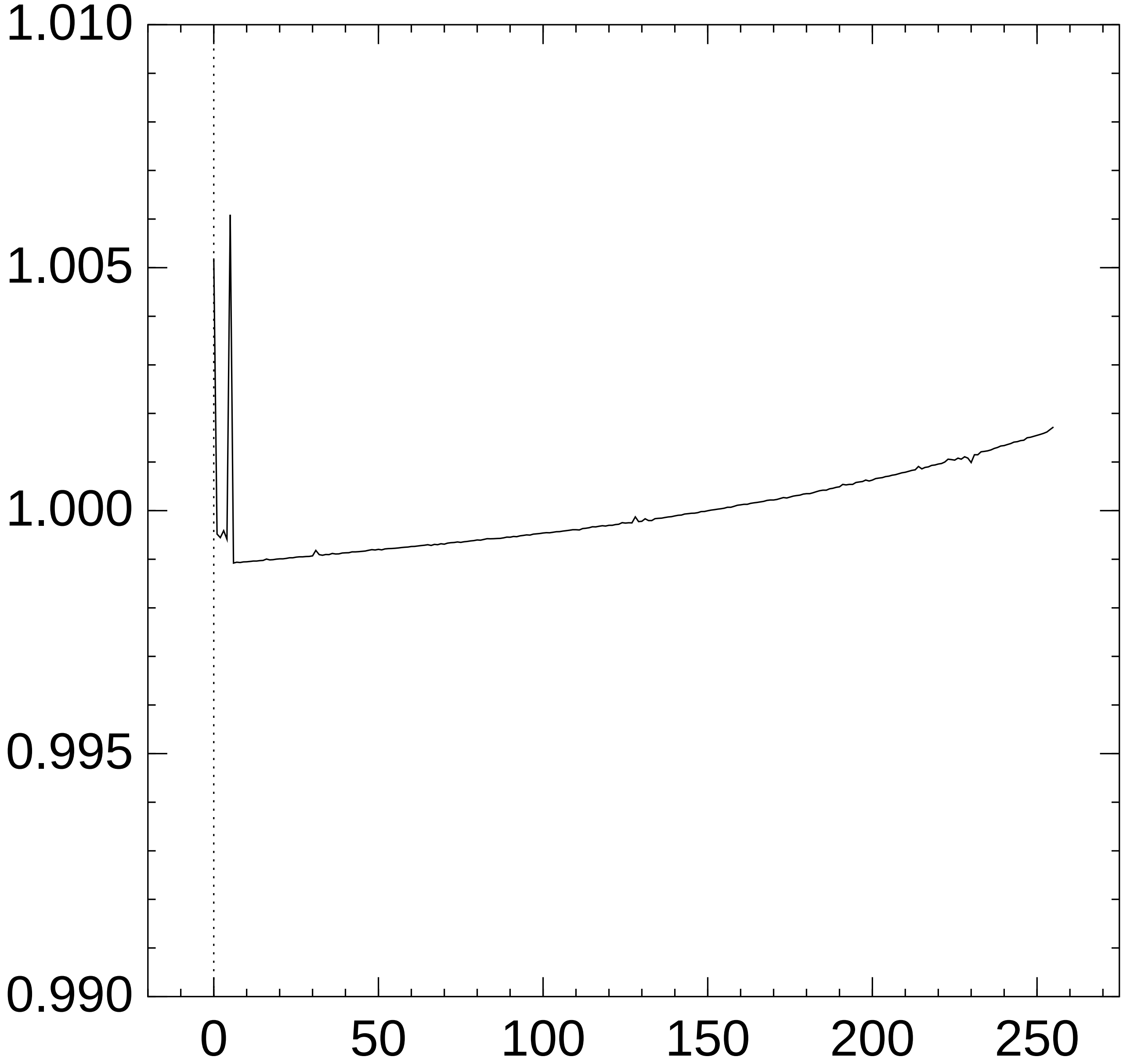
Graph of $256\,\mathrm{Pr}[z_3 = x]$:



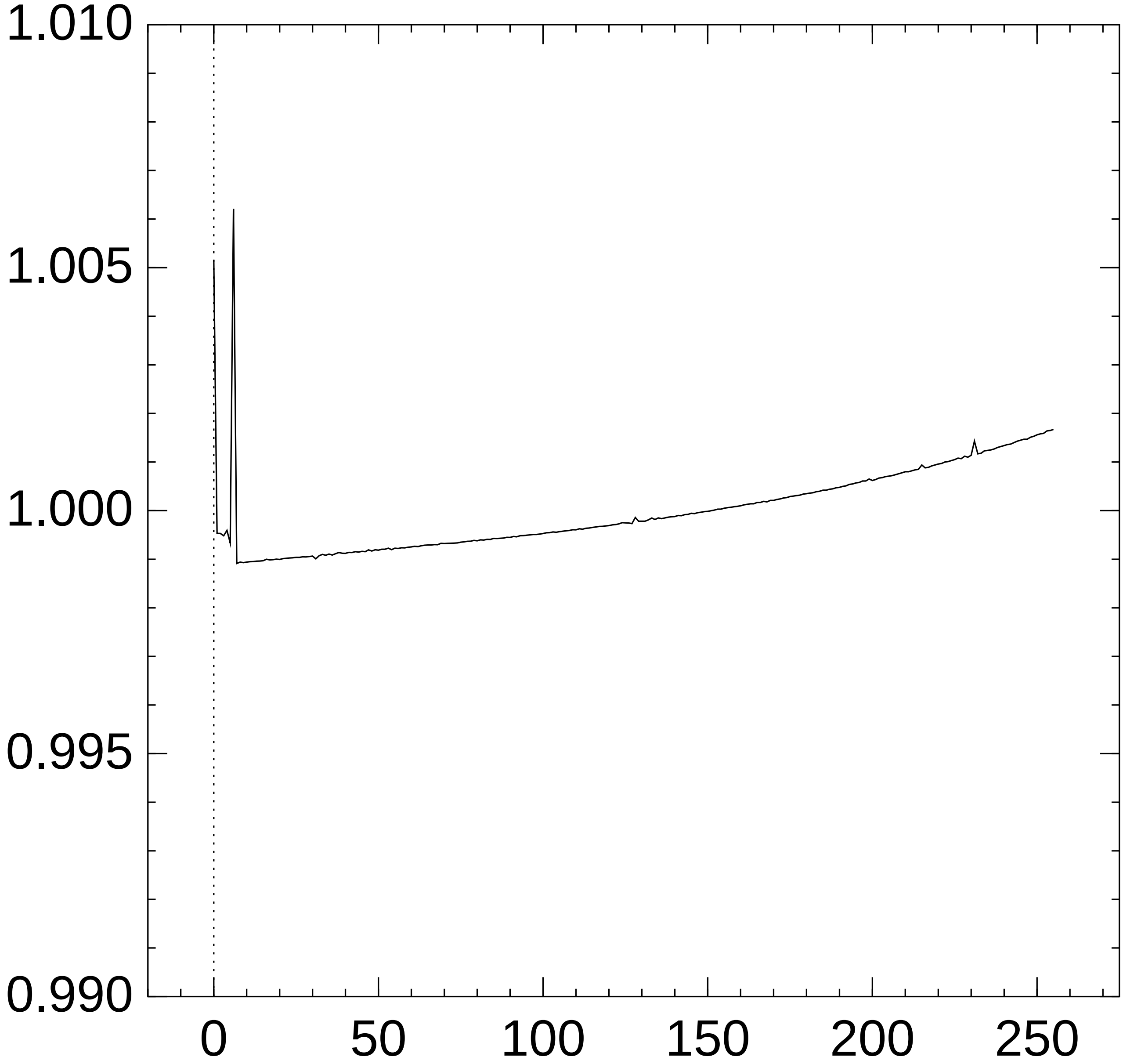
Graph of $256\,\Pr[z_4 = x]$:



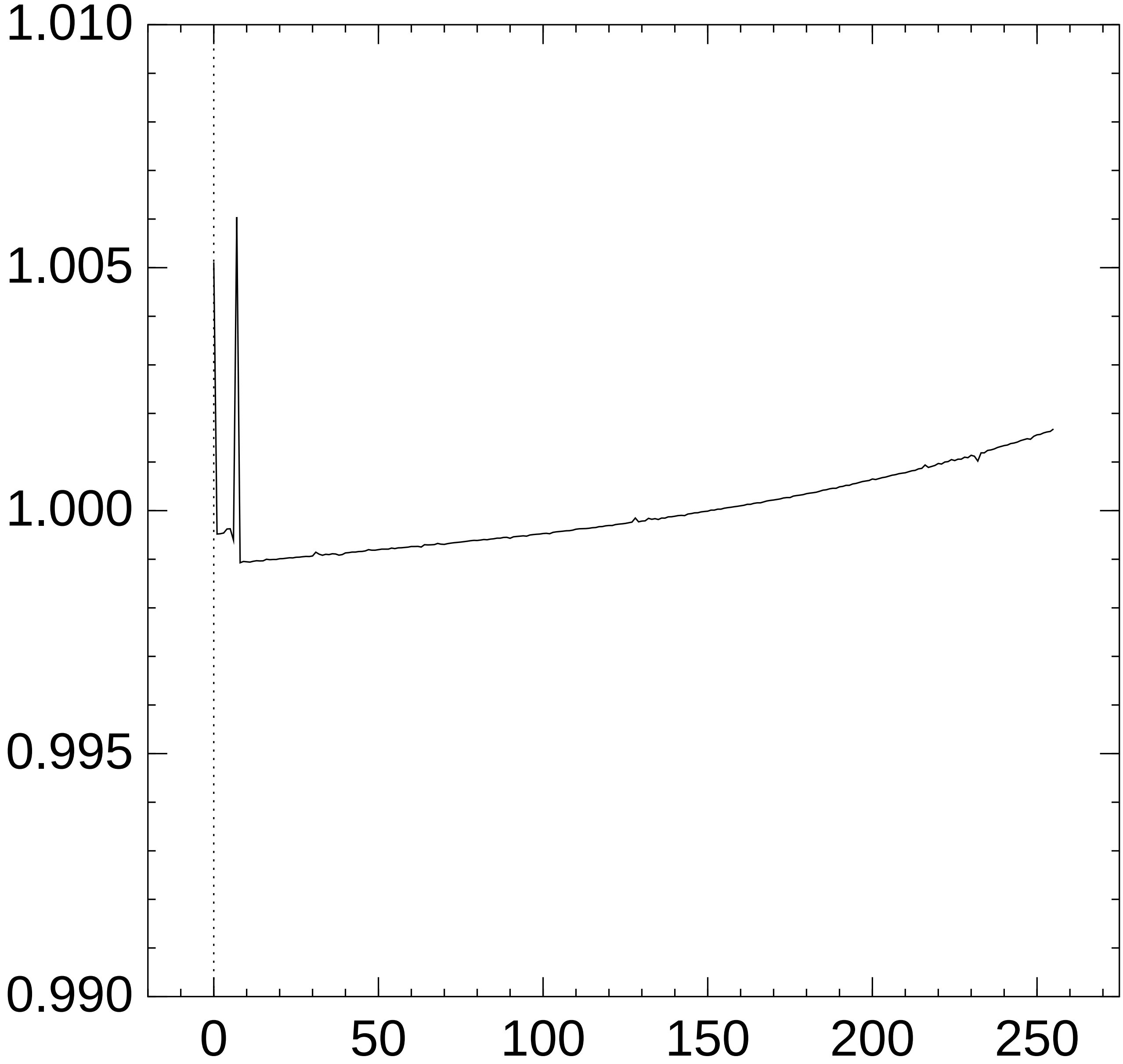
Graph of $256\,\Pr[z_5 = x]$:



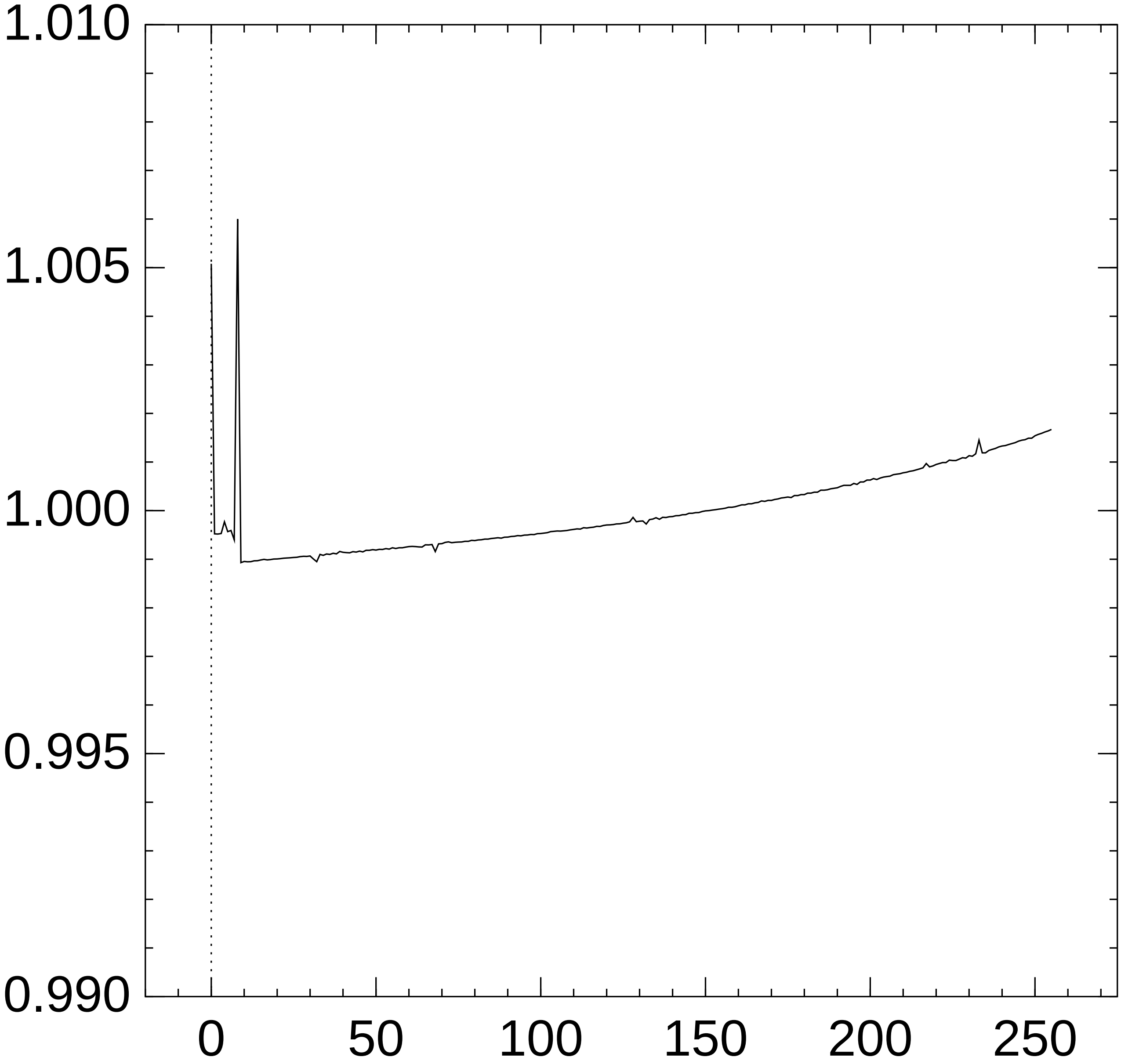
Graph of $256\,\Pr[z_6 = x]$:



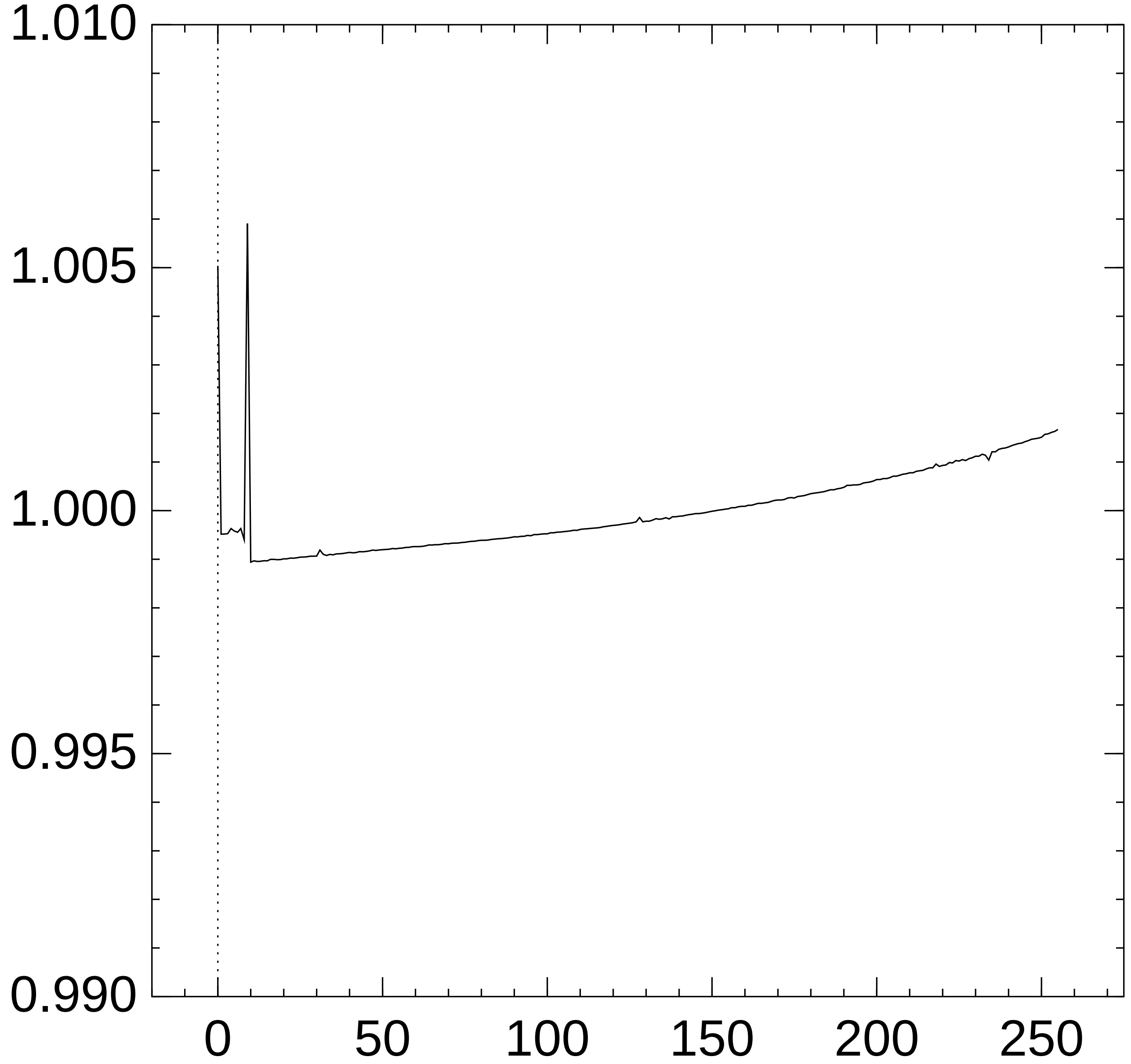
Graph of $256 \Pr[z_7 = x]$:



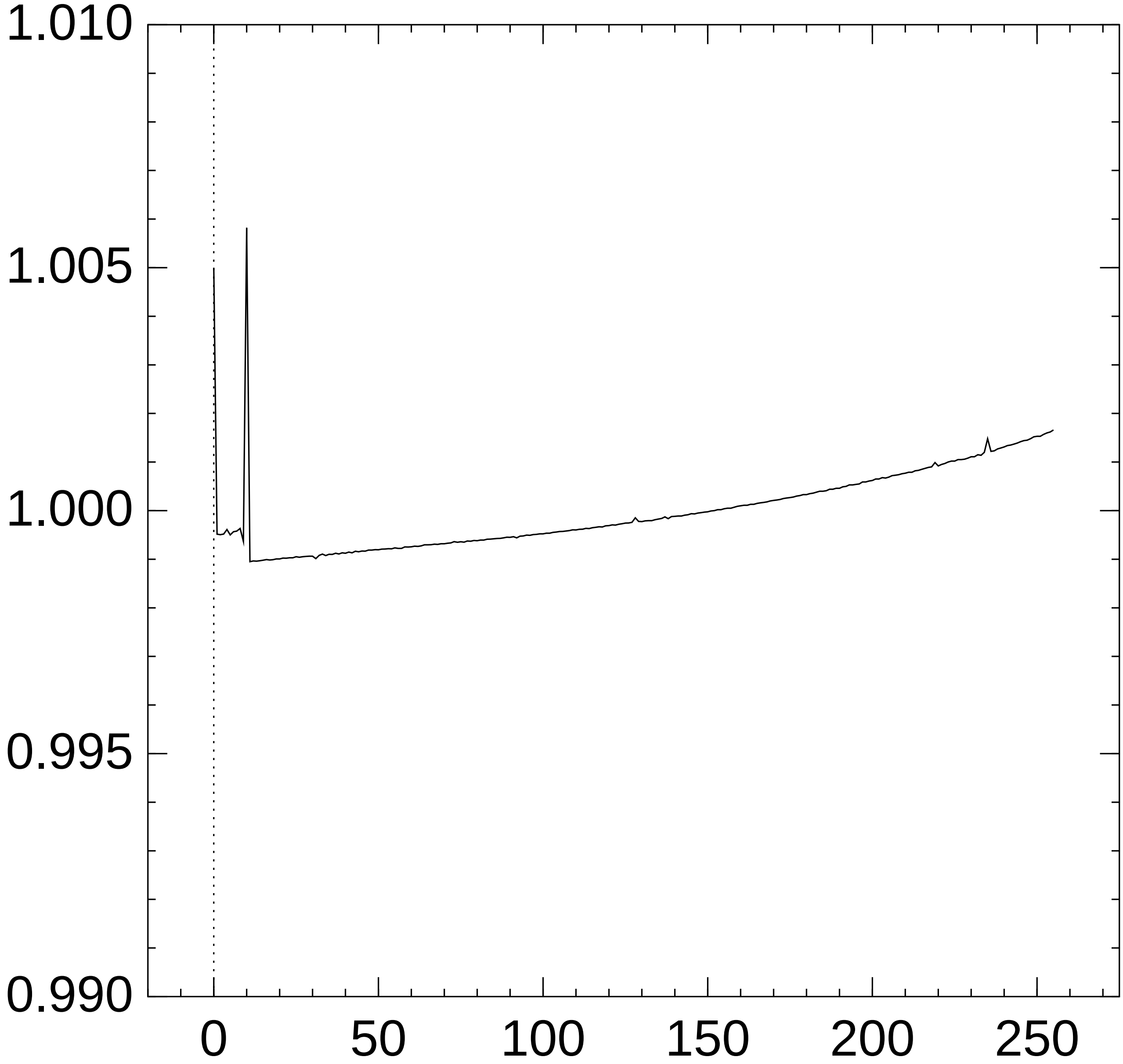
Graph of $256\,\Pr[z_8 = x]$:



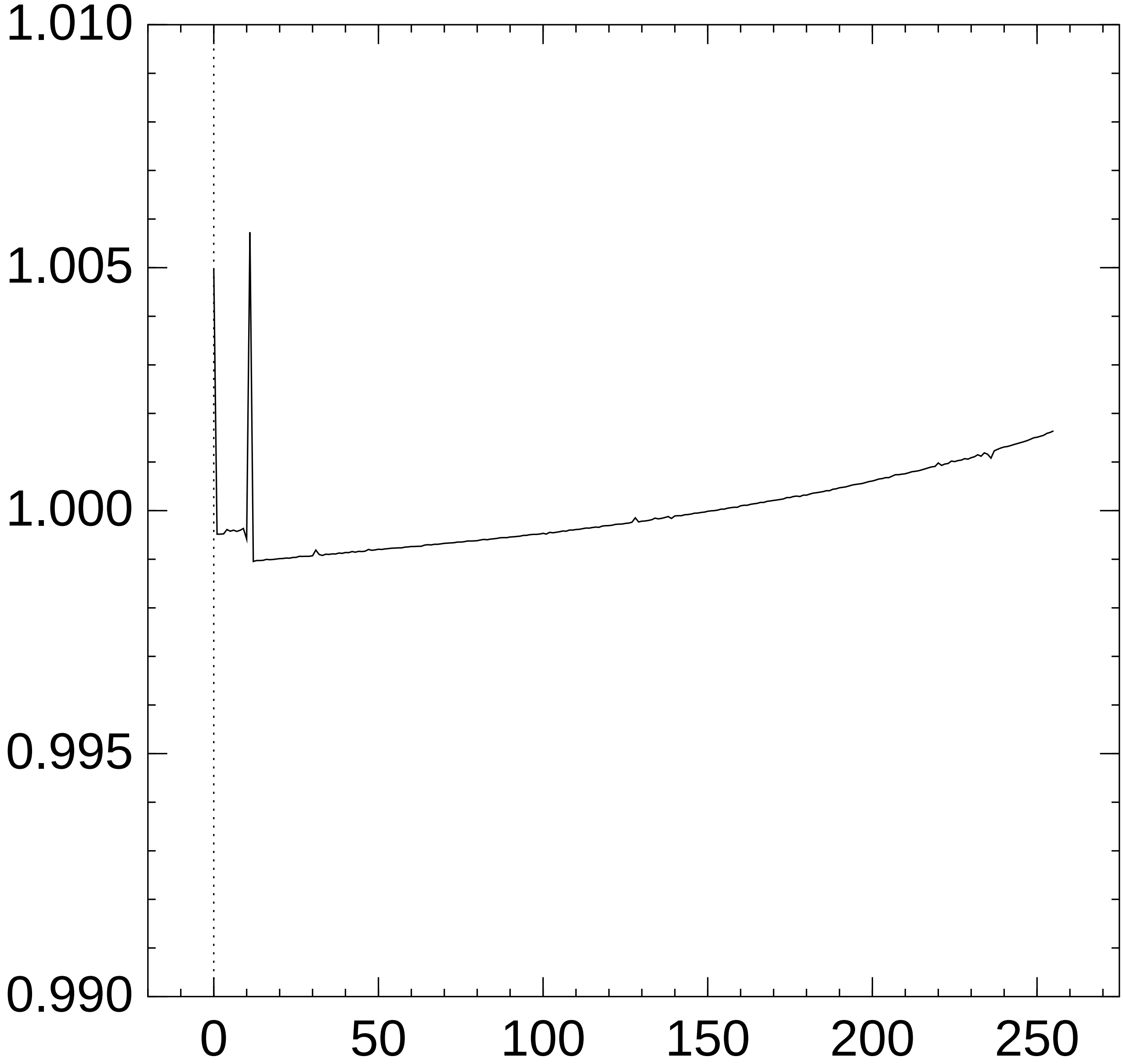
Graph of $256\,\mathrm{Pr}[z_9 = x]$:



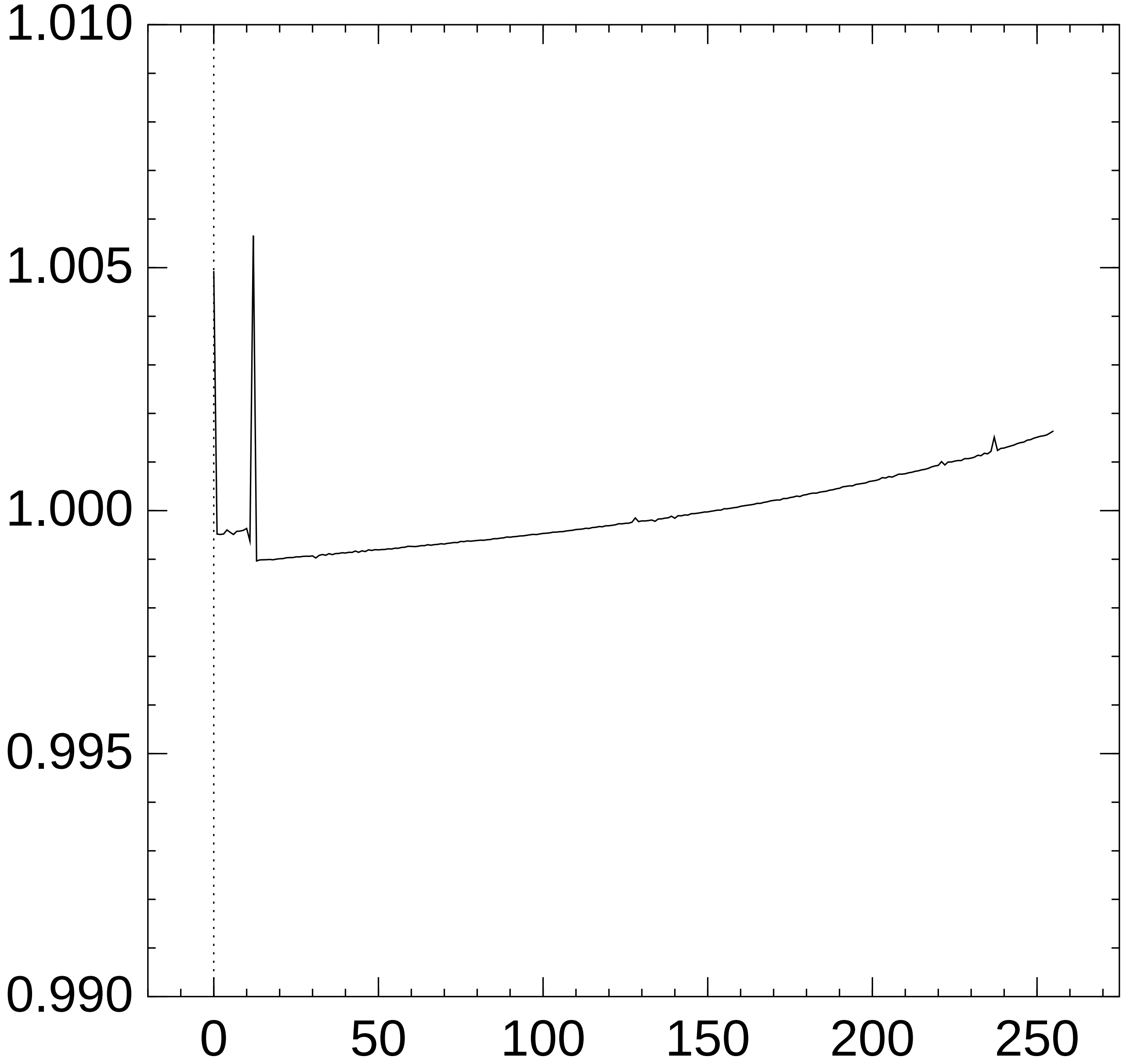
Graph of $256\,\mathrm{Pr}[z_{10} = x]$:



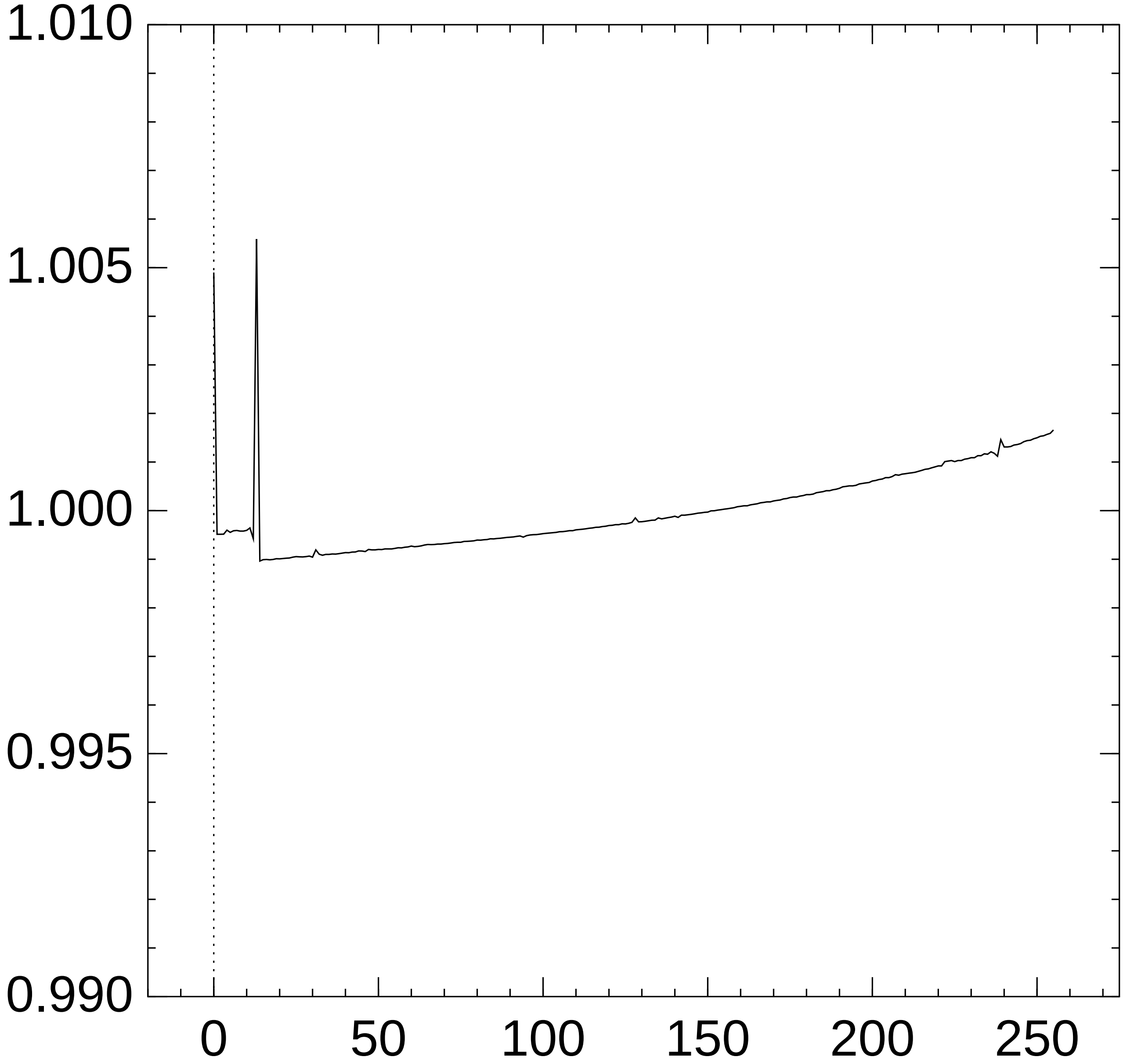
Graph of $256 \Pr[z_{11} = x]$:



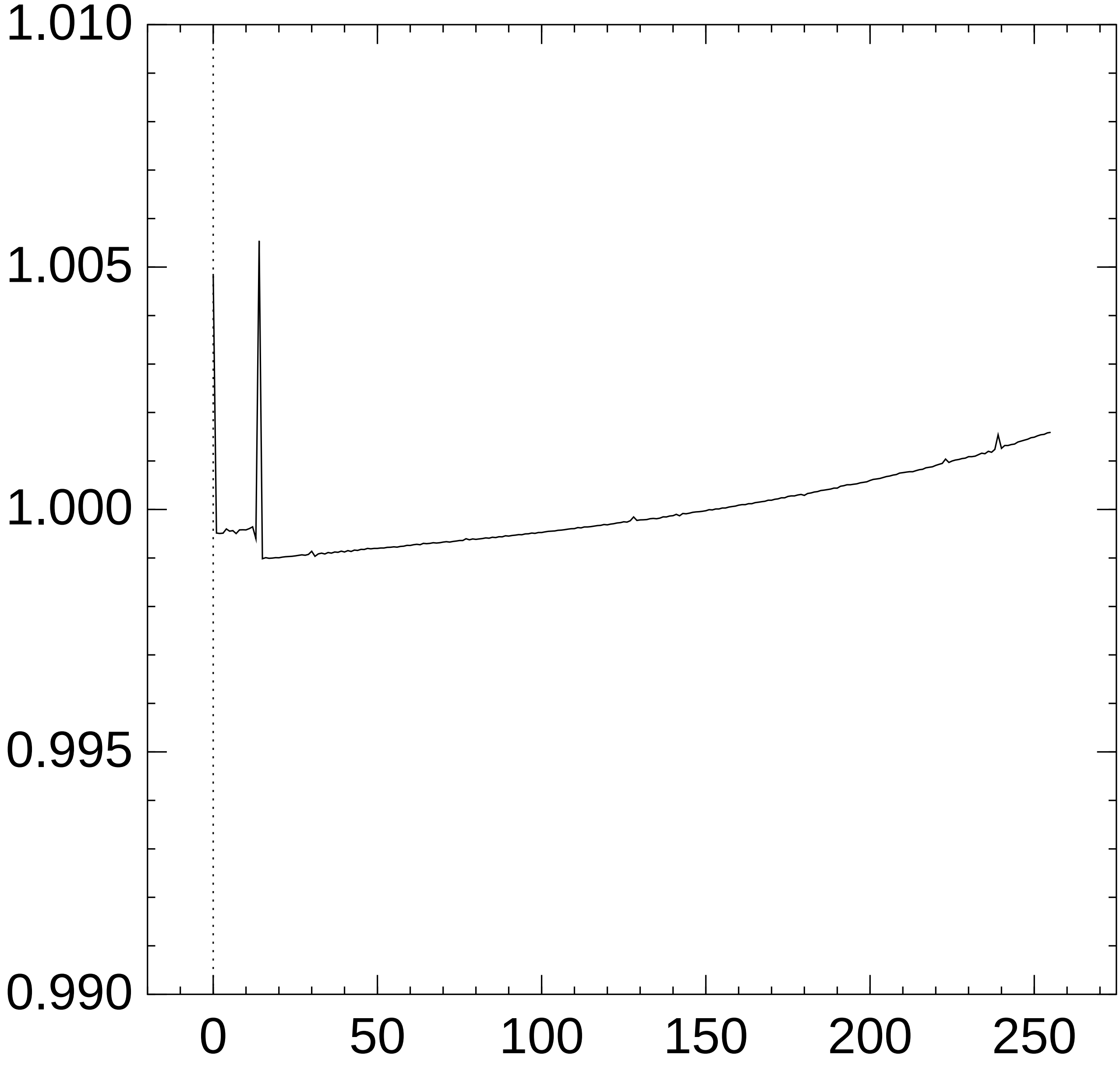
Graph of $256\,\Pr[z_{12} = x]$:



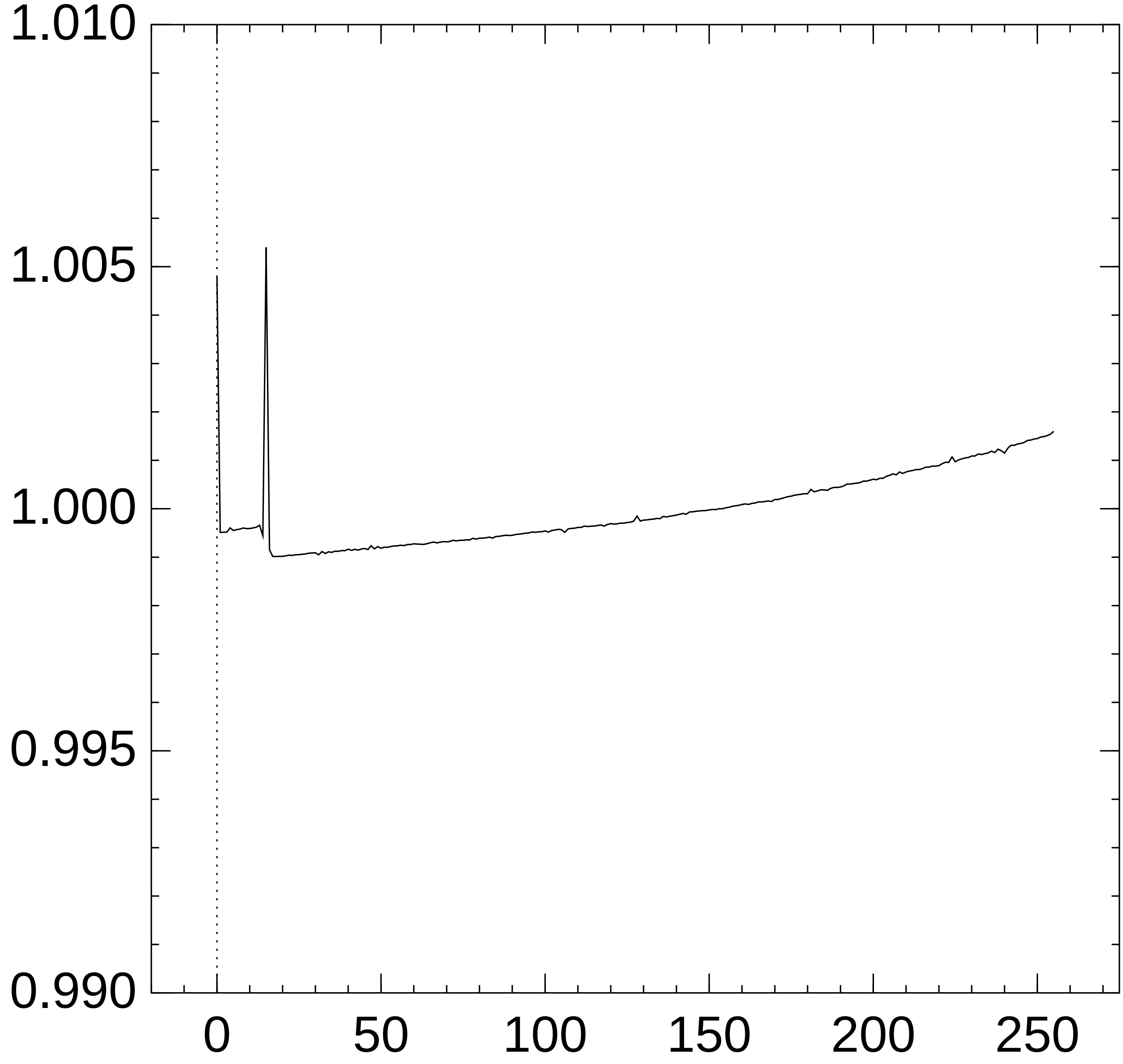
Graph of $256\,\Pr[z_{13} = x]$:



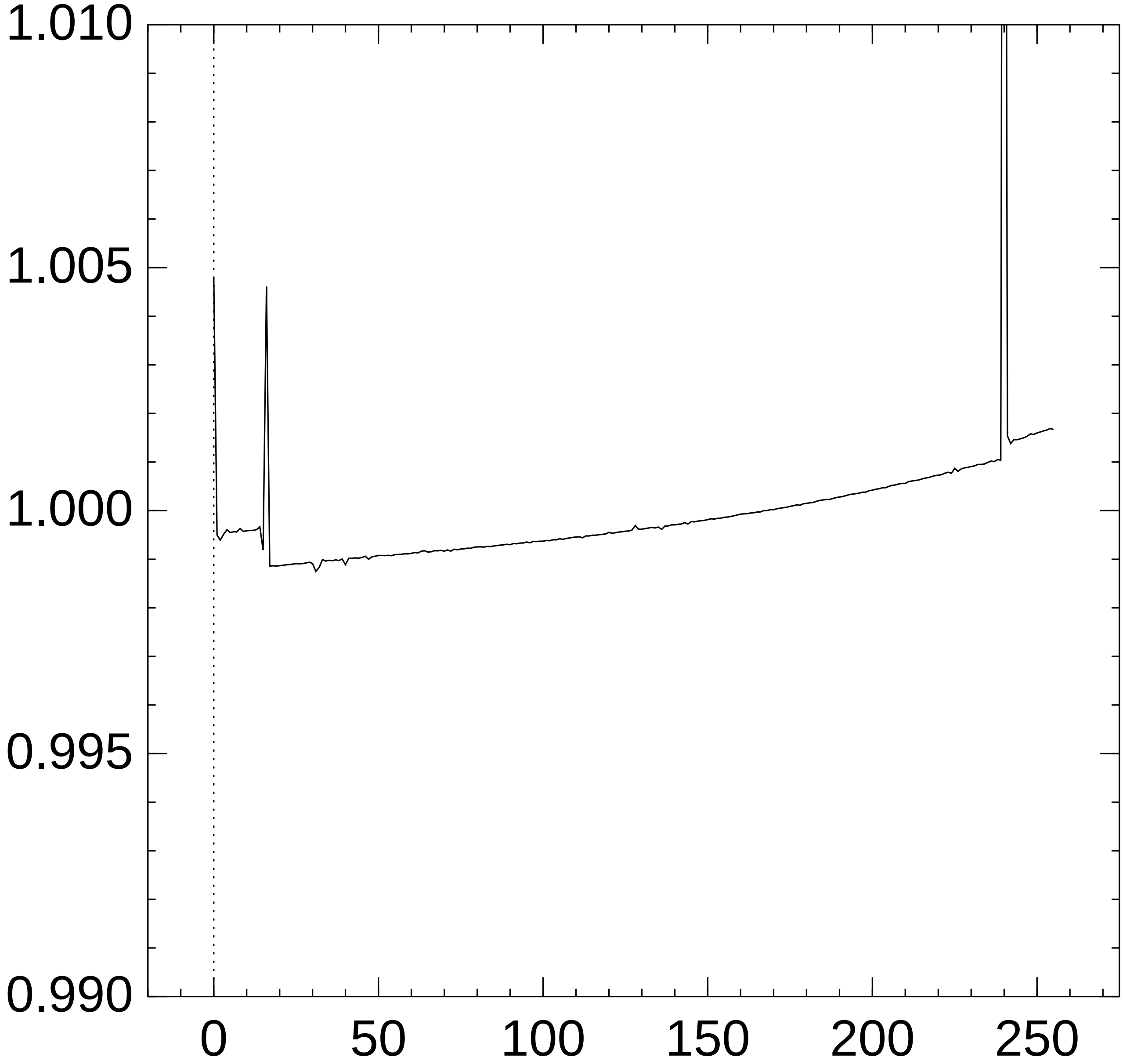
Graph of $256\,\Pr[z_{14} = x]$:



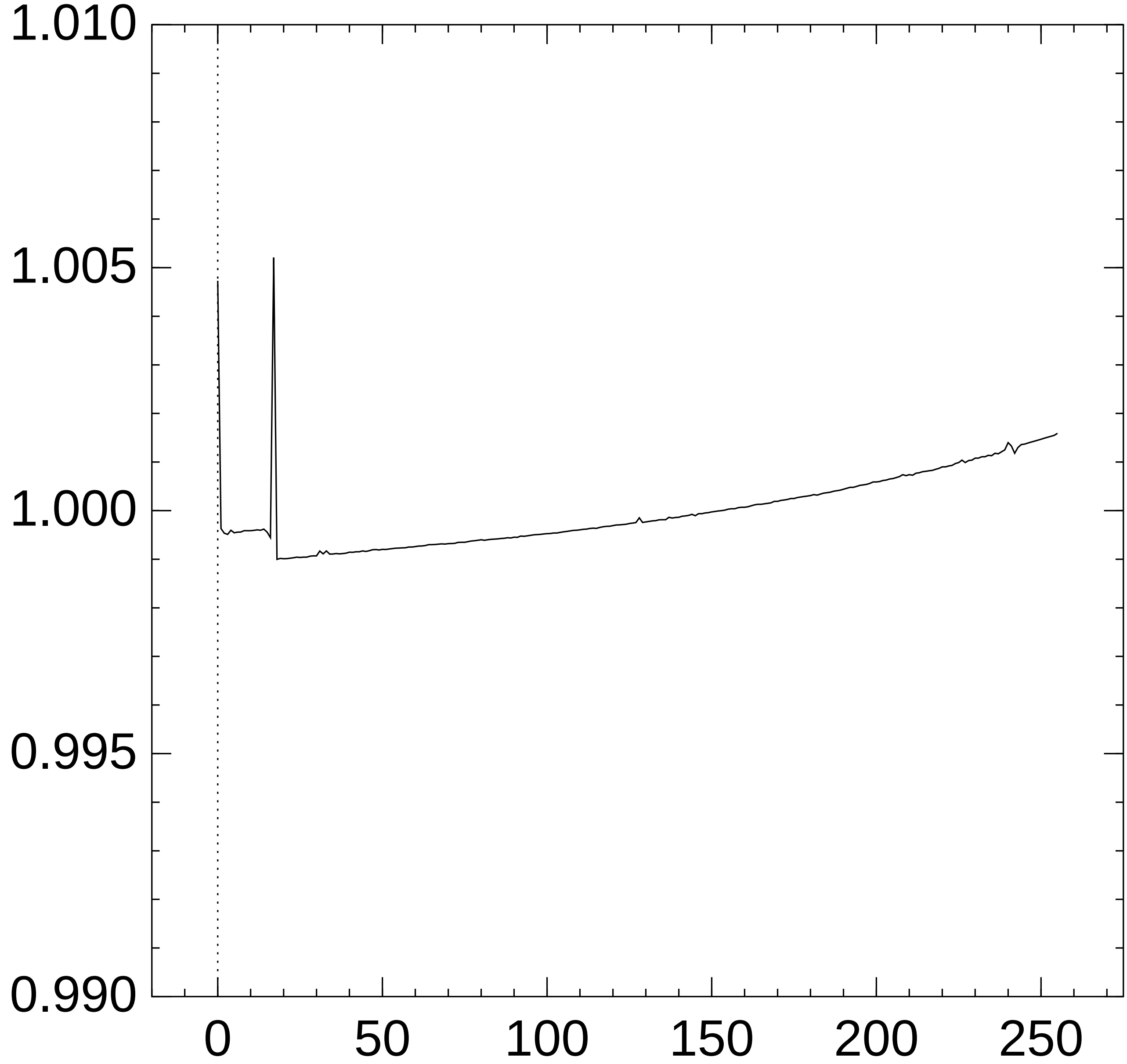
Graph of $256\,\Pr[z_{15} = x]$:



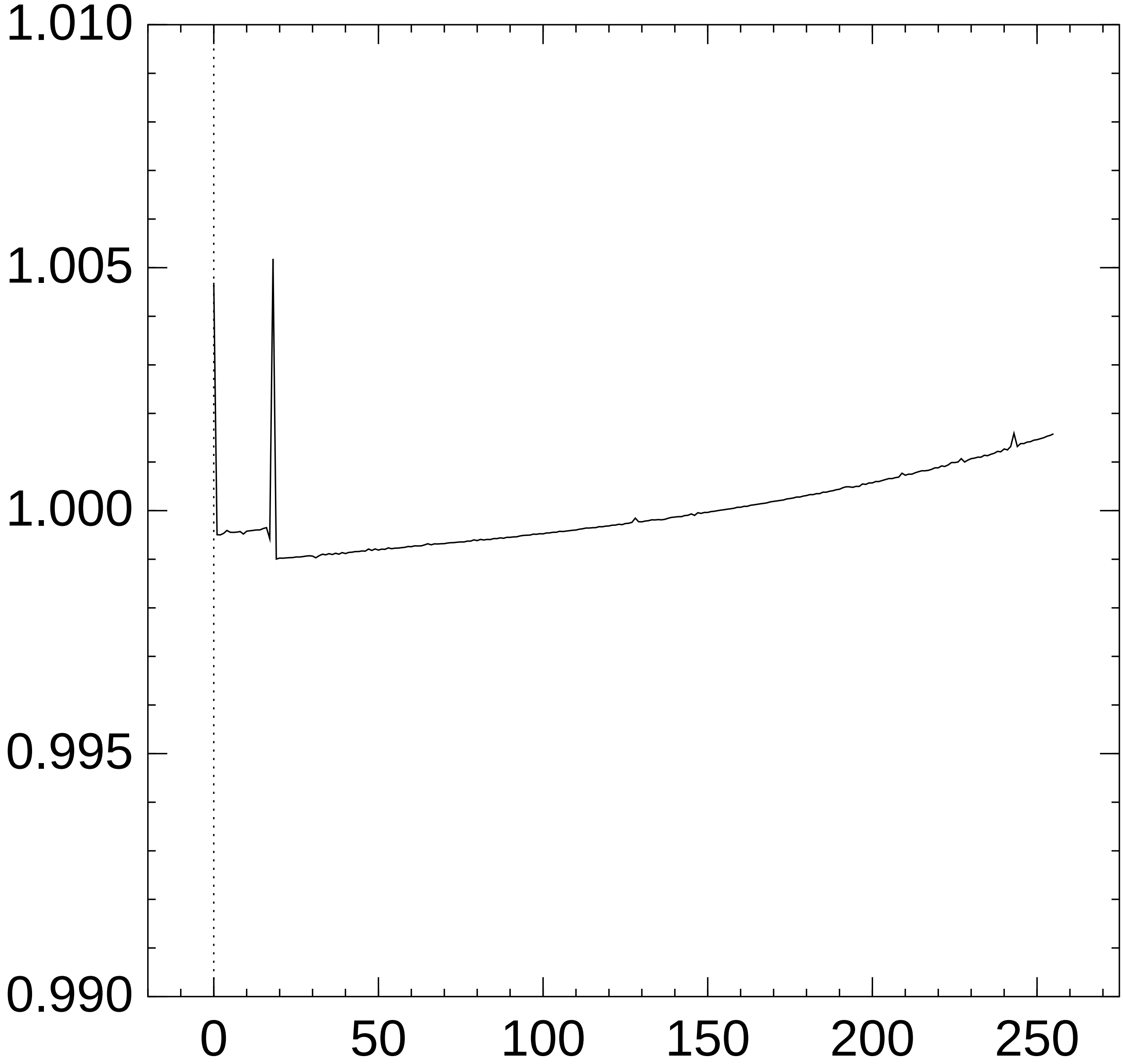
Graph of $256\,\mathrm{Pr}[z_{16} = x]$:



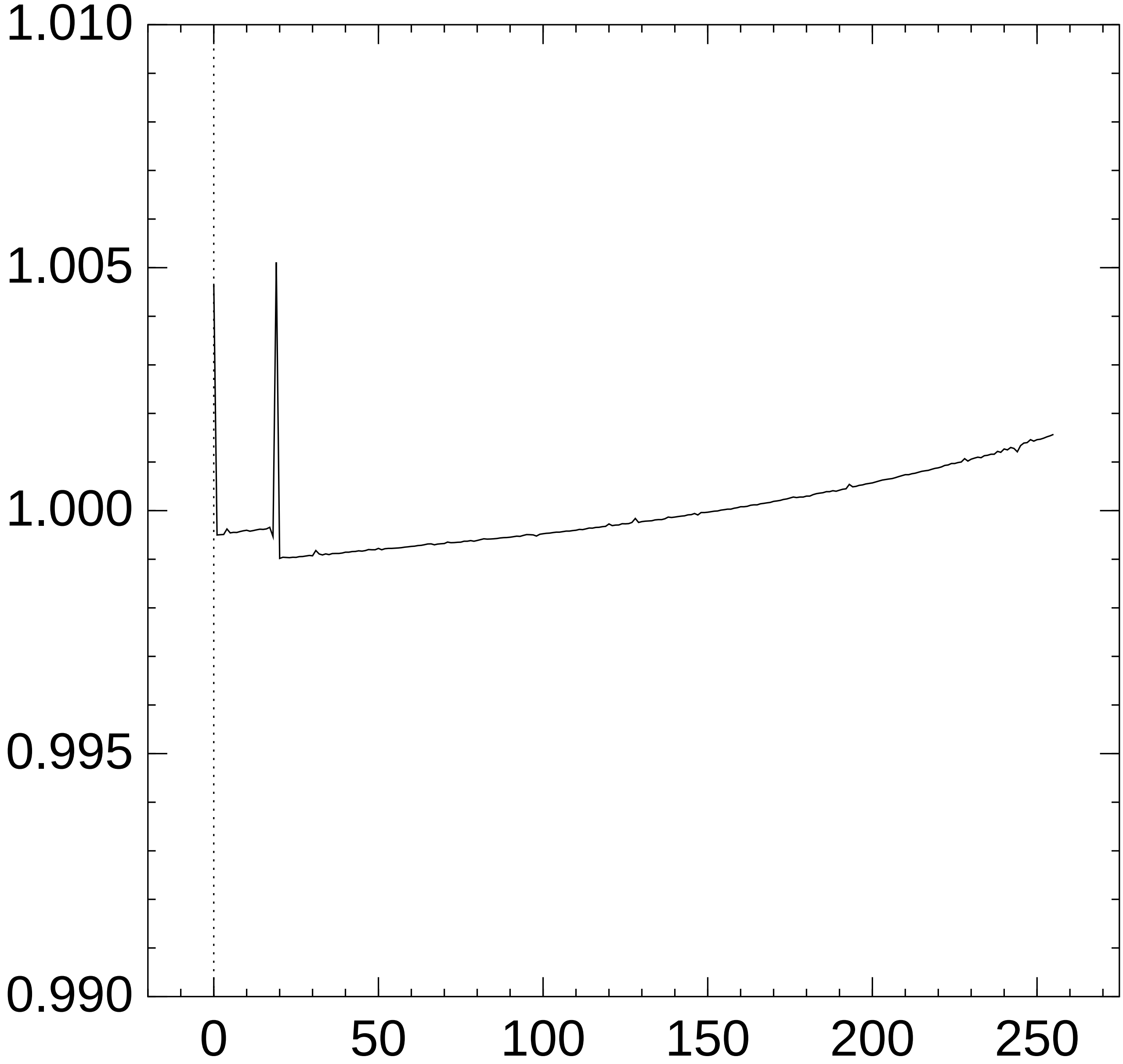
Graph of $256\,\Pr[z_{17} = x]$:



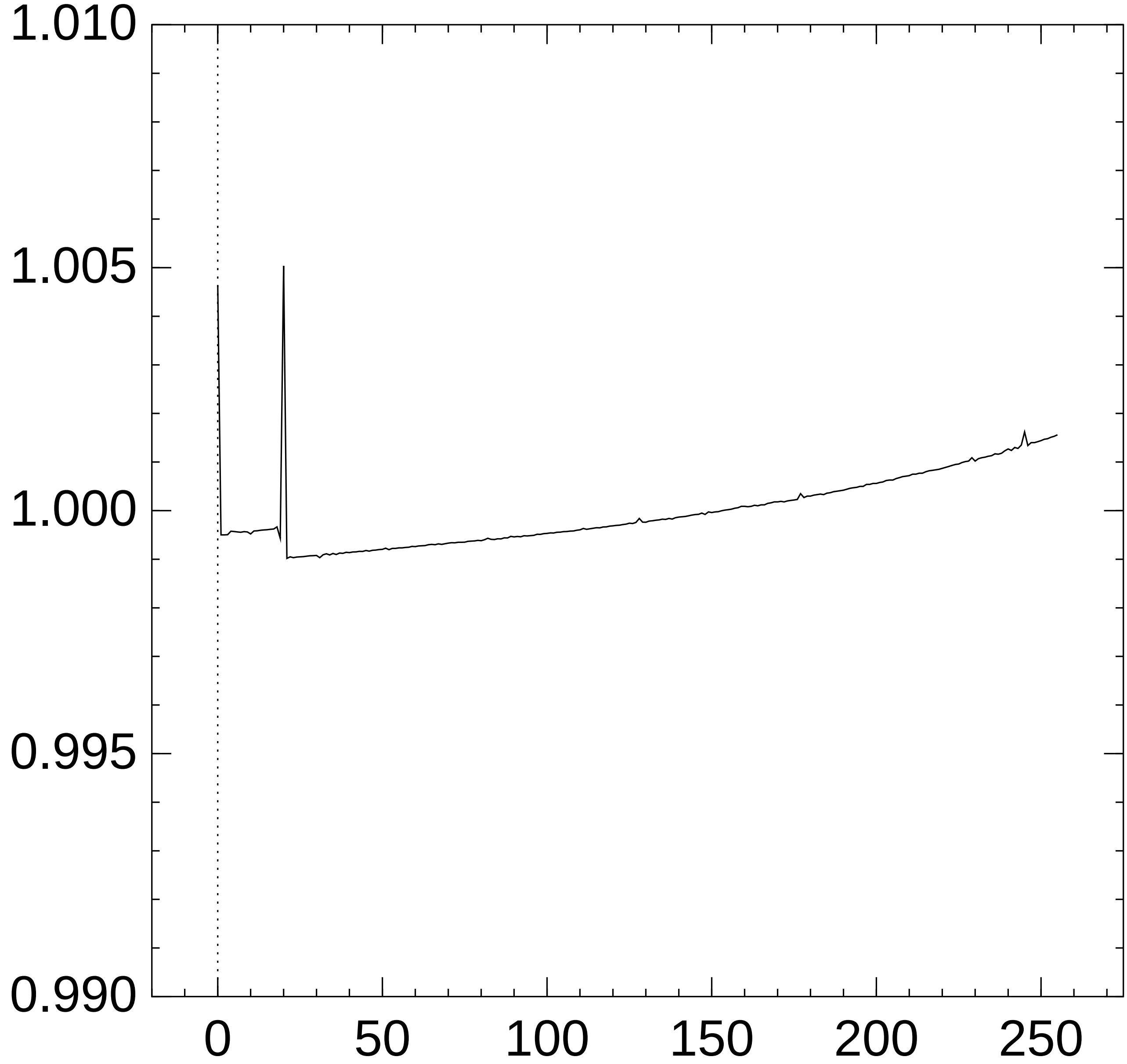
Graph of $256\,\mathrm{Pr}[z_{18} = x]$:



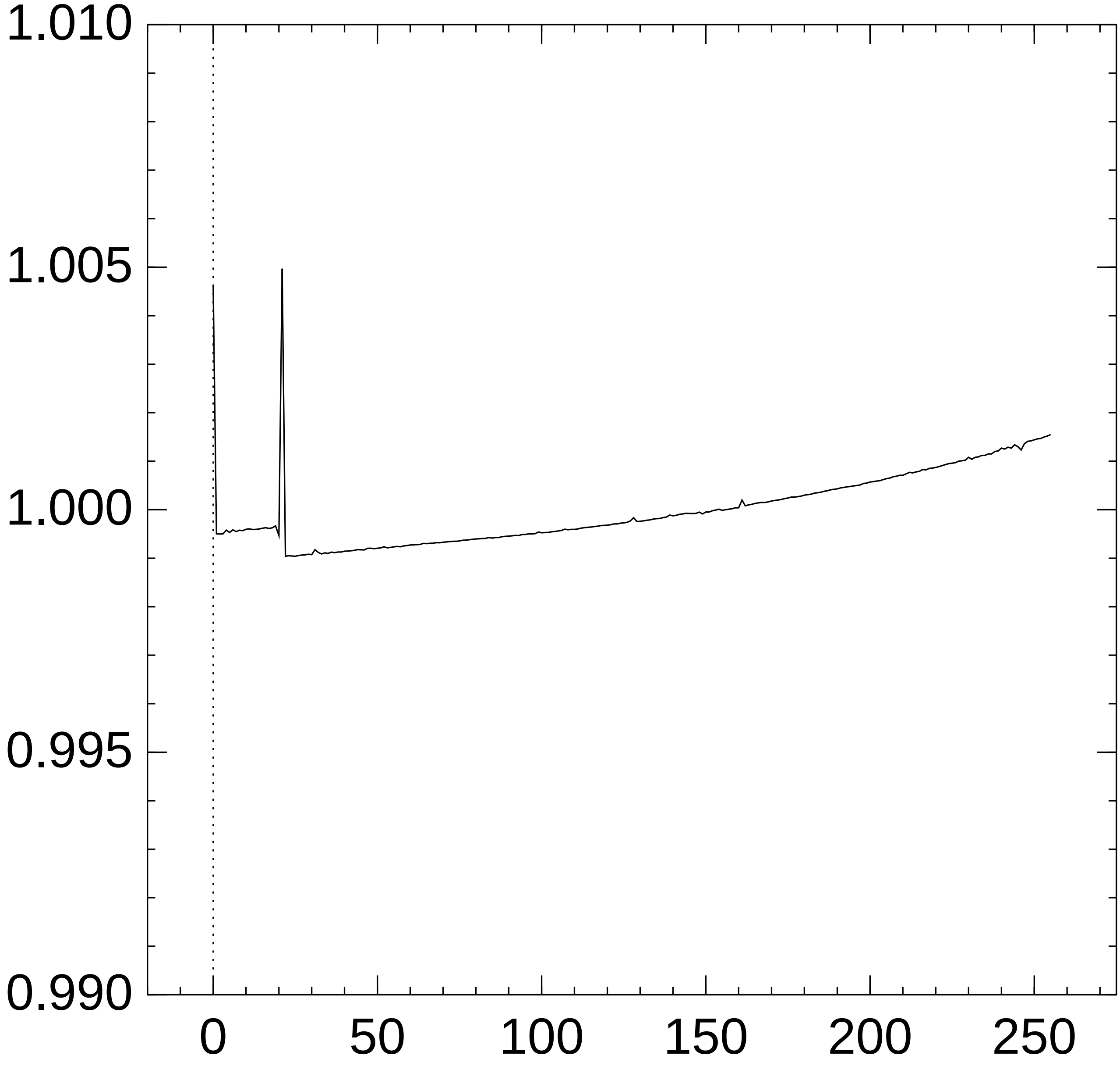
Graph of $256\,\mathrm{Pr}[z_{19} = x]$:



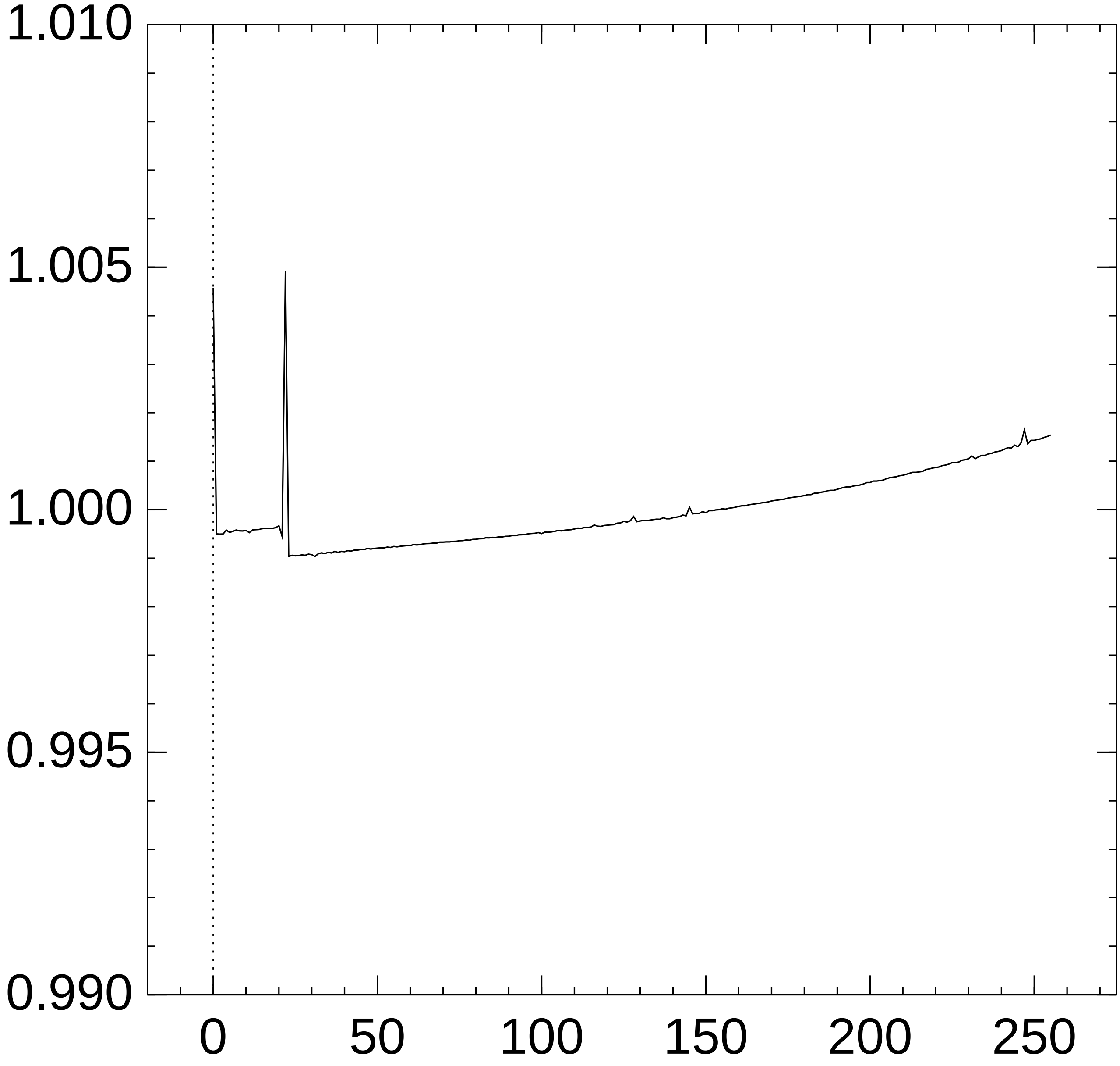
Graph of $256\,\Pr[z_{20} = x]$:



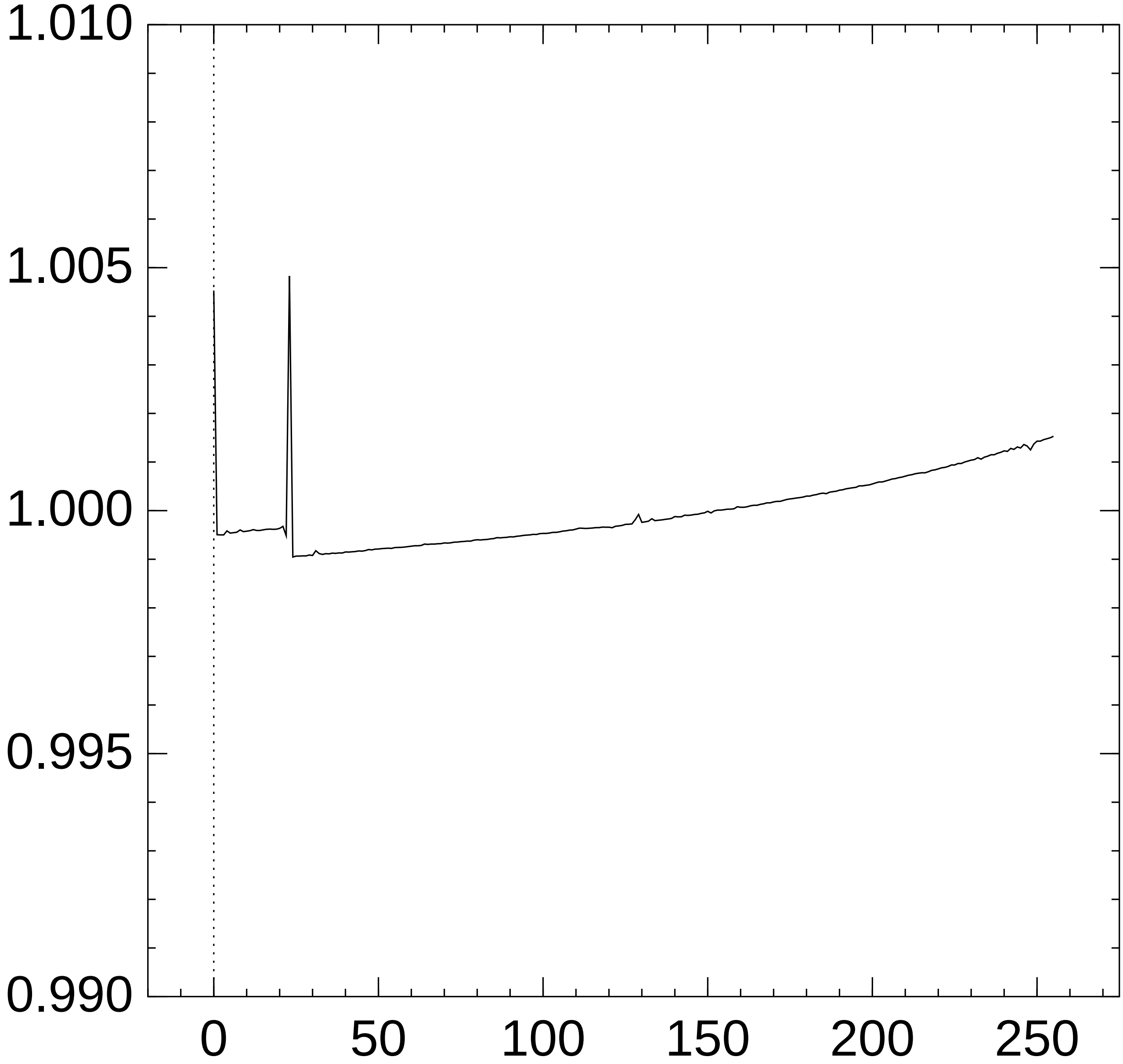
Graph of $256\,\Pr[z_{21} = x]$:



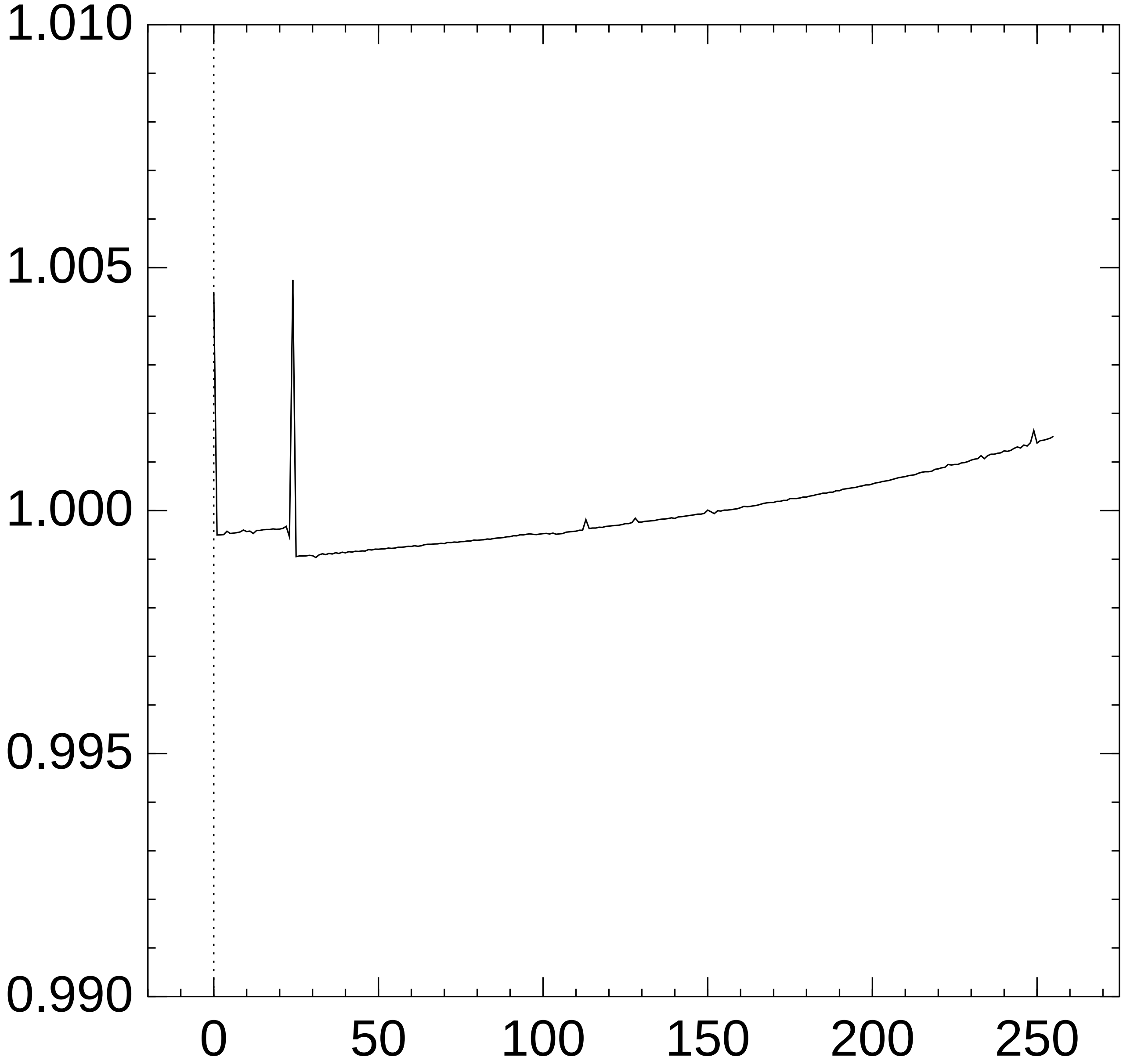
Graph of $256\,\mathrm{Pr}[z_{22} = x]$:



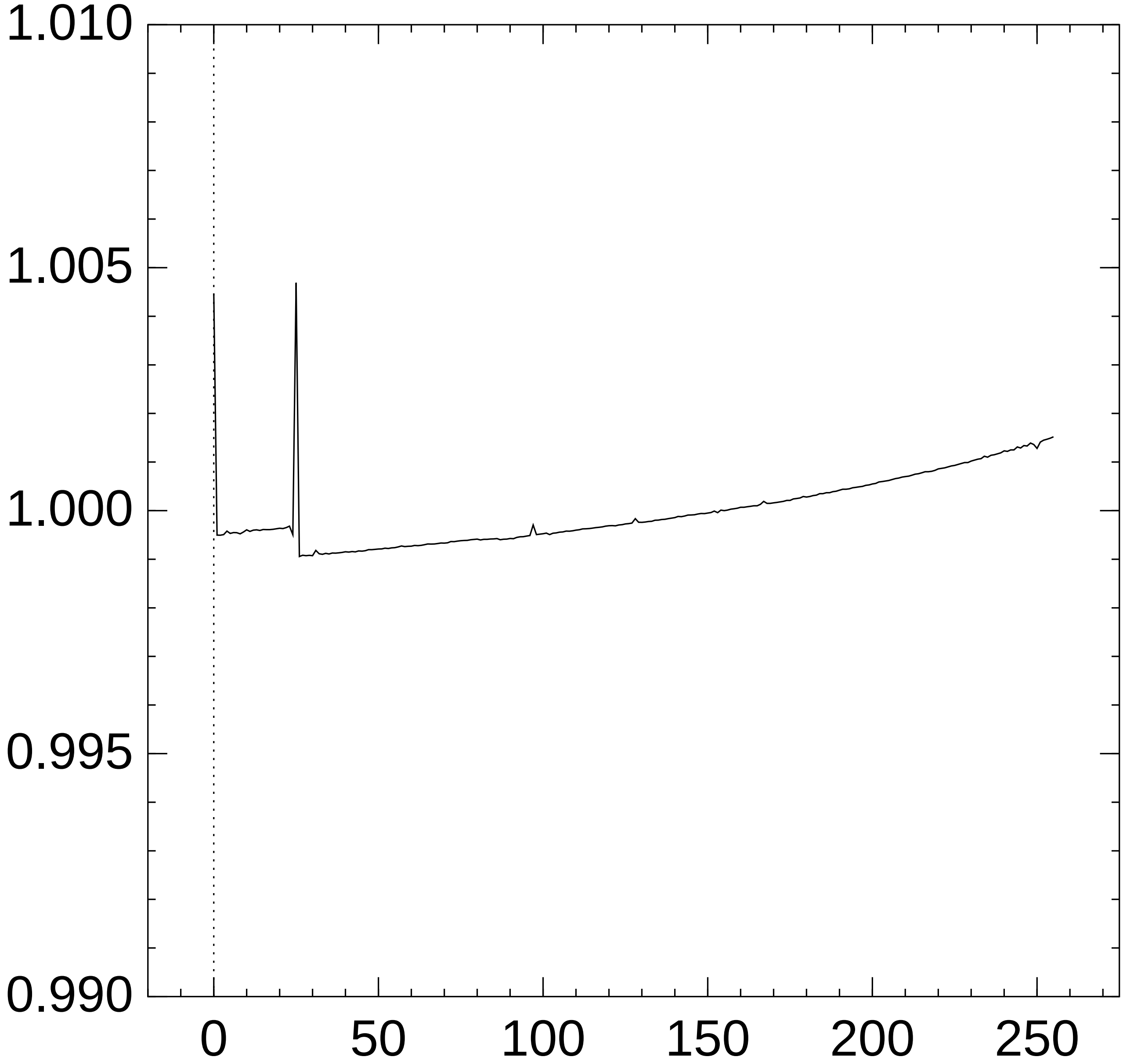
Graph of $256 \Pr[z_{23} = x]$:



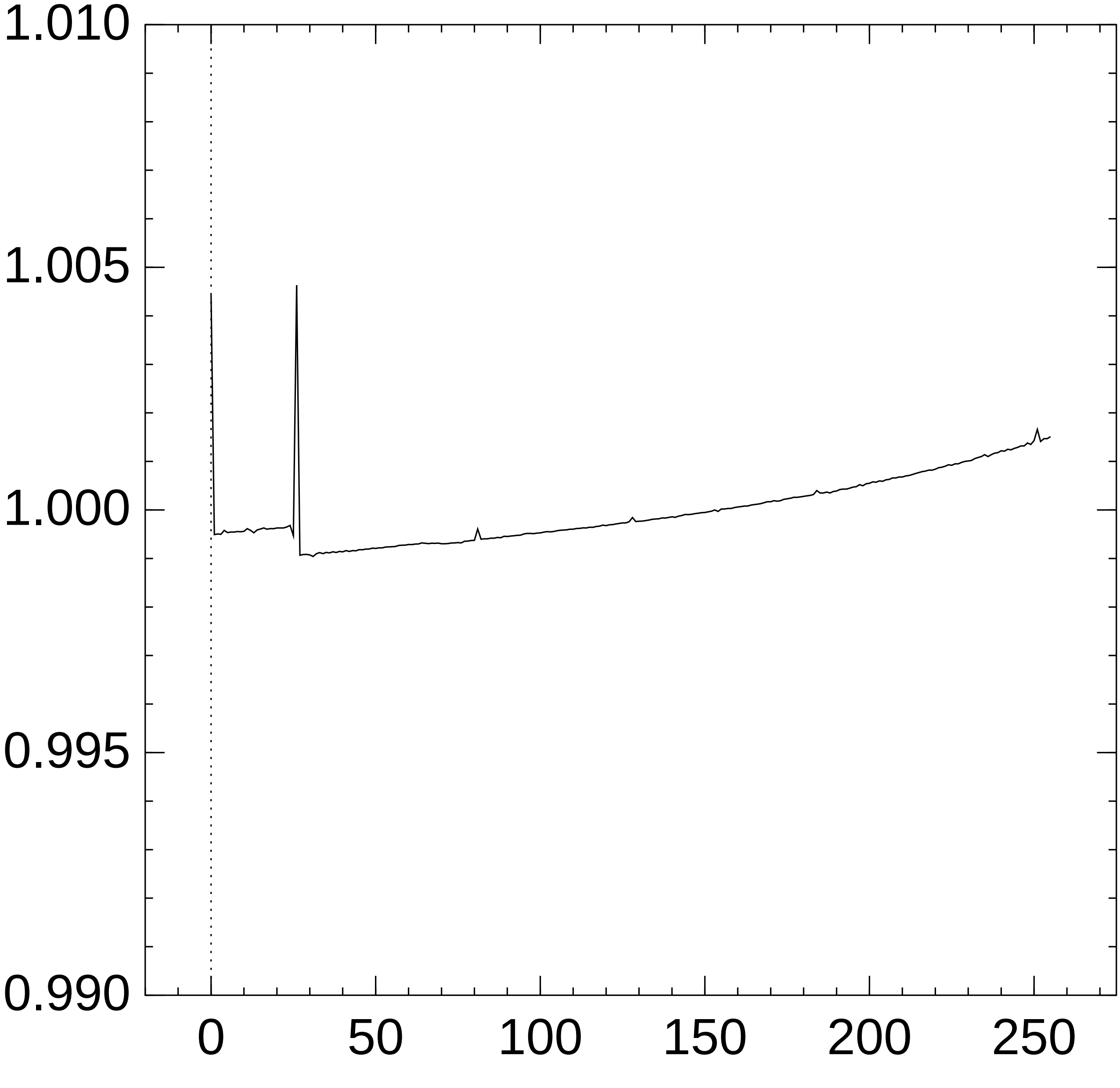
Graph of $256\,\Pr[z_{24} = x]$:



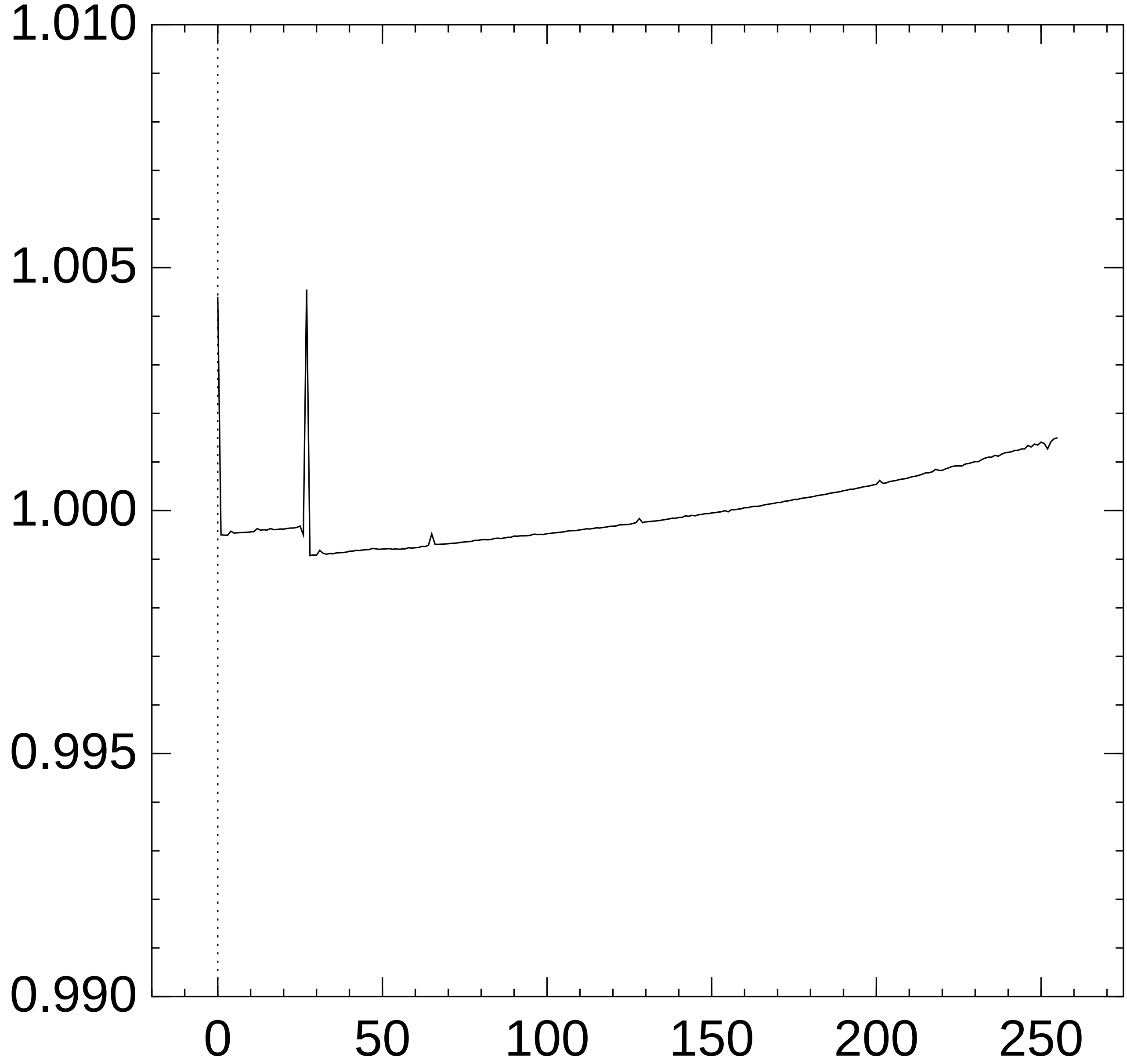
Graph of $256\,\mathrm{Pr}[z_{25} = x]$:



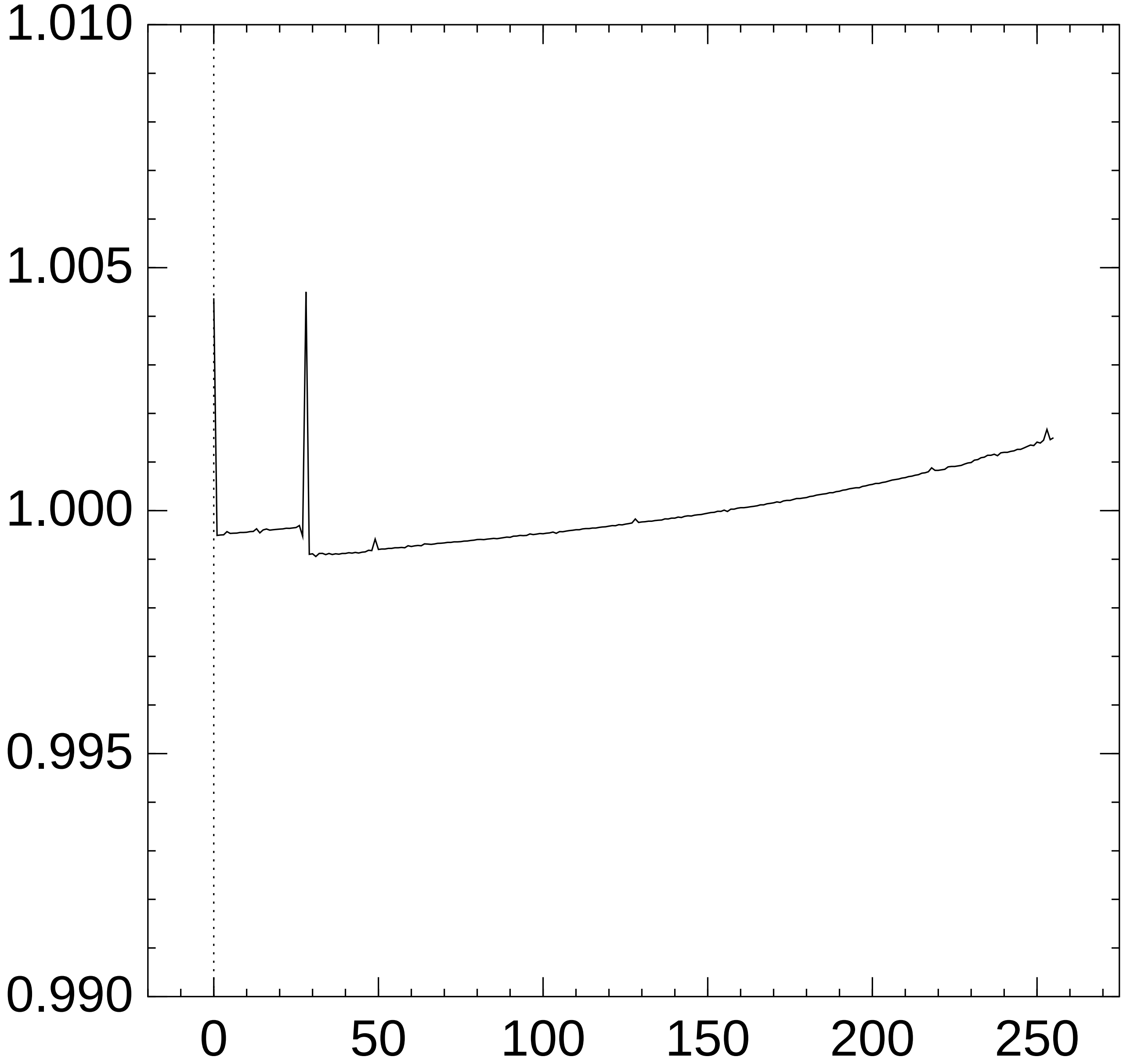
Graph of $256\,\Pr[z_{26} = x]$:



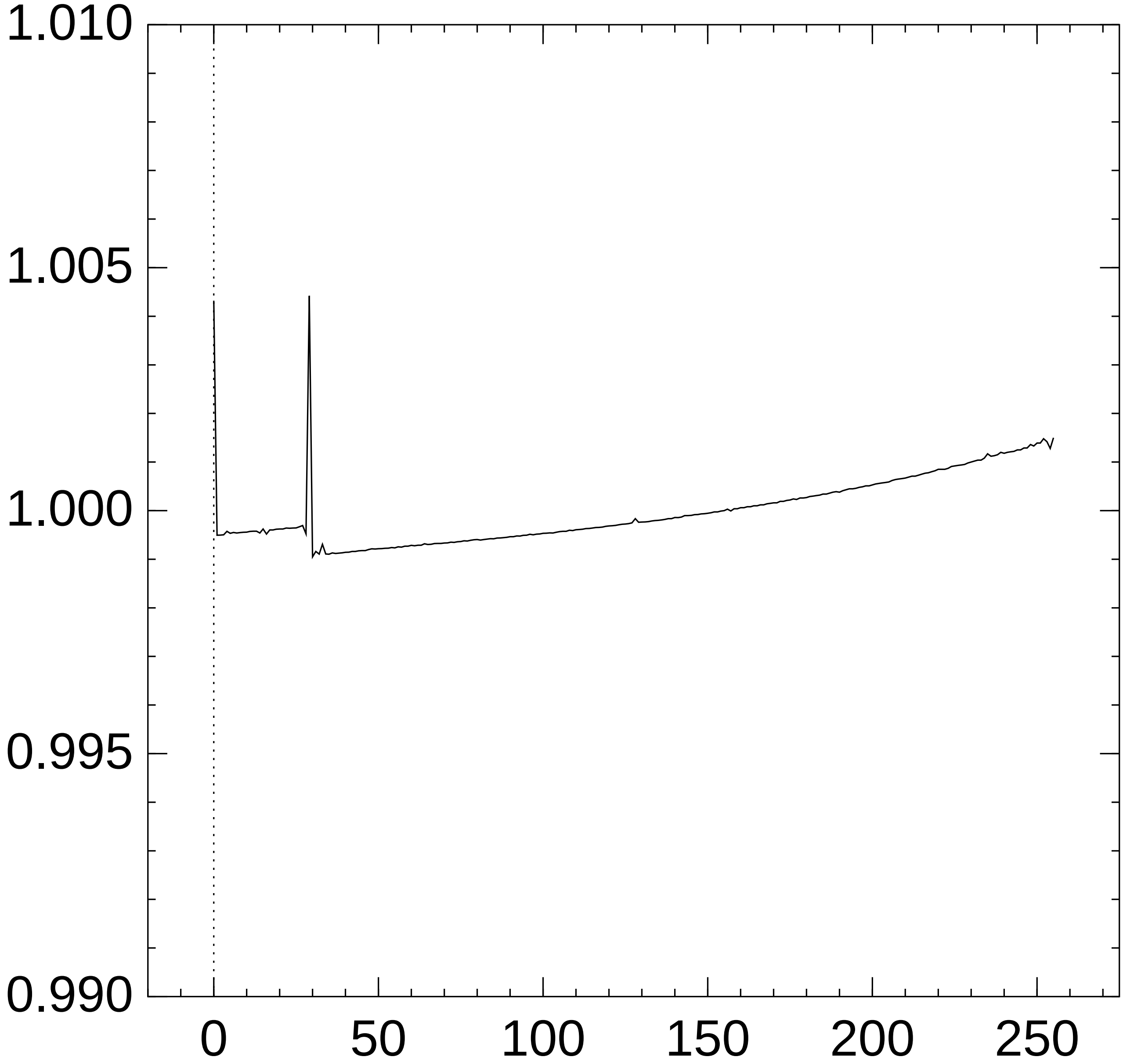
Graph of $256 \Pr[z_{27} = x]$:



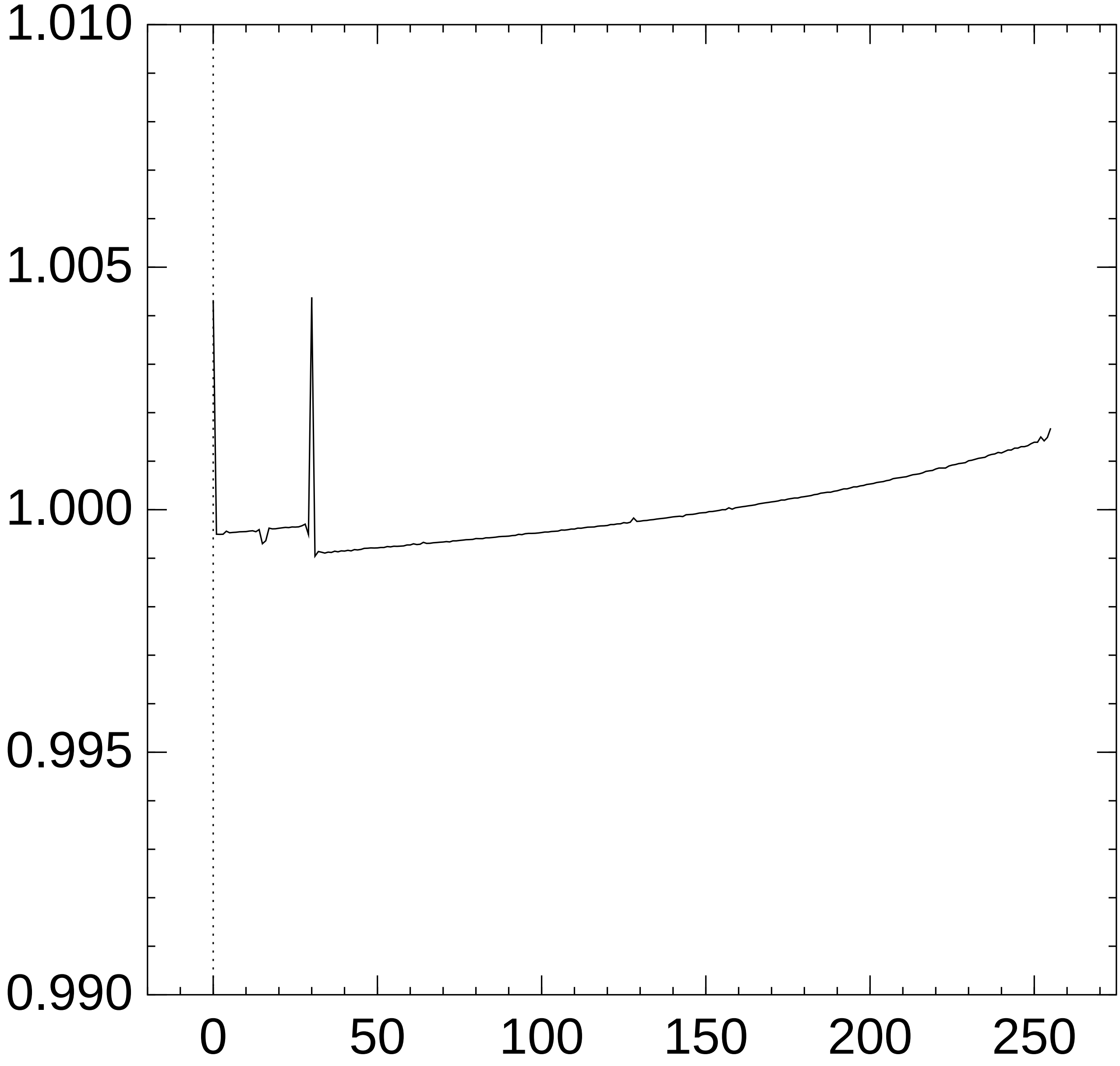
Graph of $256\,\Pr[z_{28} = x]$:



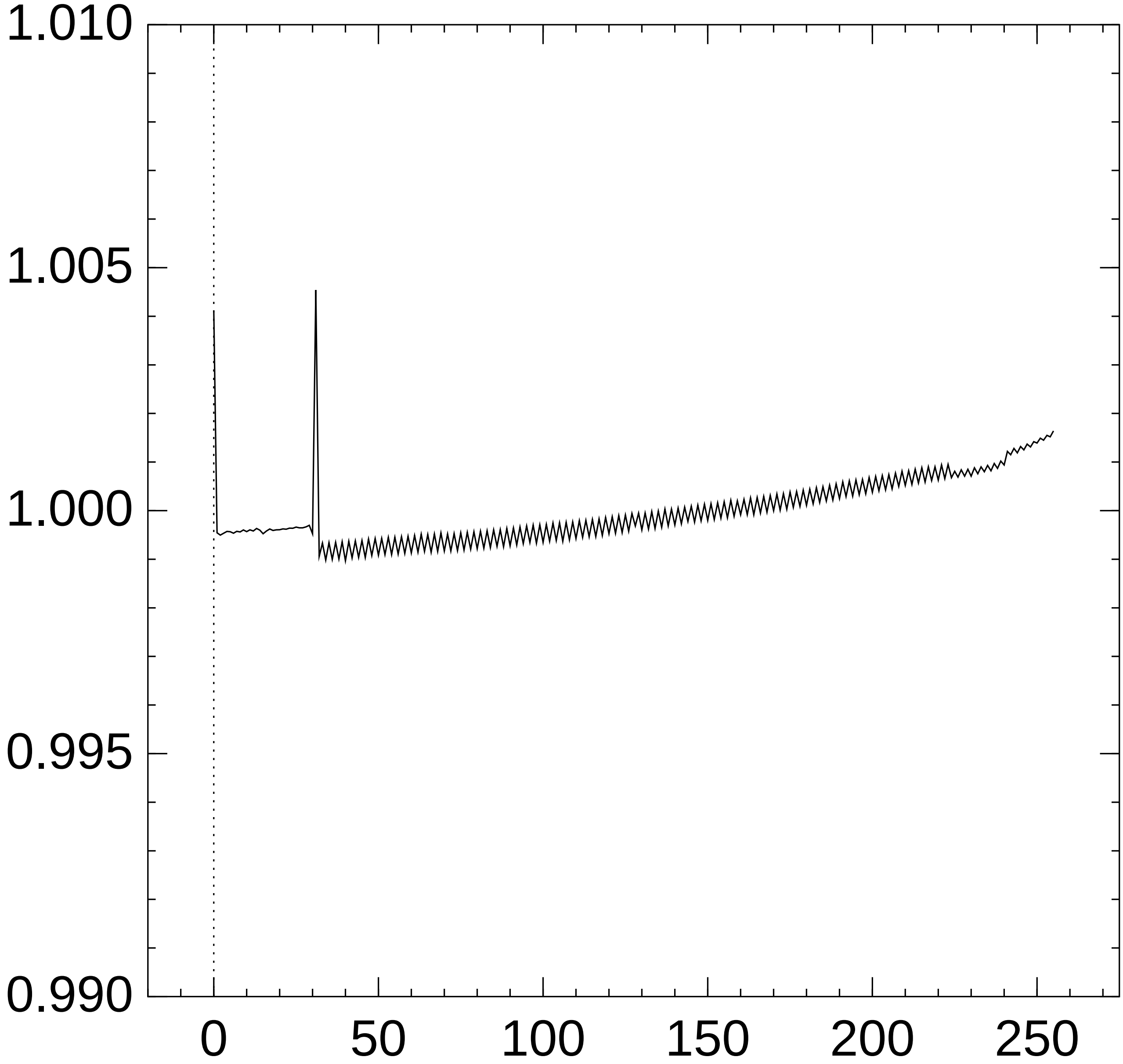
Graph of $256\,\mathrm{Pr}[z_{29} = x]$:



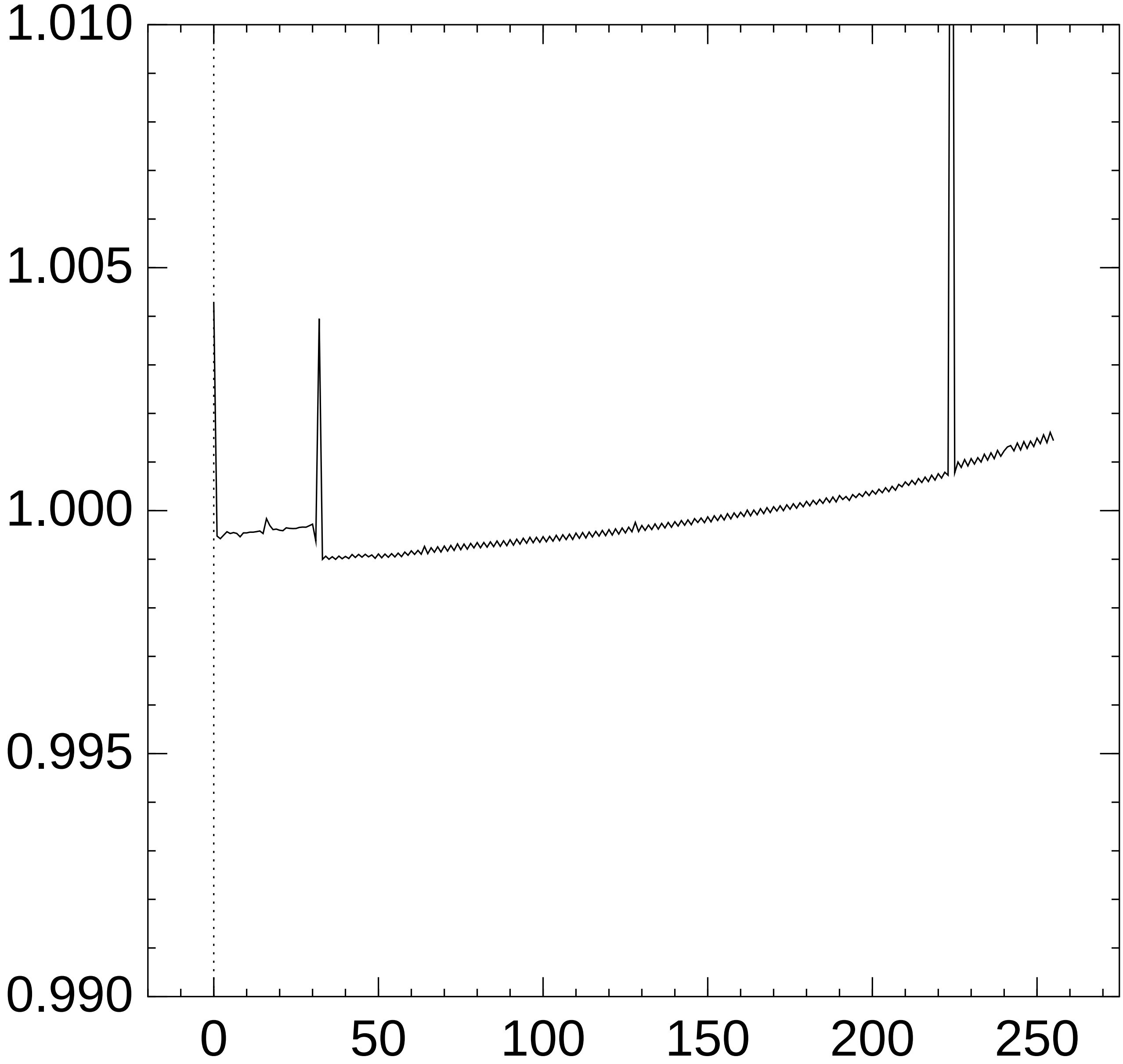
Graph of $256\,\Pr[z_{30} = x]$:



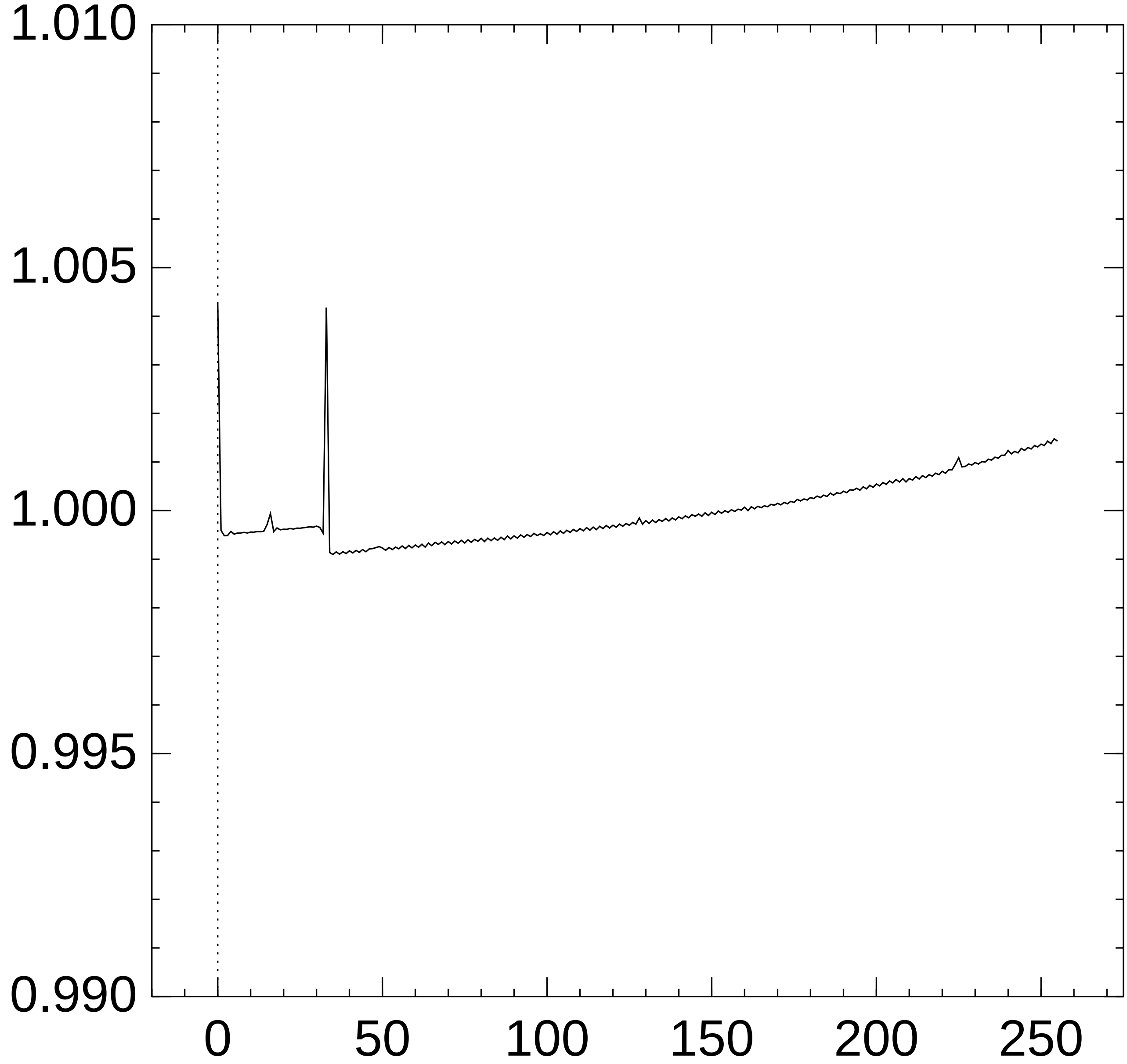
Graph of $256 \Pr[z_{31} = x]$:



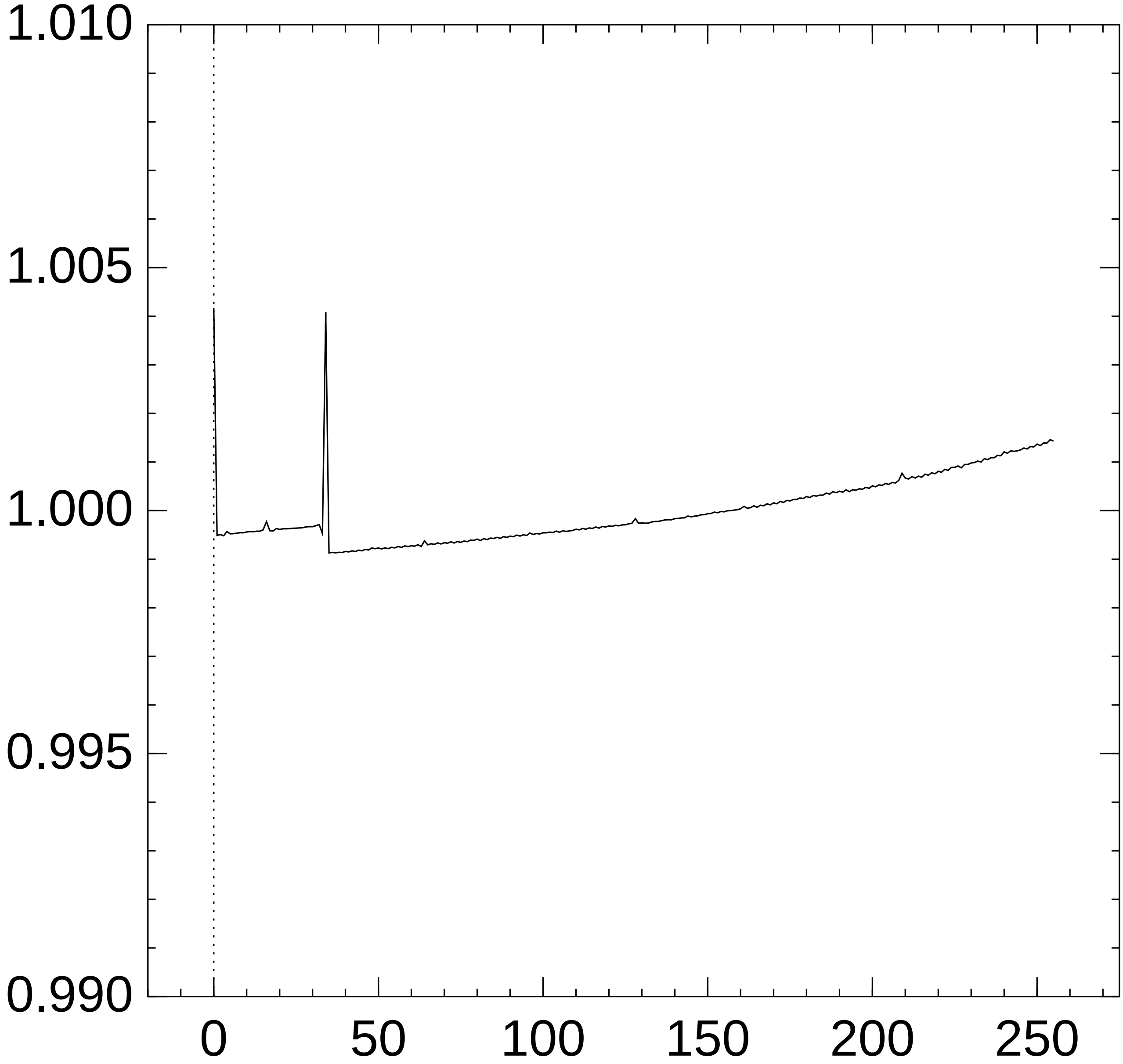
Graph of $256\,\Pr[z_{32} = x]$:



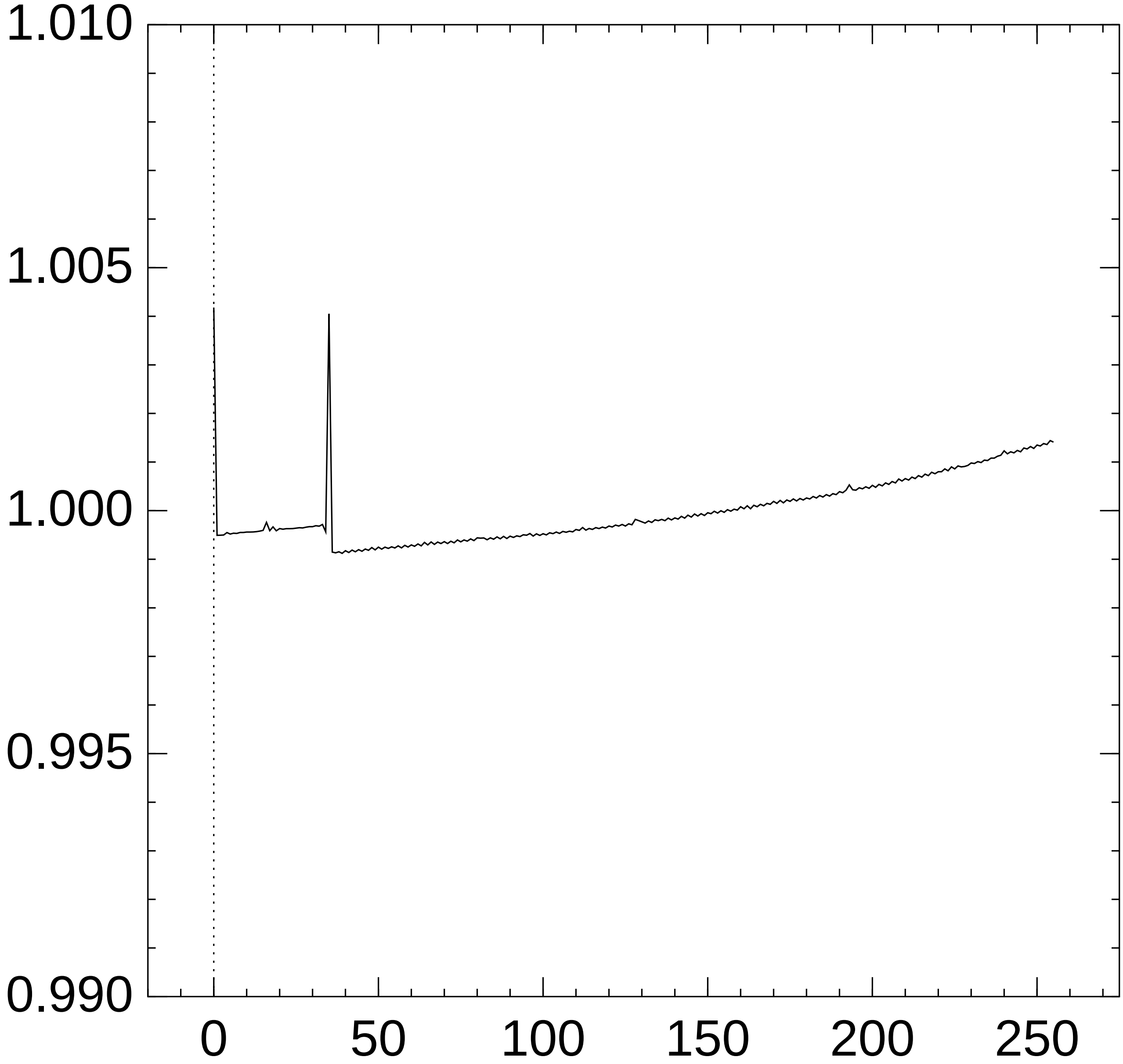
Graph of $256\,\Pr[z_{33} = x]$:



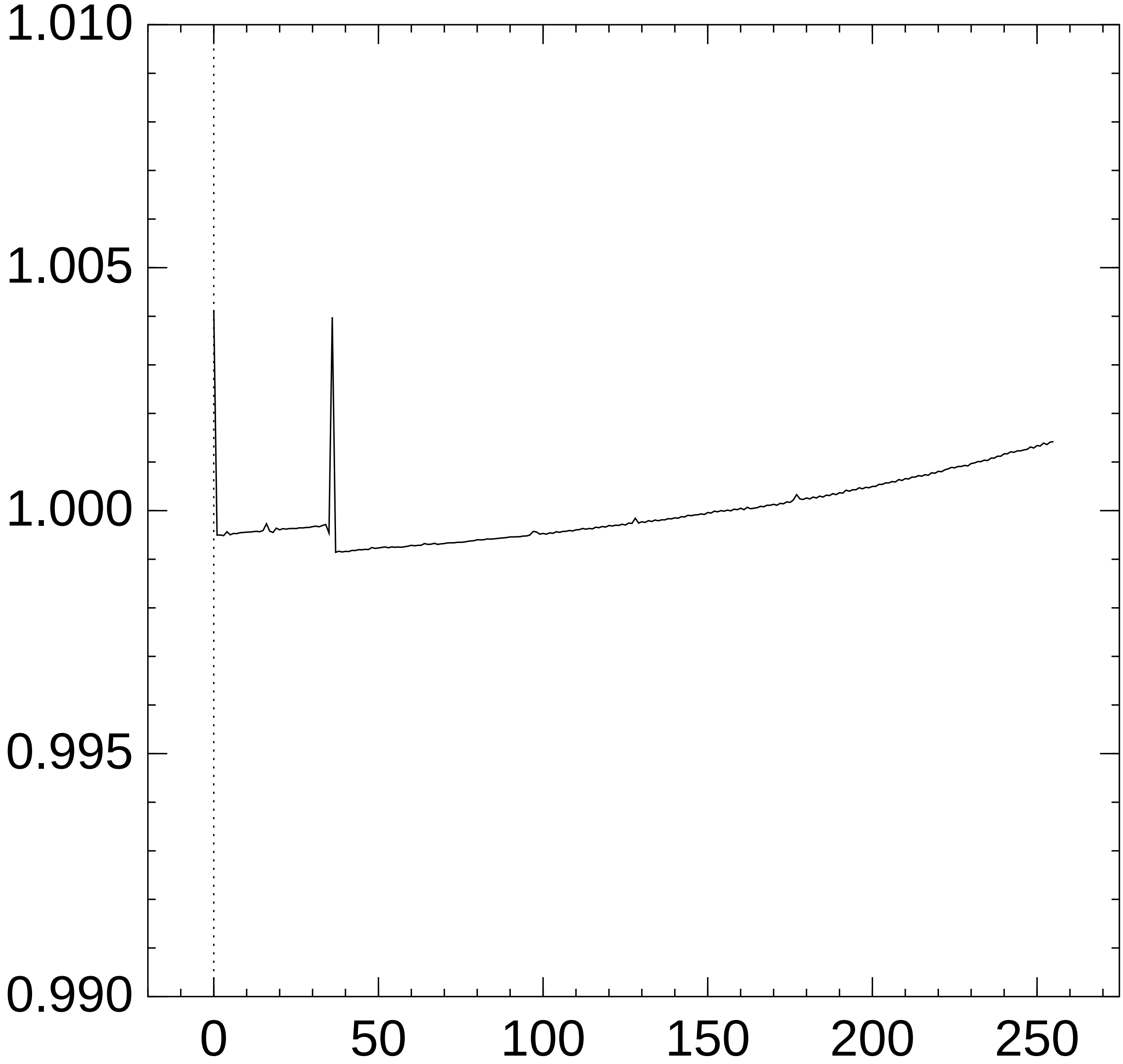
Graph of $256\,\Pr[z_{34} = x]$:



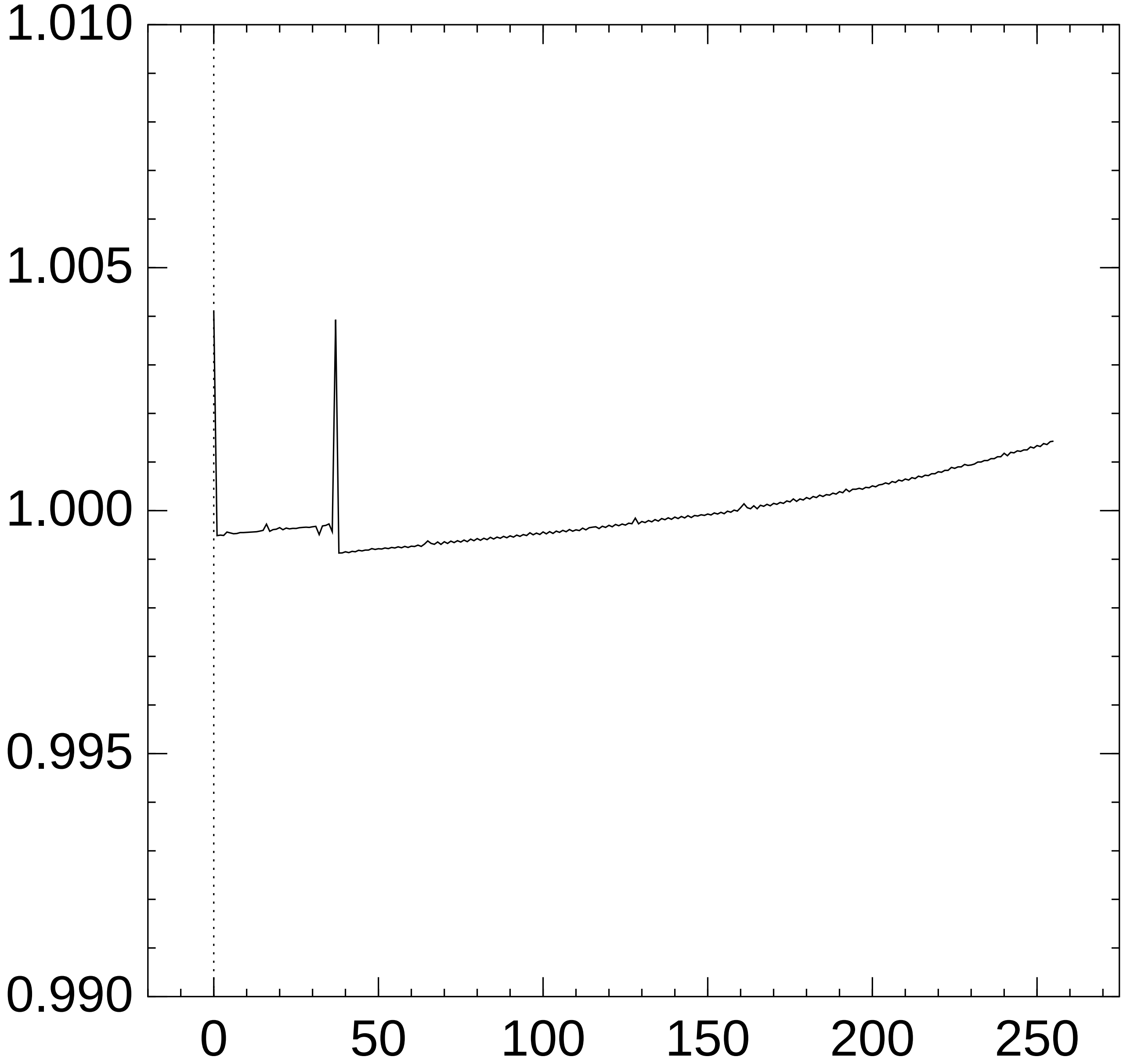
Graph of $256\,\Pr[z_{35} = x]$:



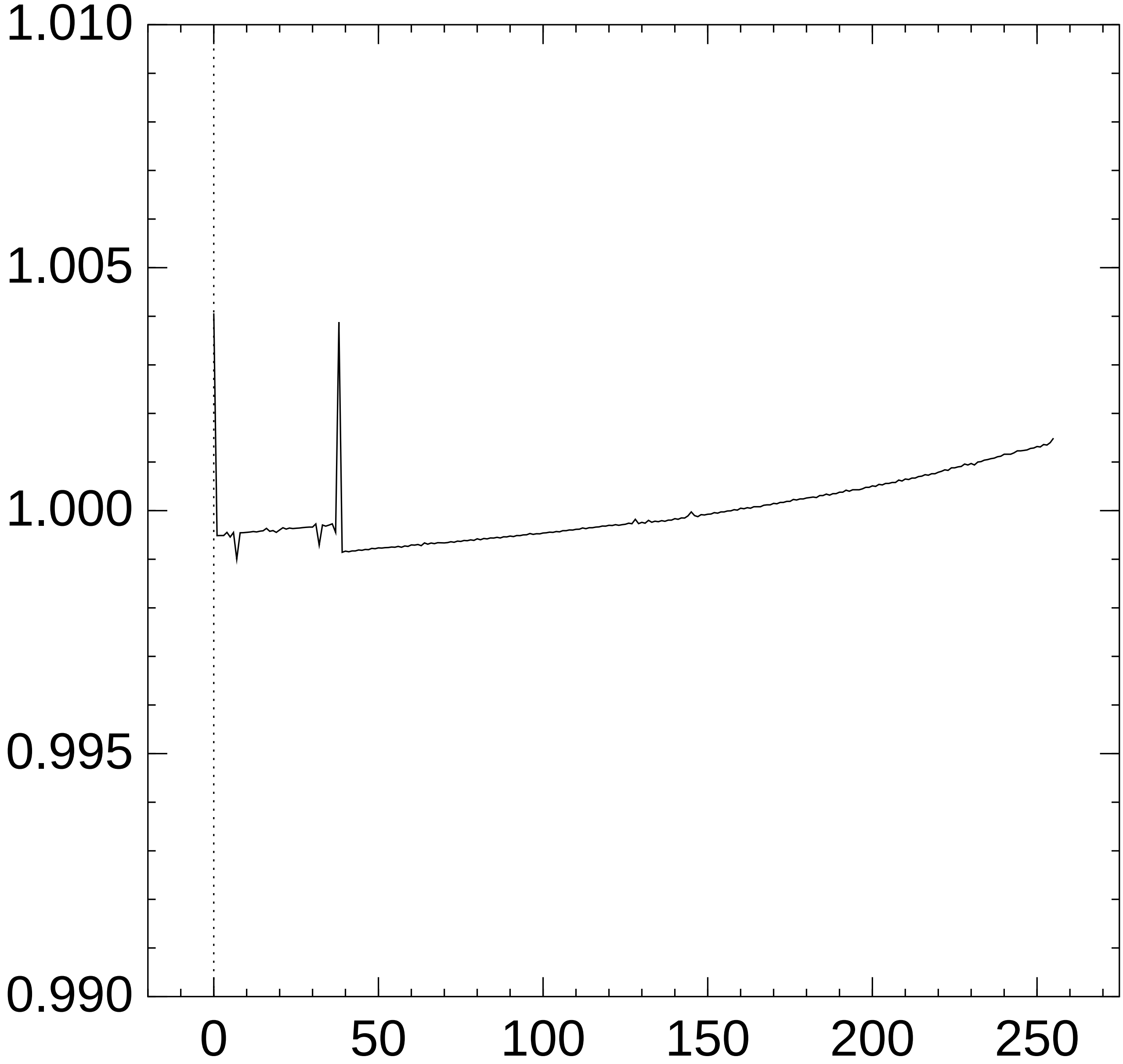
Graph of $256\,\mathrm{Pr}[z_{36} = x]$:



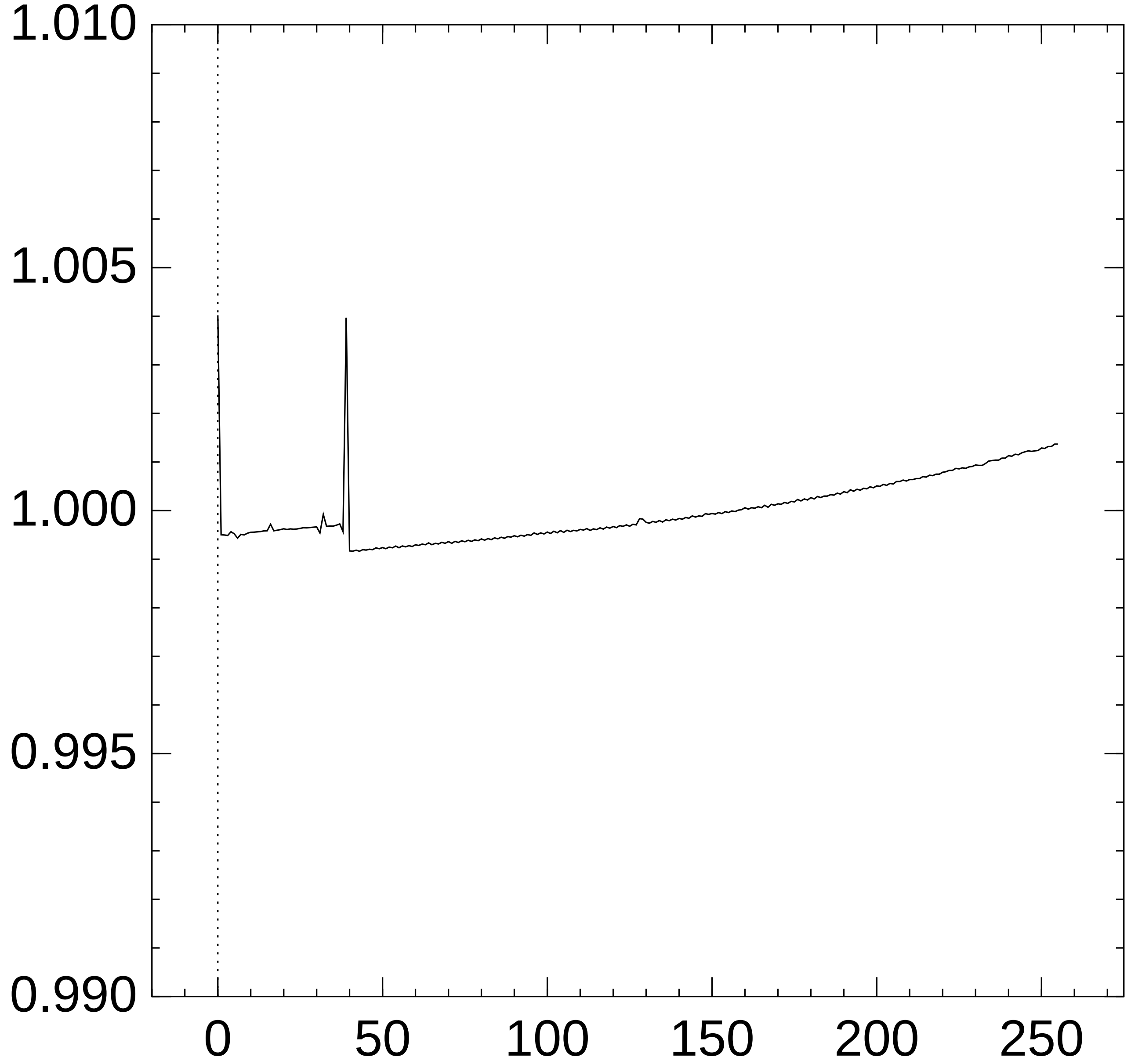
Graph of $256 \Pr[z_{37} = x]$:



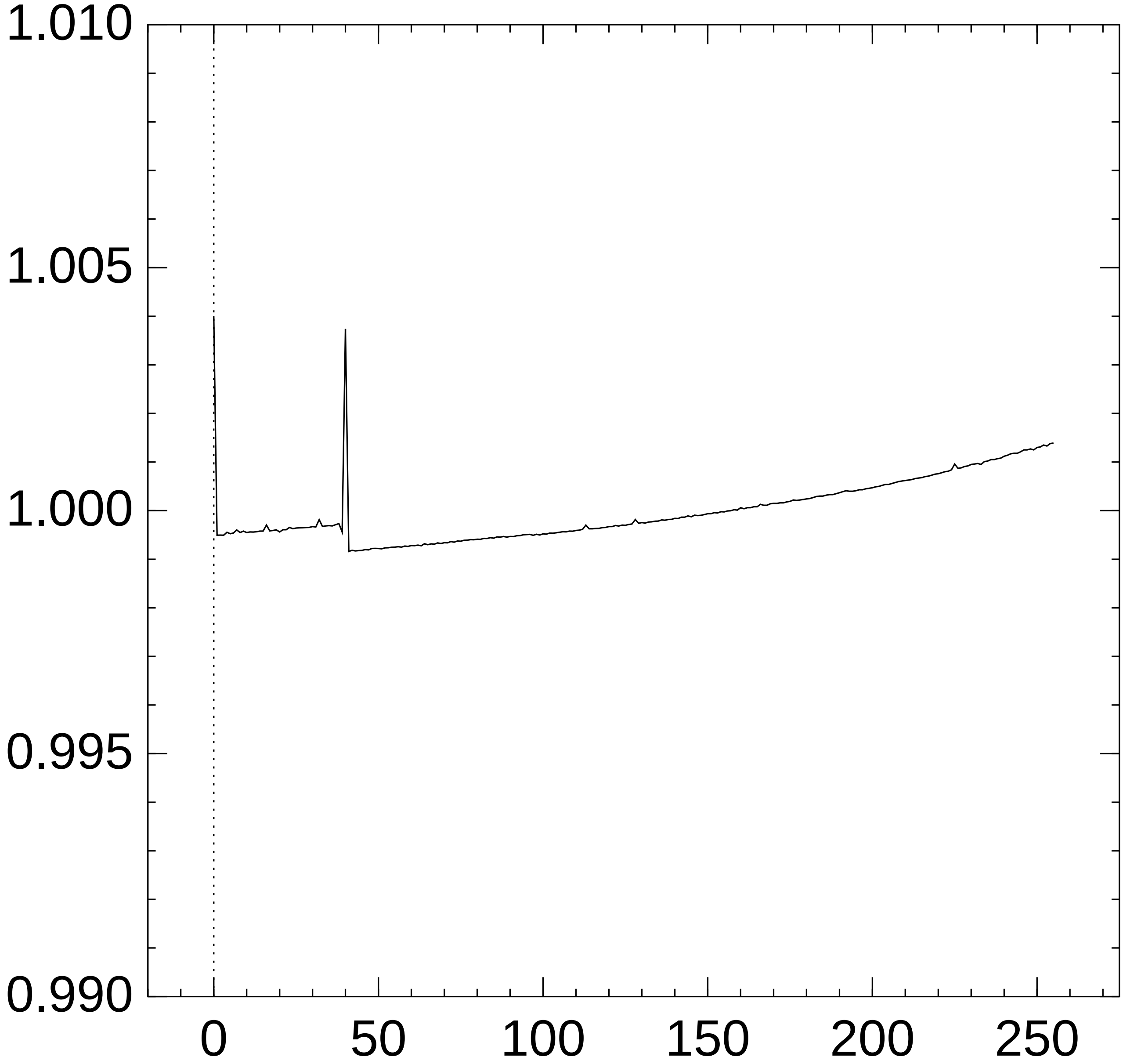
Graph of $256\,\Pr[z_{38} = x]$:



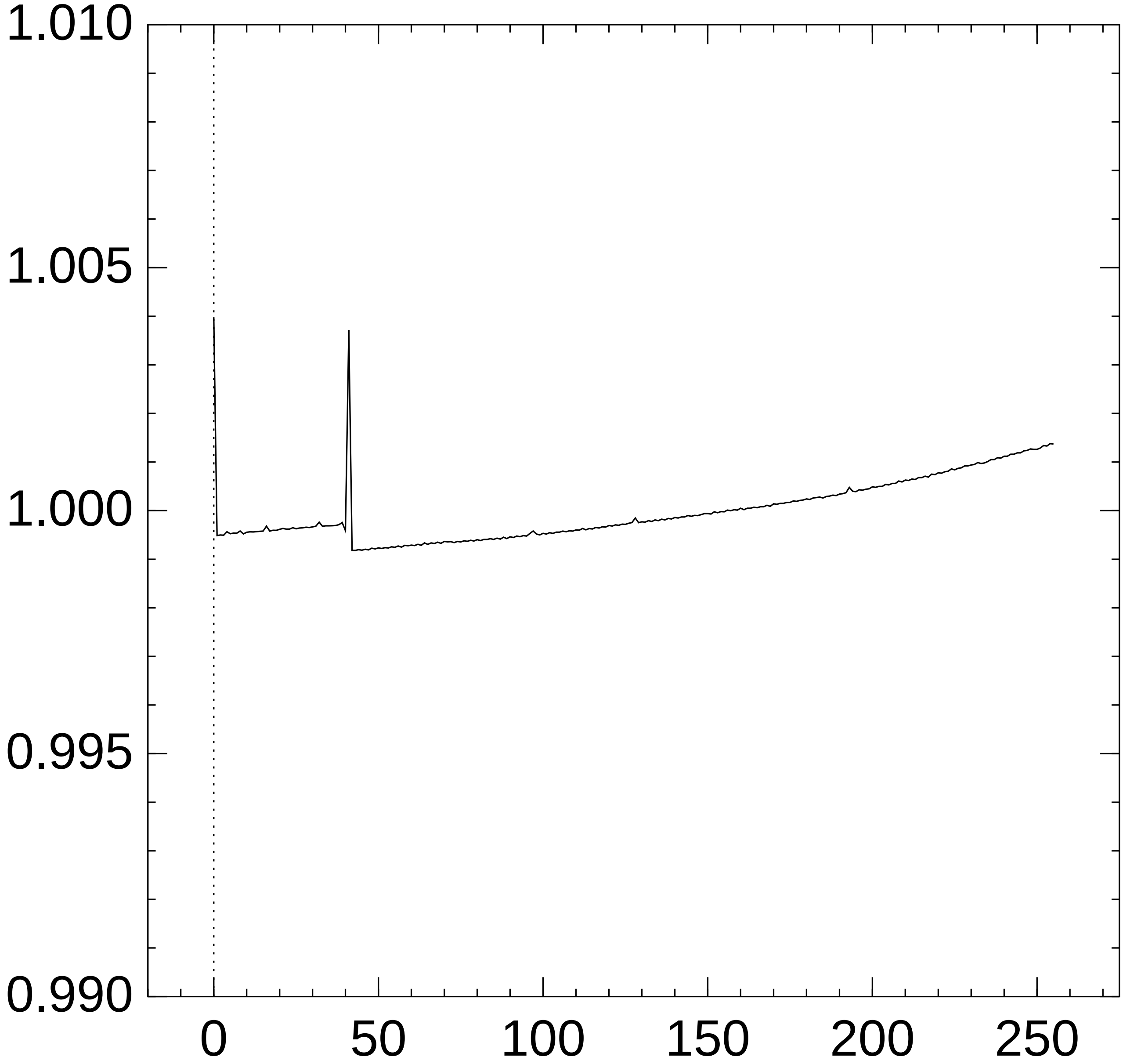
Graph of $256 \Pr[z_{39} = x]$:



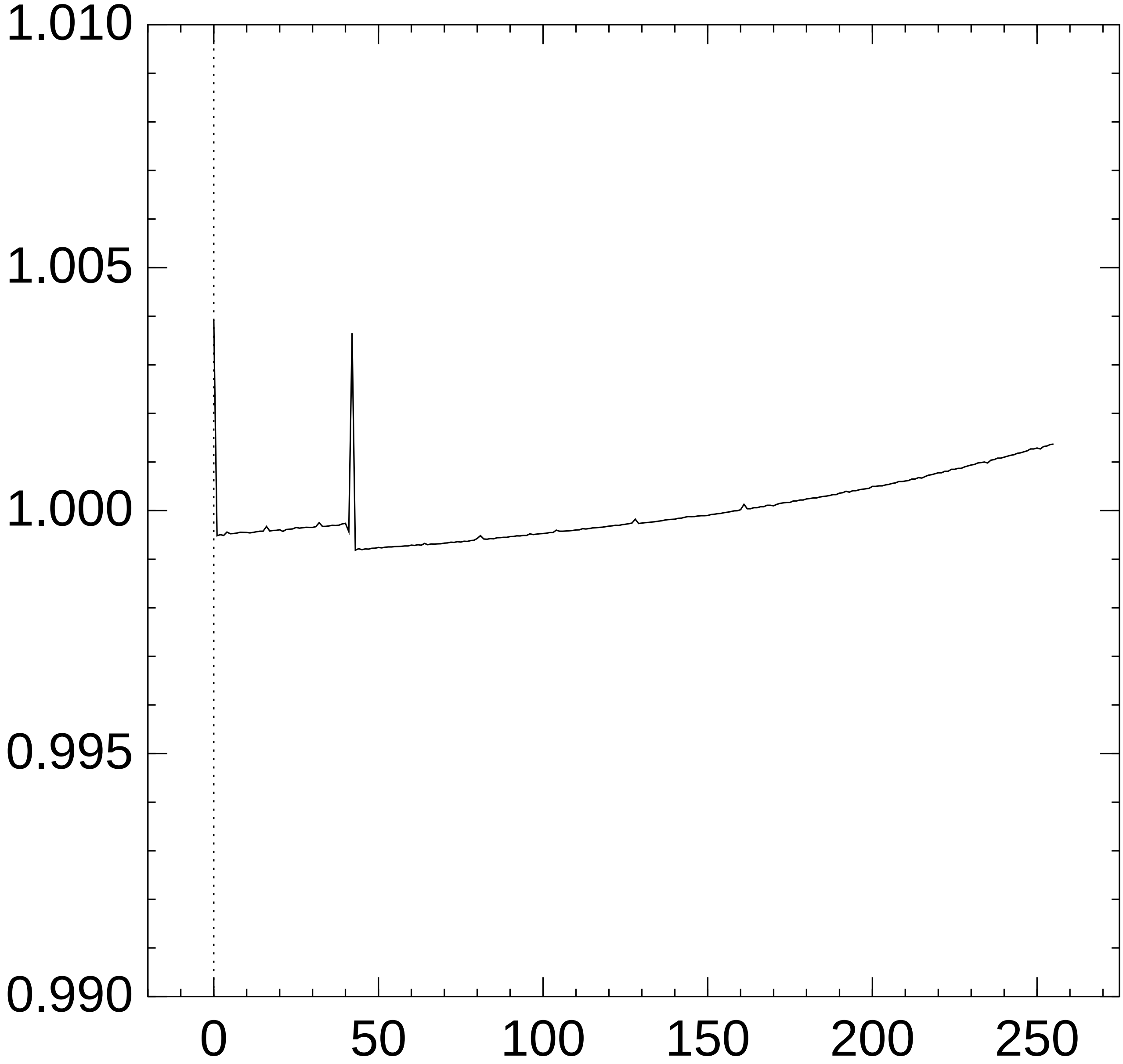
Graph of $256\,\Pr[z_{40} = x]$:



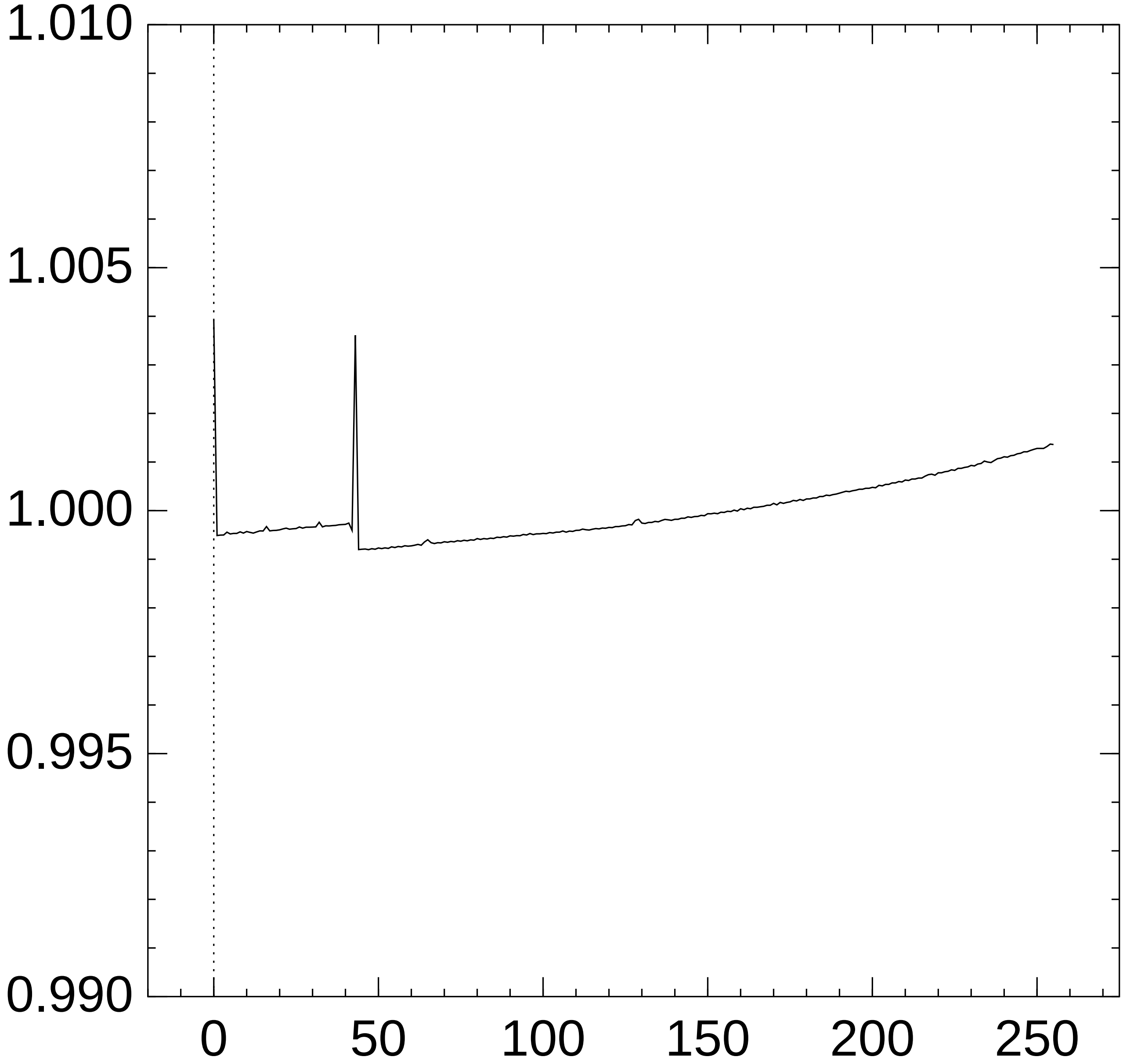
Graph of $256\,\Pr[z_{41} = x]$:



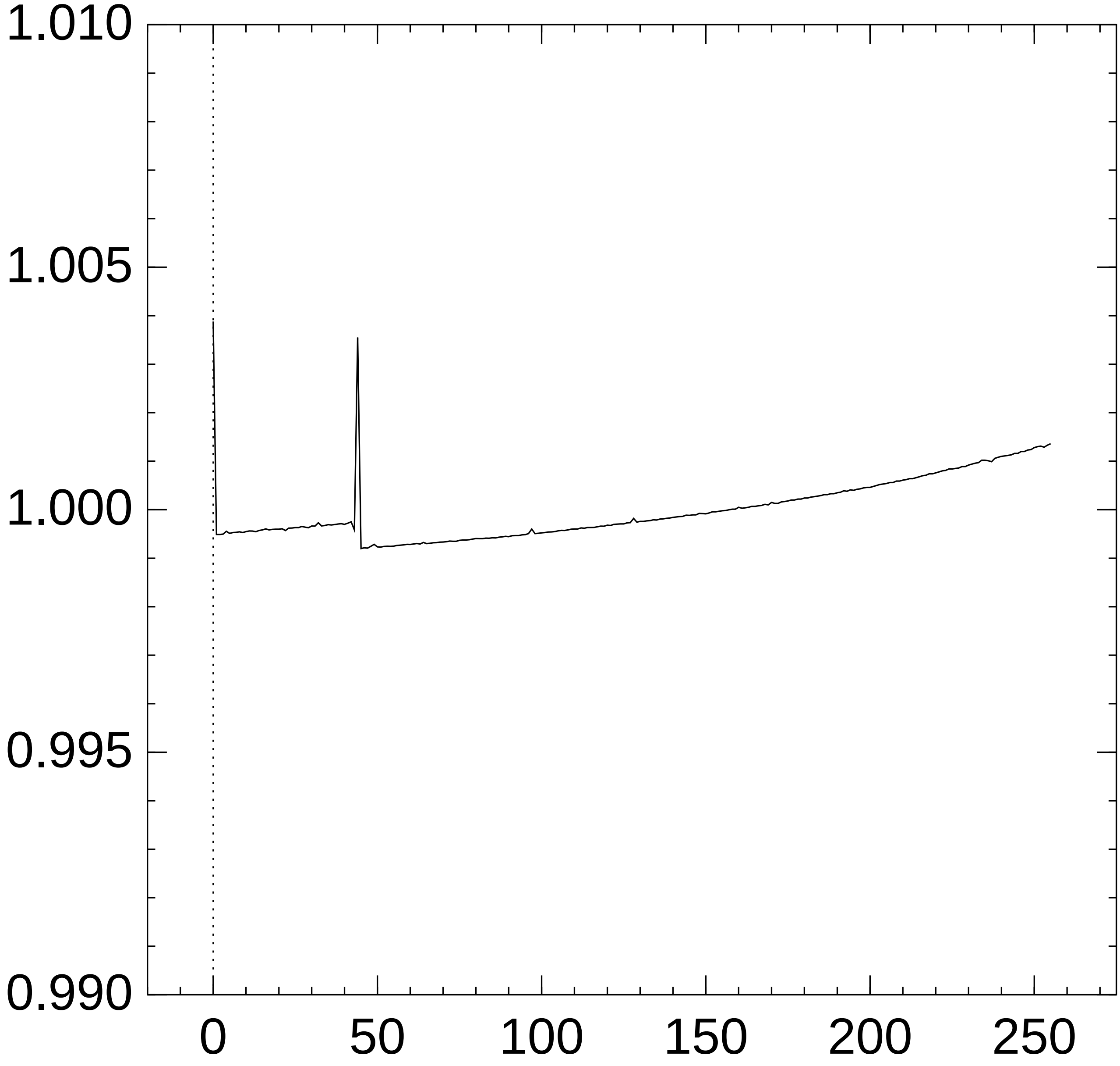
Graph of $256\,\Pr[z_{42} = x]$:



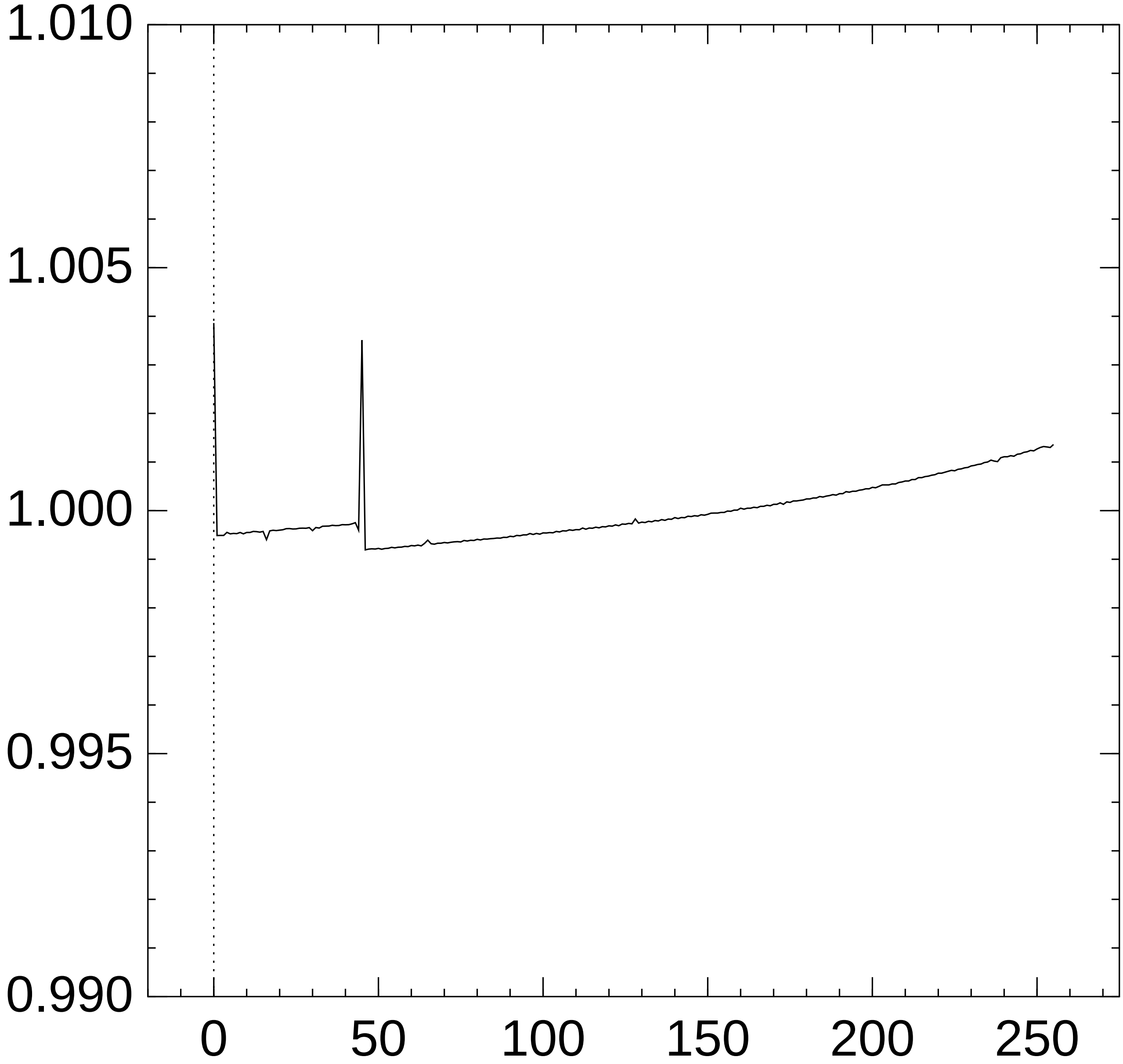
Graph of $256\,\Pr[z_{43} = x]$:



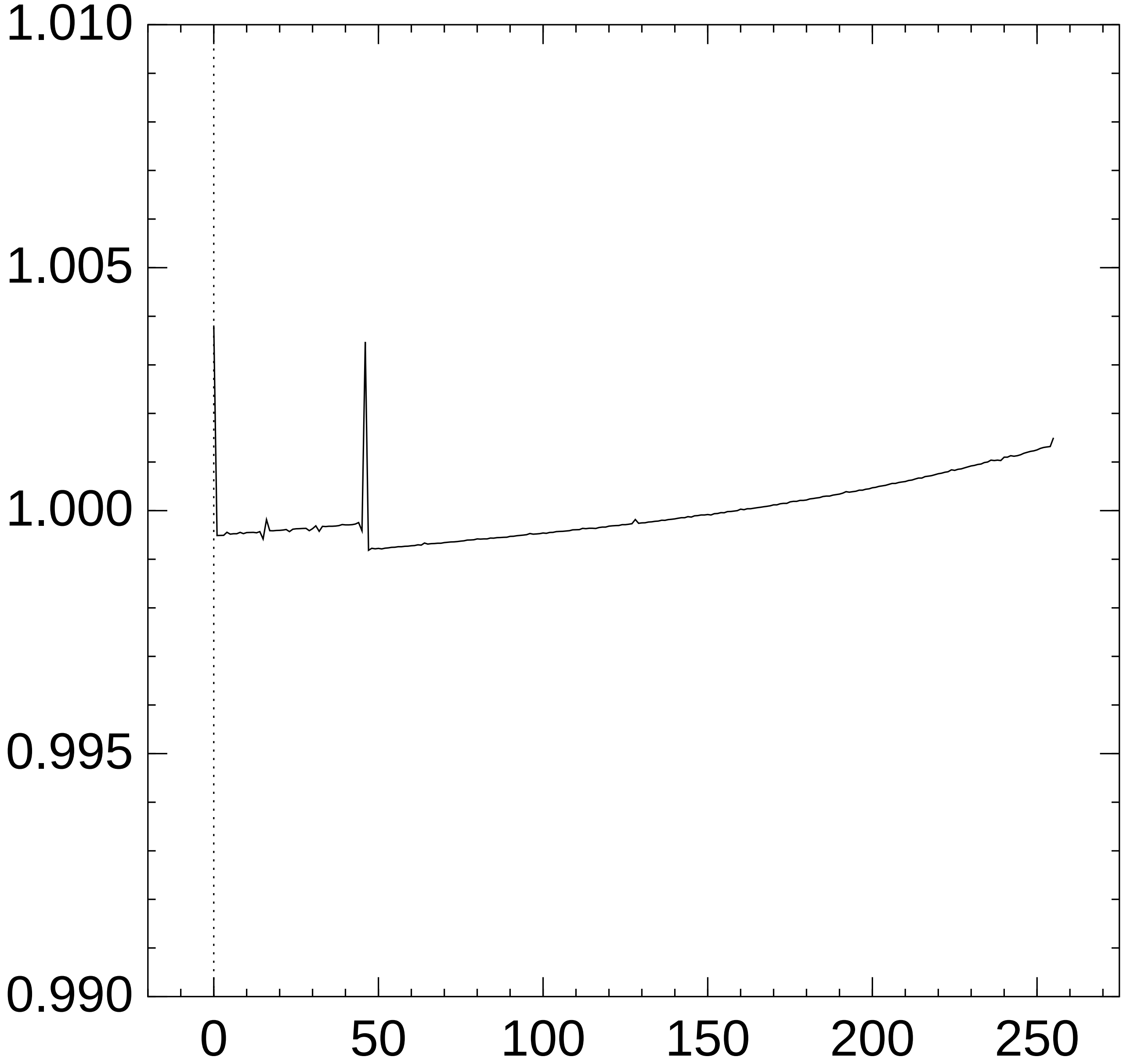
Graph of $256\,\Pr[z_{44} = x]$:



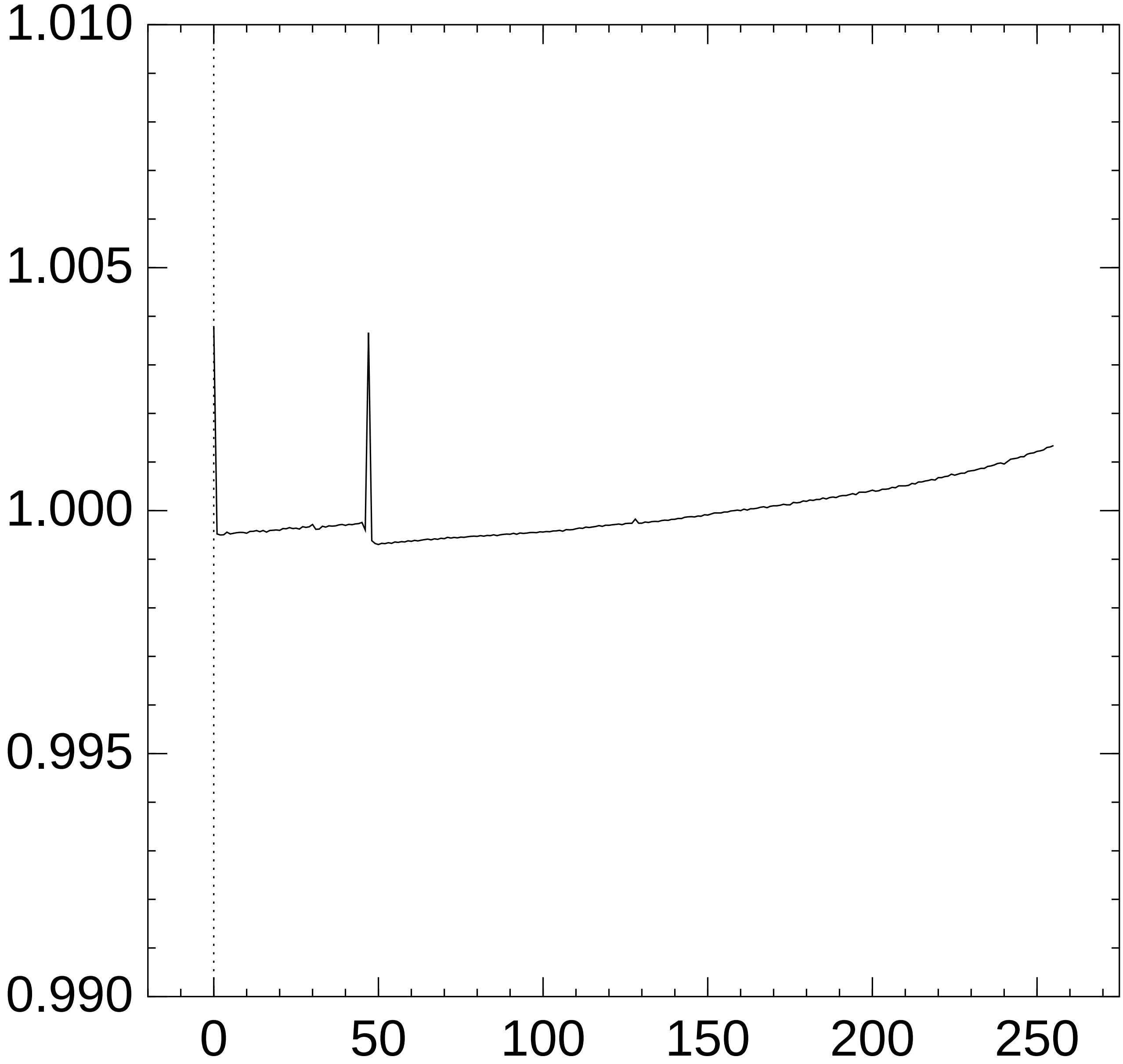
Graph of $256 \Pr[z_{45} = x]$:



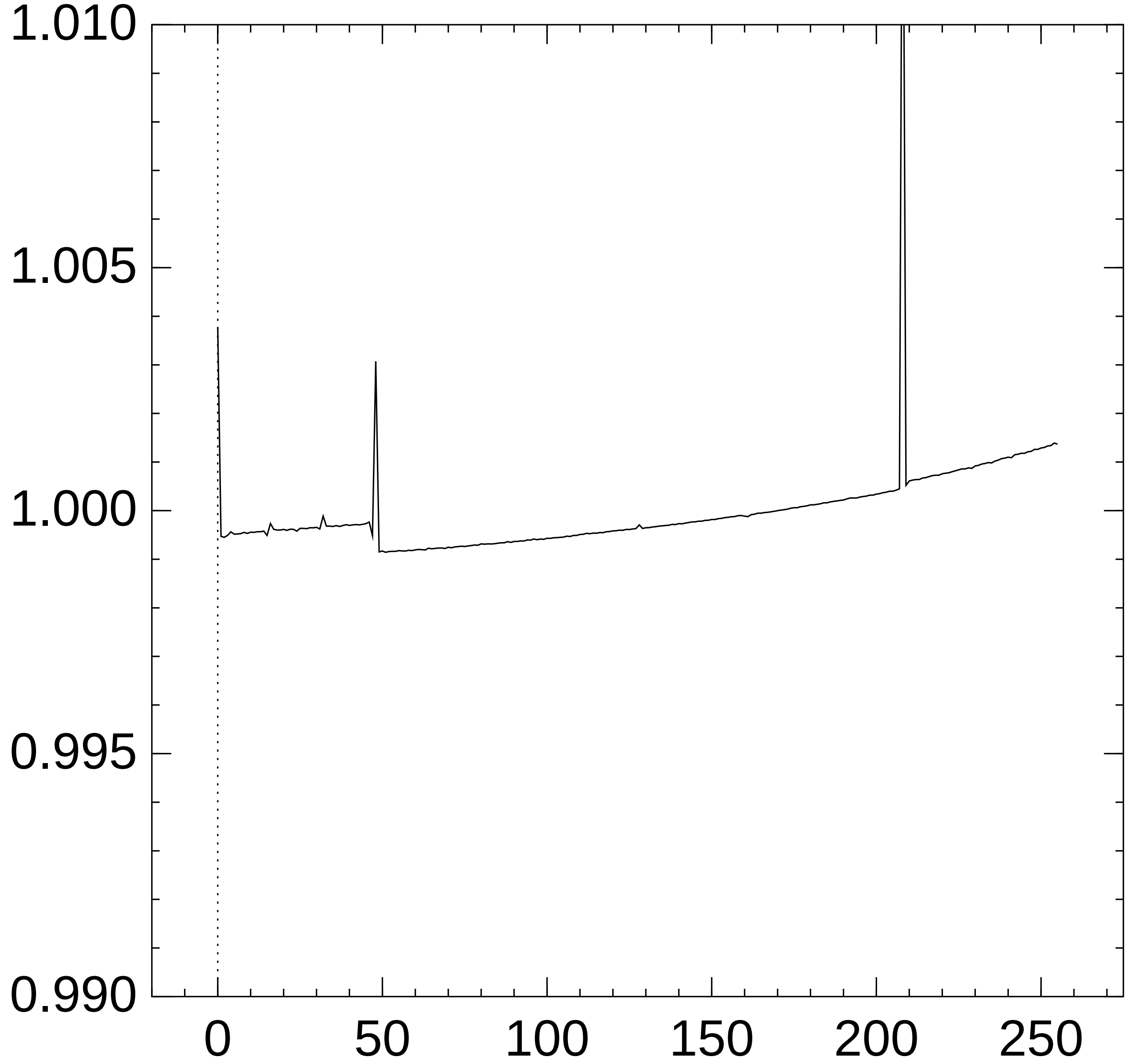
Graph of $256\,\Pr[z_{46} = x]$:



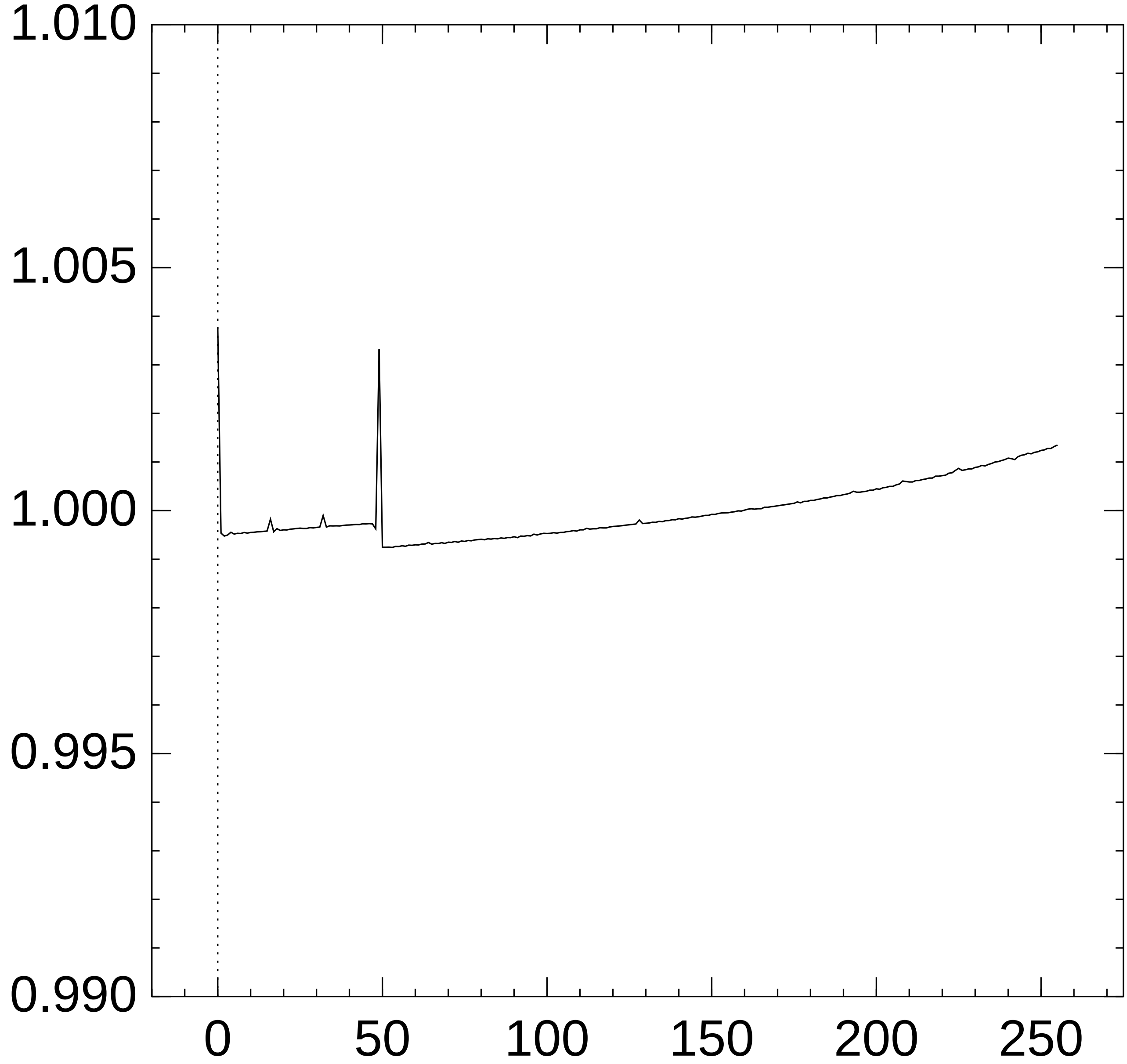
Graph of $256\,\Pr[z_{47} = x]$:



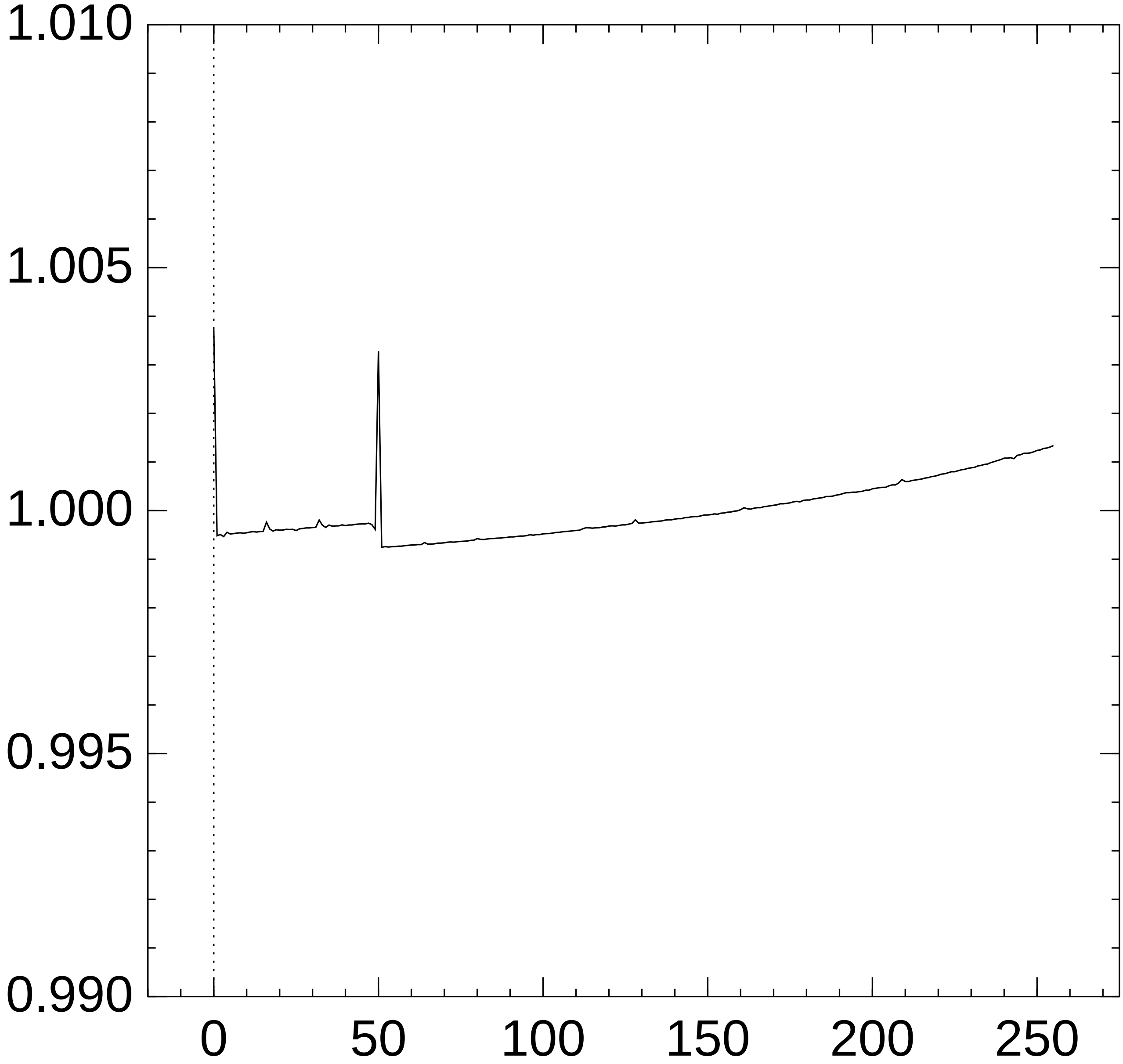
Graph of $256\,\Pr[z_{48} = x]$:



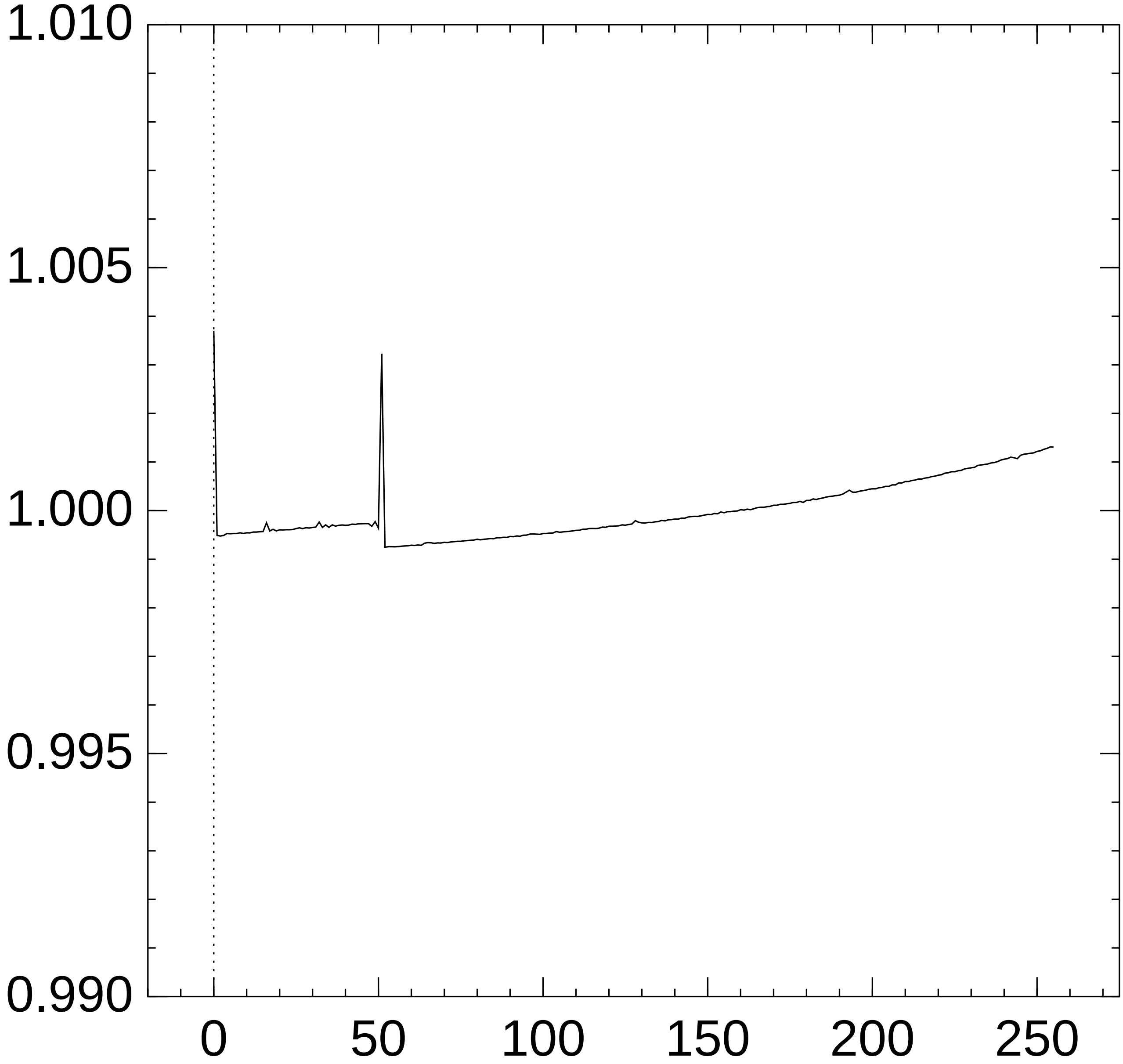
Graph of $256\,\Pr[z_{49} = x]$:



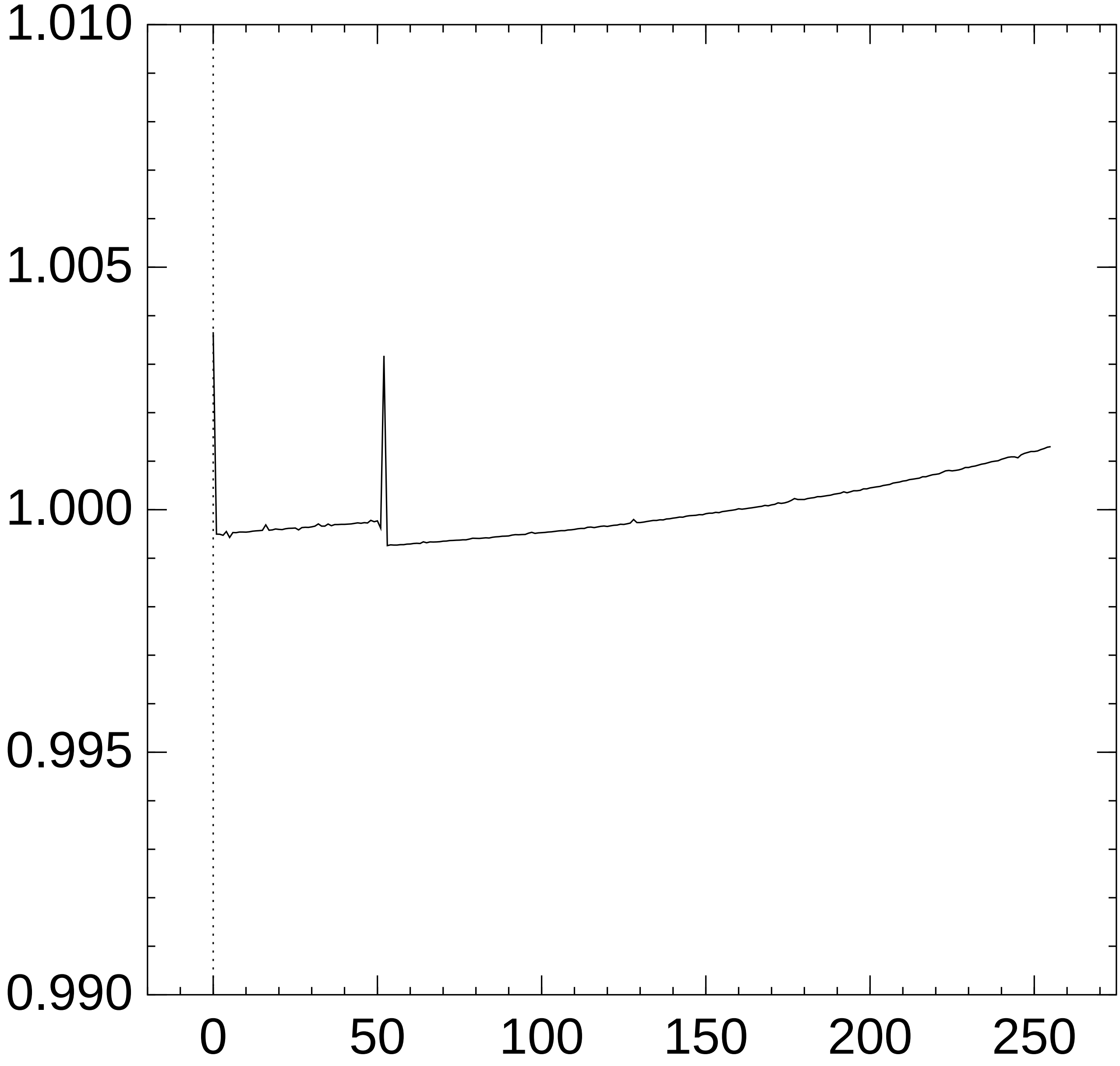
Graph of $256\,\Pr[z_{50} = x]$:



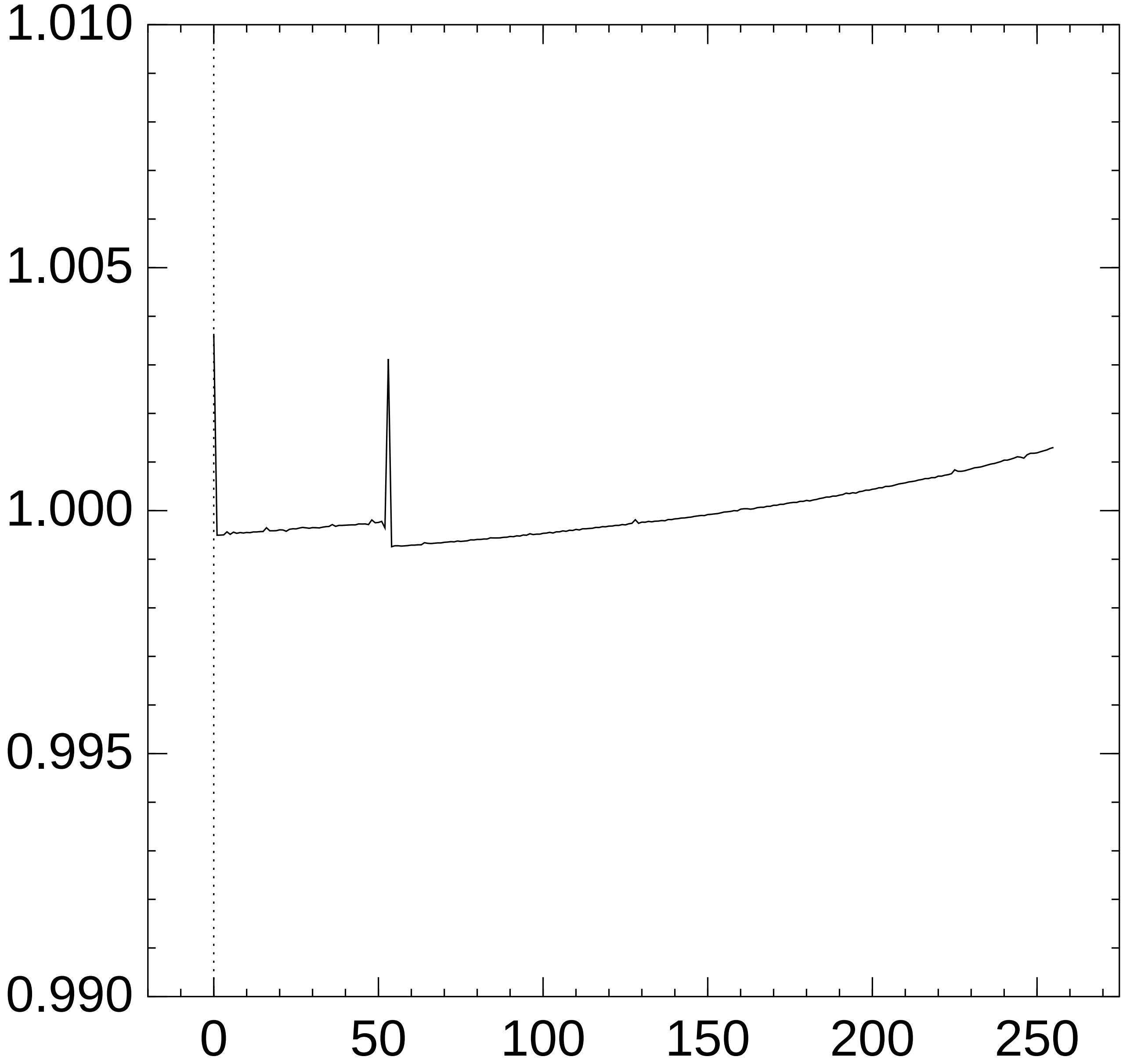
Graph of $256\,\mathrm{Pr}[z_{51} = x]$:



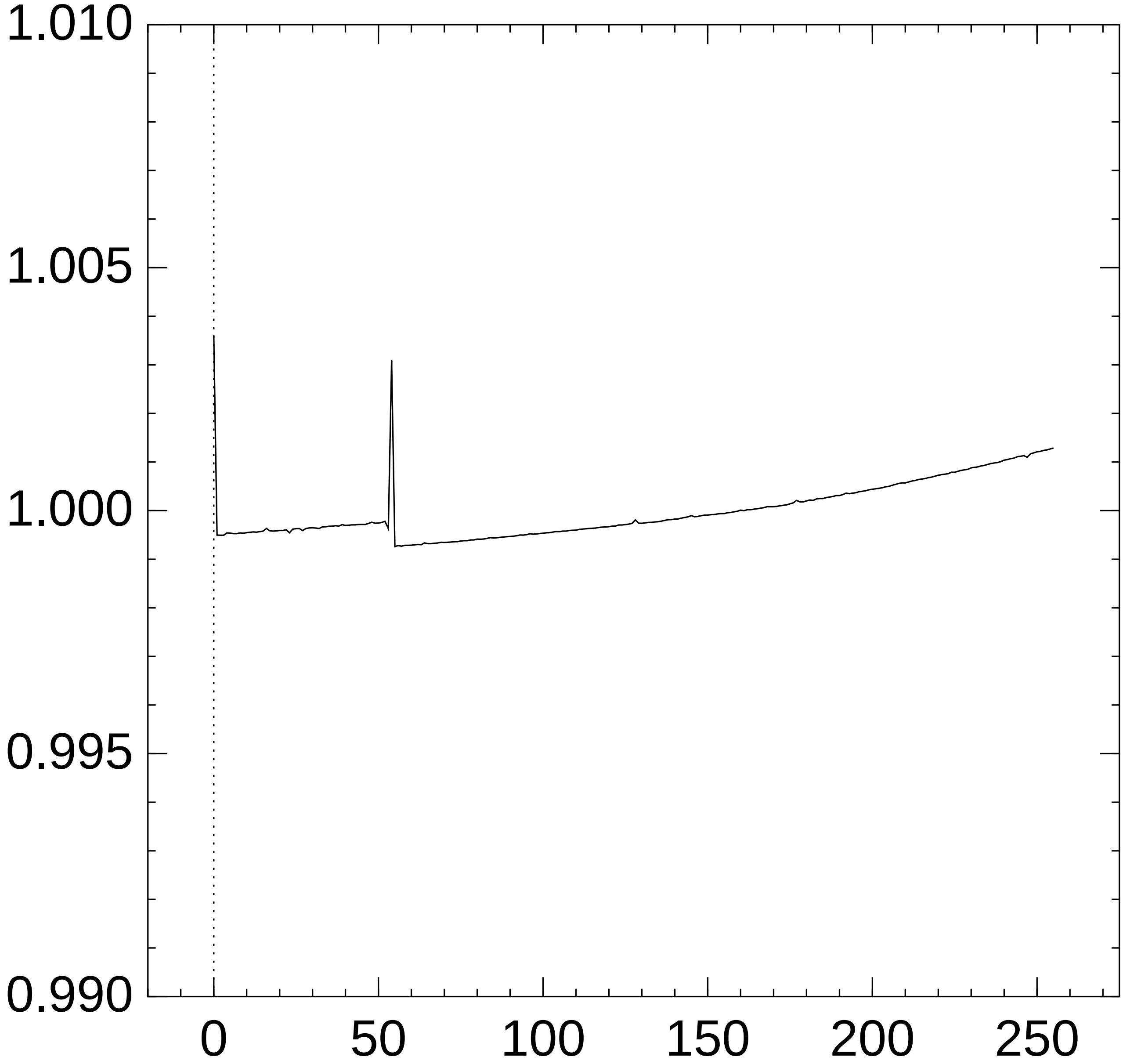
Graph of $256\,\Pr[z_{52} = x]$:



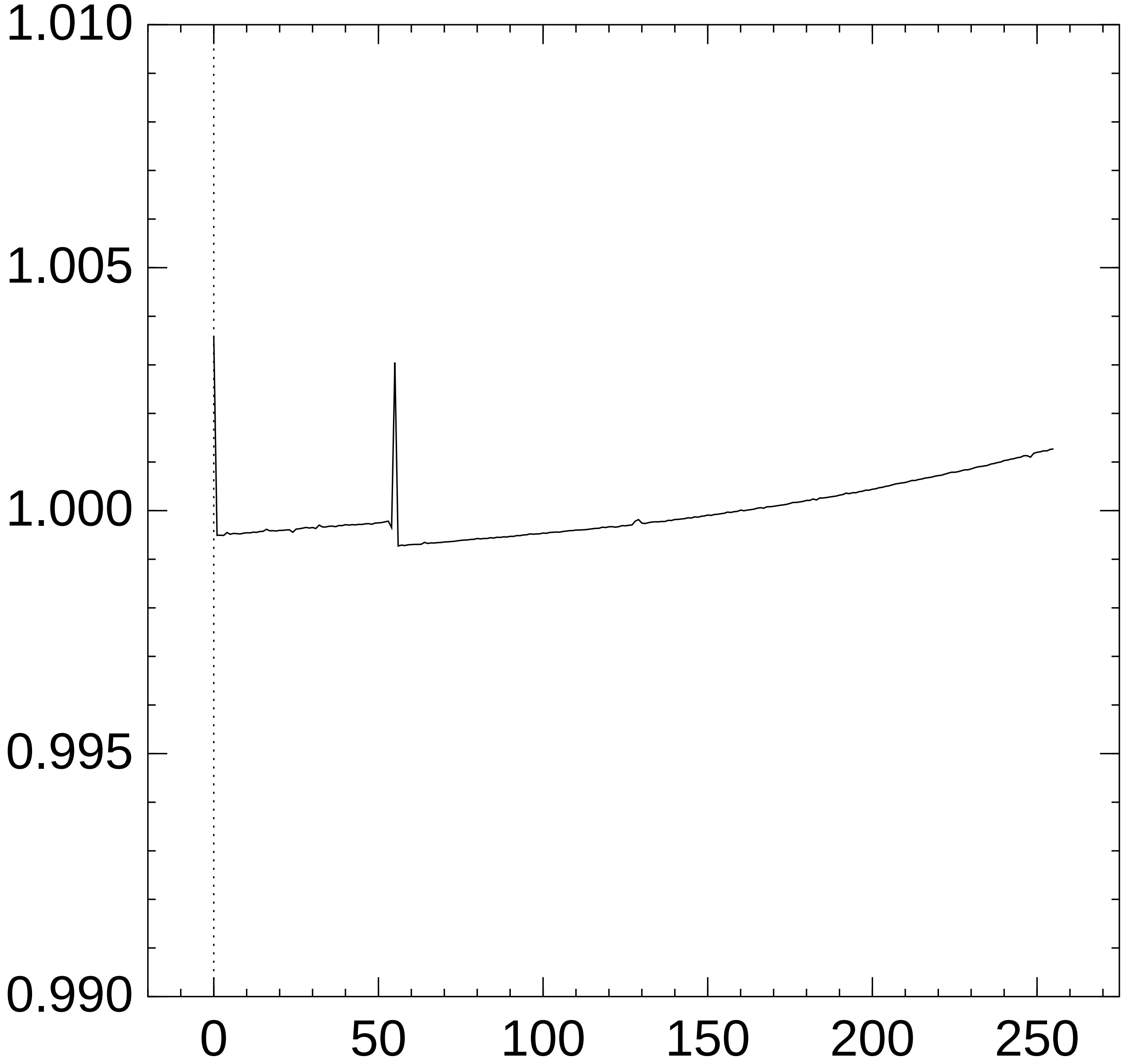
Graph of $256\,\Pr[z_{53} = x]$:



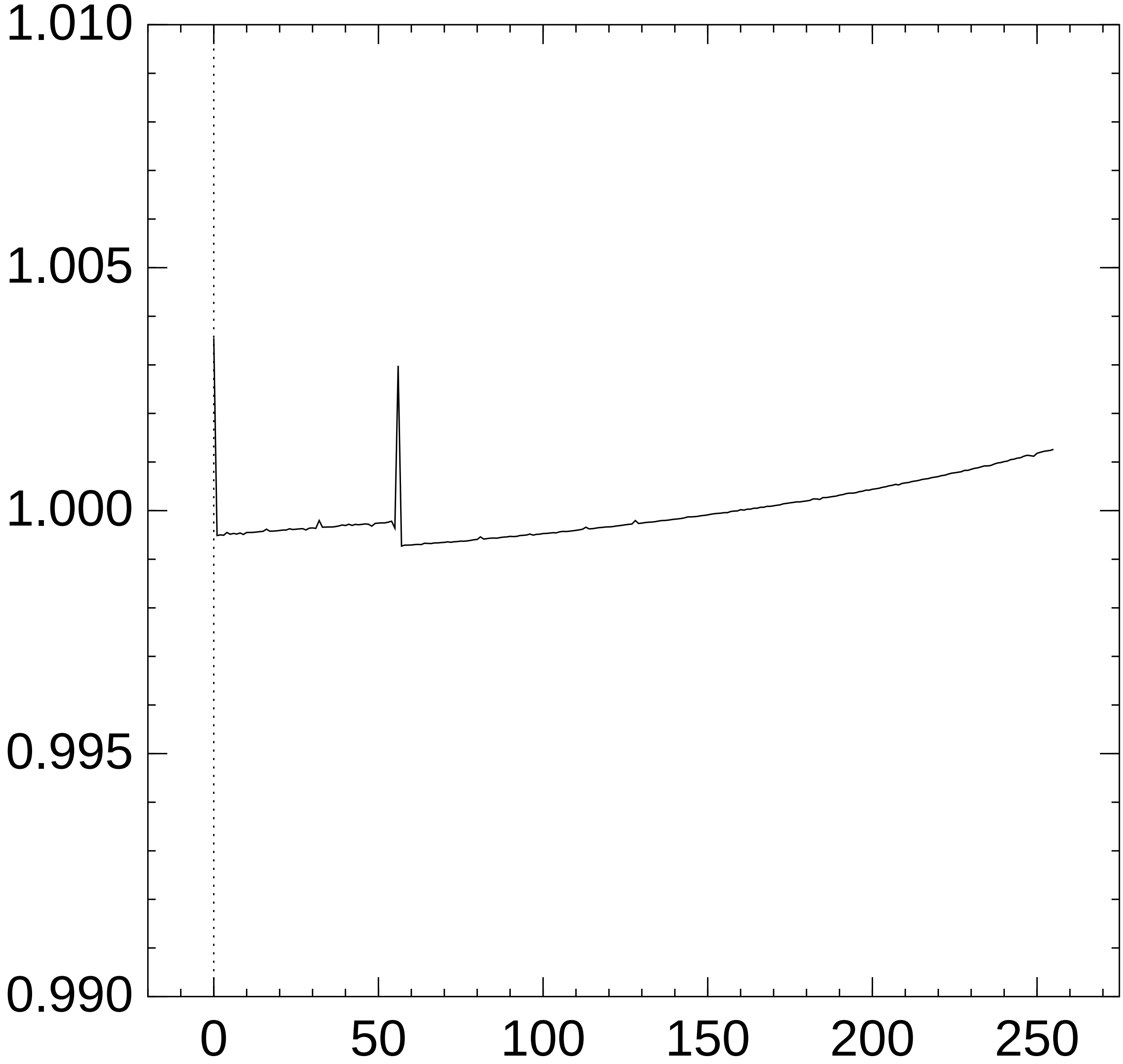
Graph of $256\,\Pr[z_{54} = x]$:



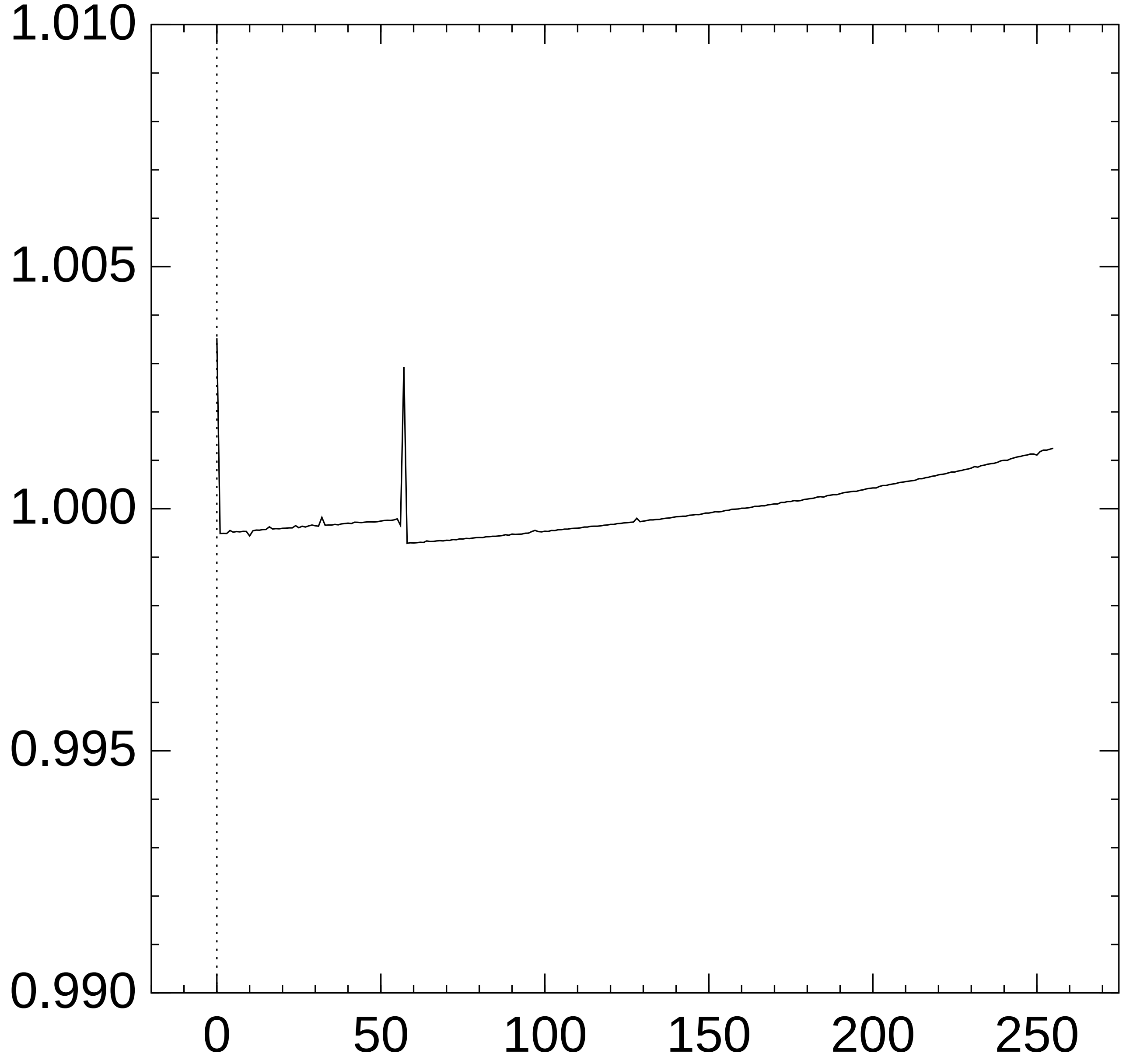
Graph of $256\,\Pr[z_{55} = x]$:



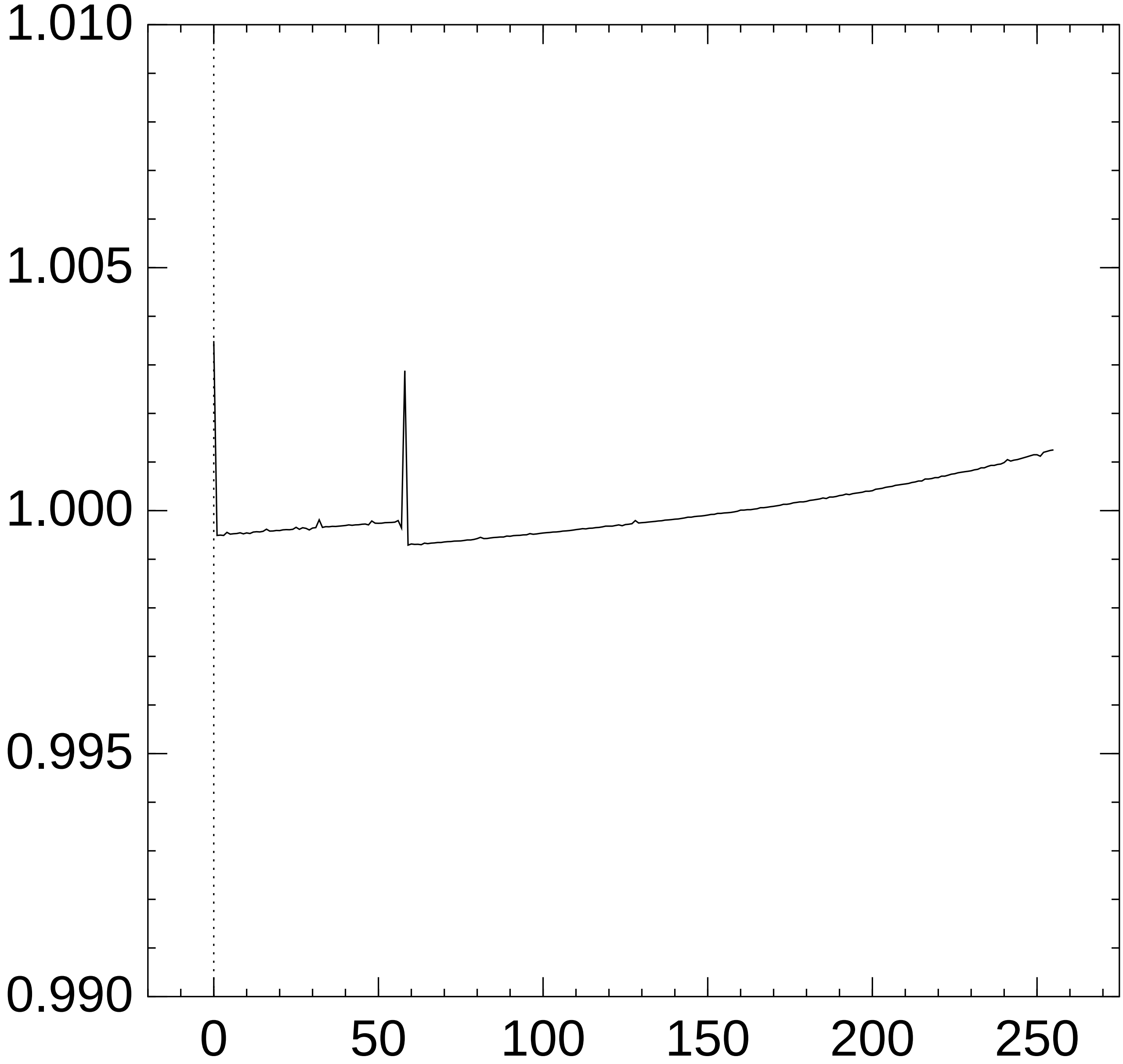
Graph of $256\,\mathrm{Pr}[z_{56} = x]$:



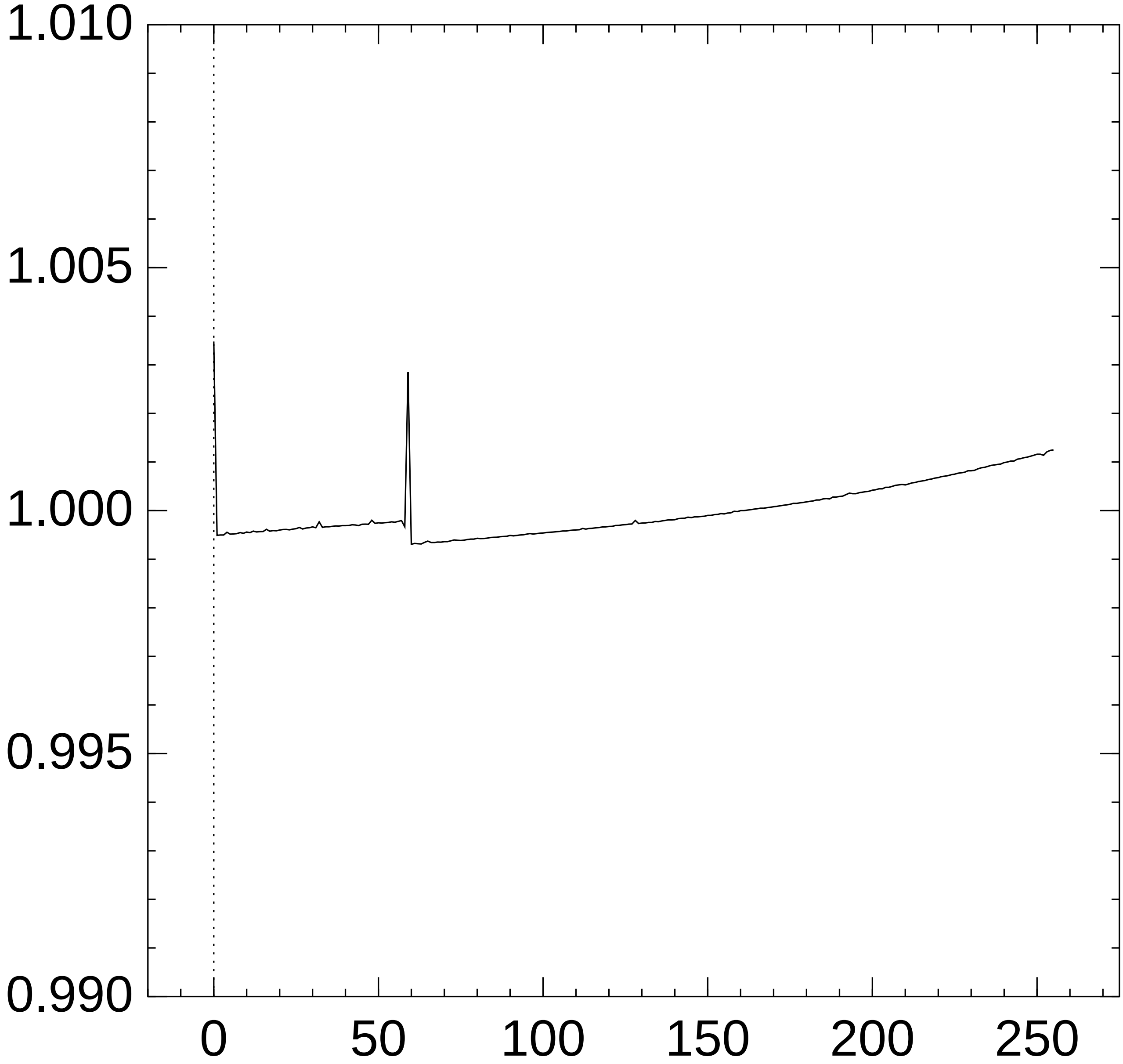
Graph of $256 \Pr[z_{57} = x]$:



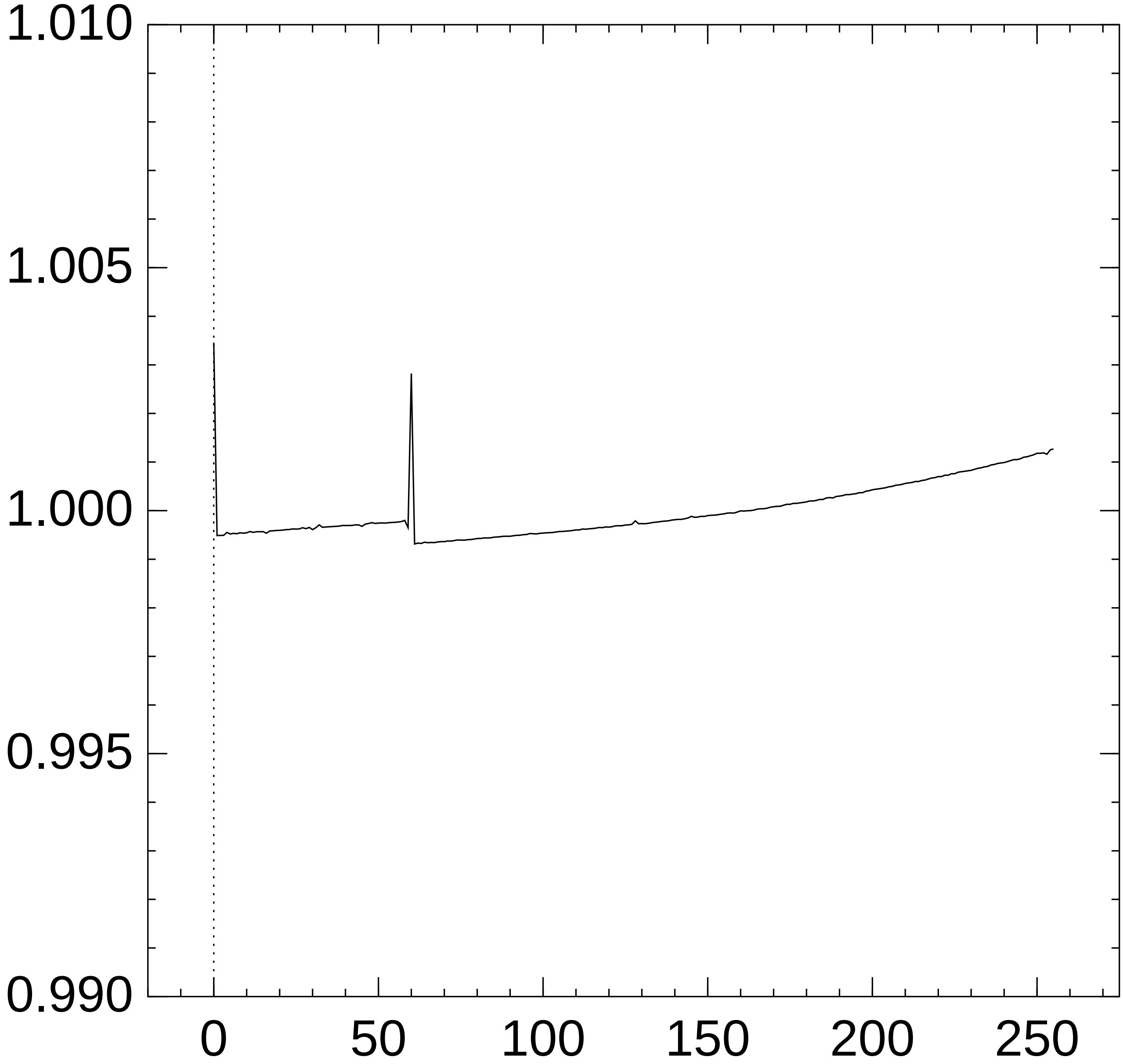
Graph of $256\,\Pr[z_{58} = x]$:



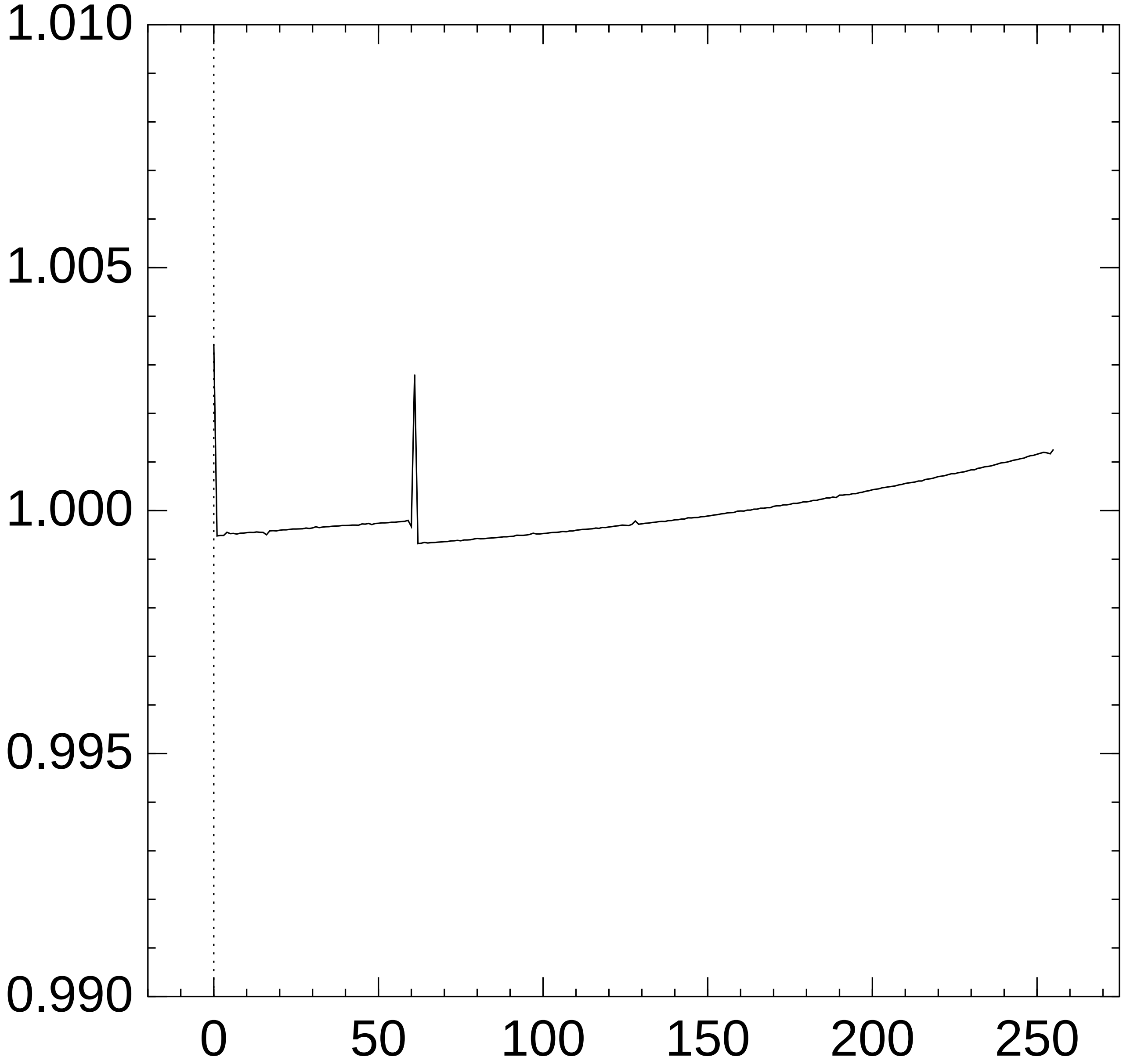
Graph of $256\,\mathrm{Pr}[z_{59} = x]$:



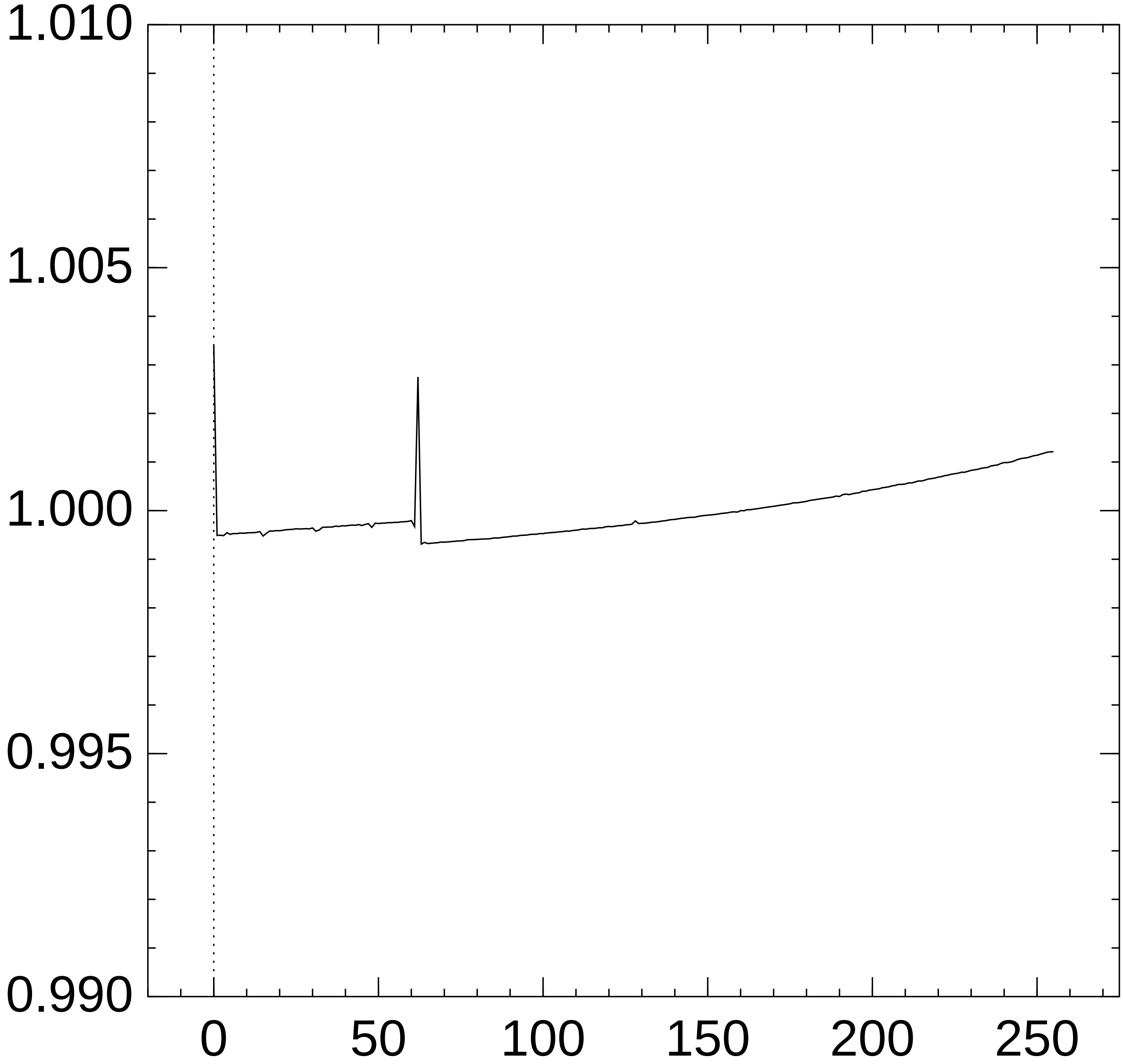
Graph of $256 \Pr[z_{60} = x]$:



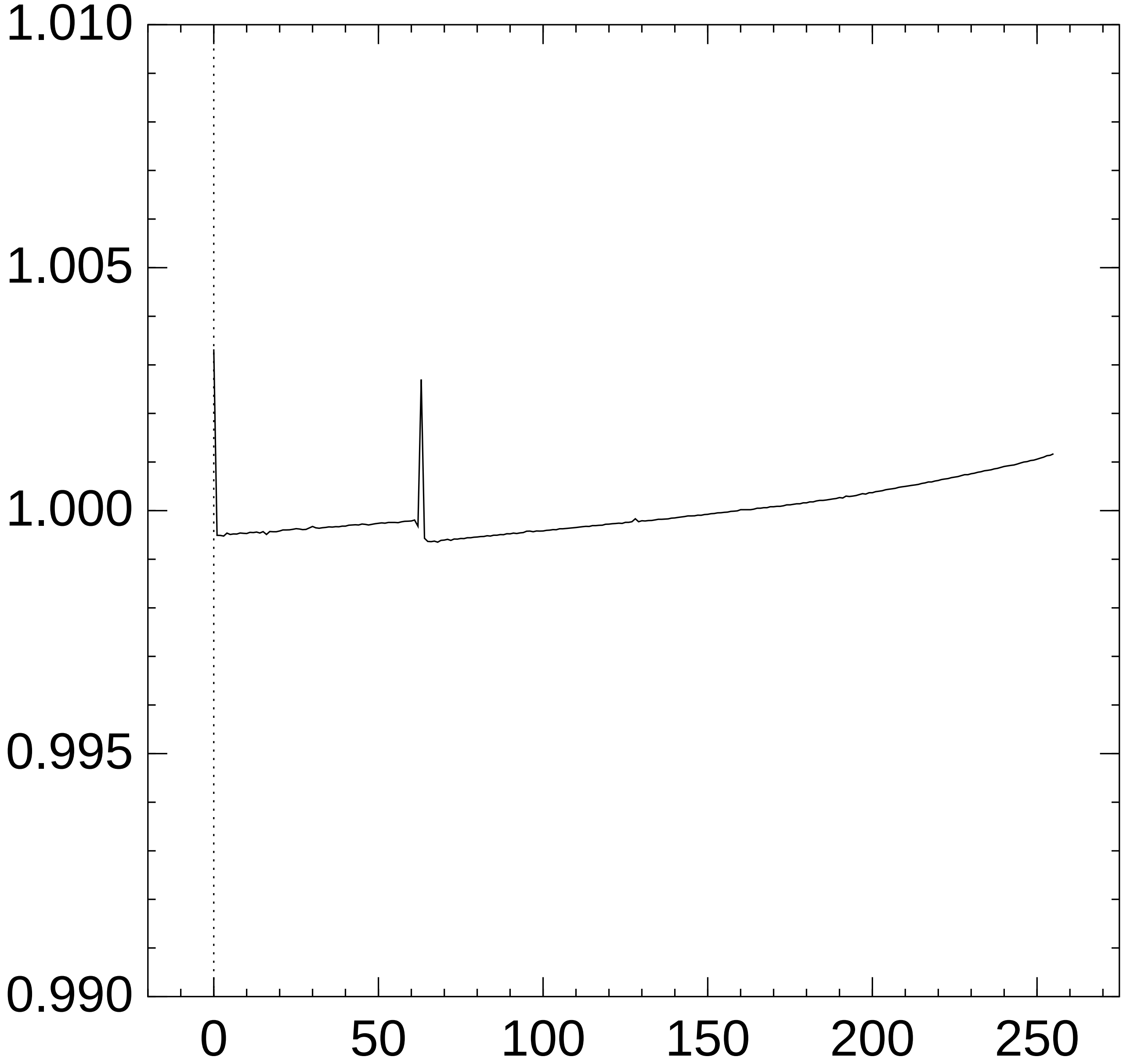
Graph of $256\,\Pr[z_{61} = x]$:



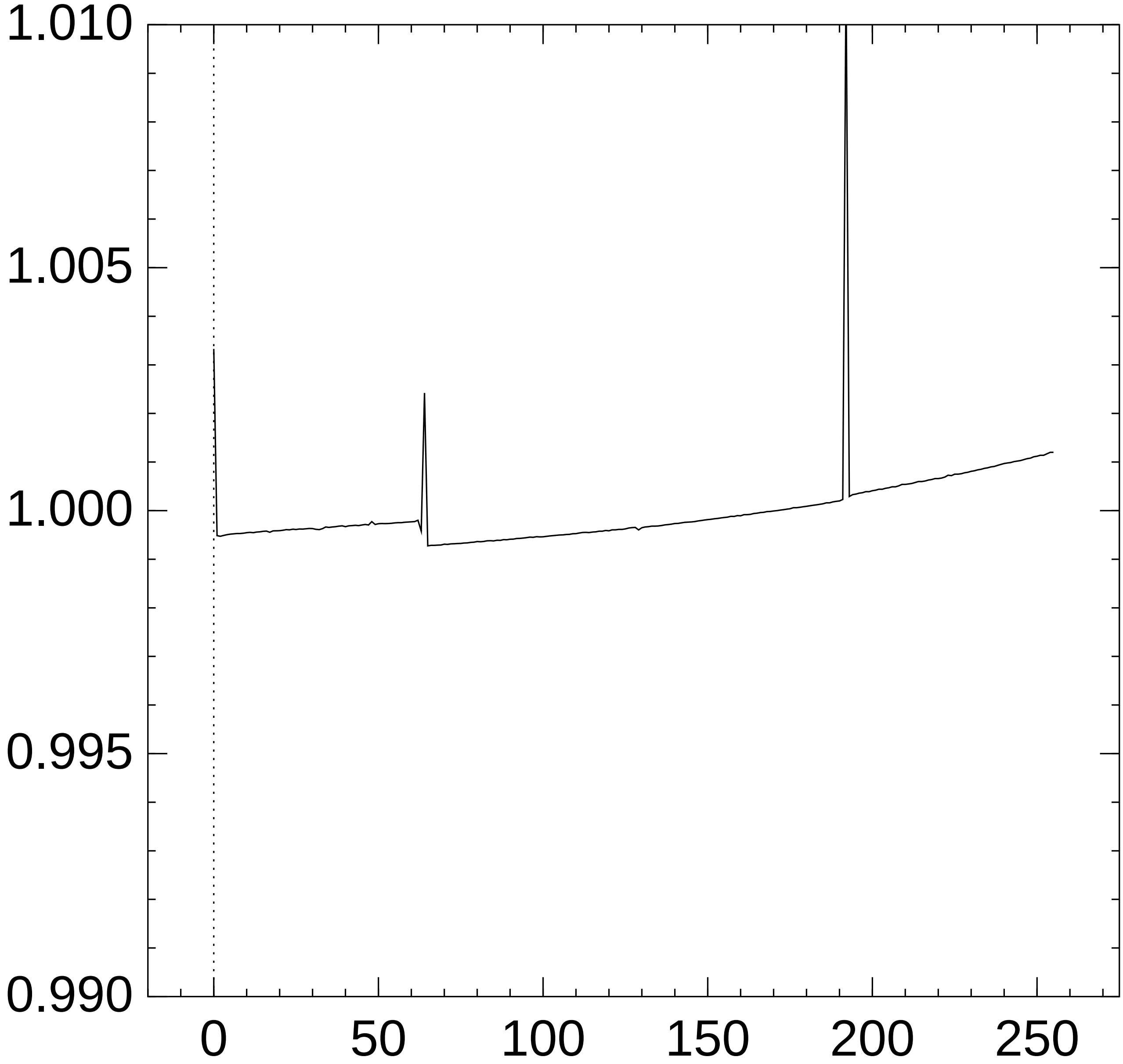
Graph of $256\,\mathrm{Pr}[z_{62} = x]$:



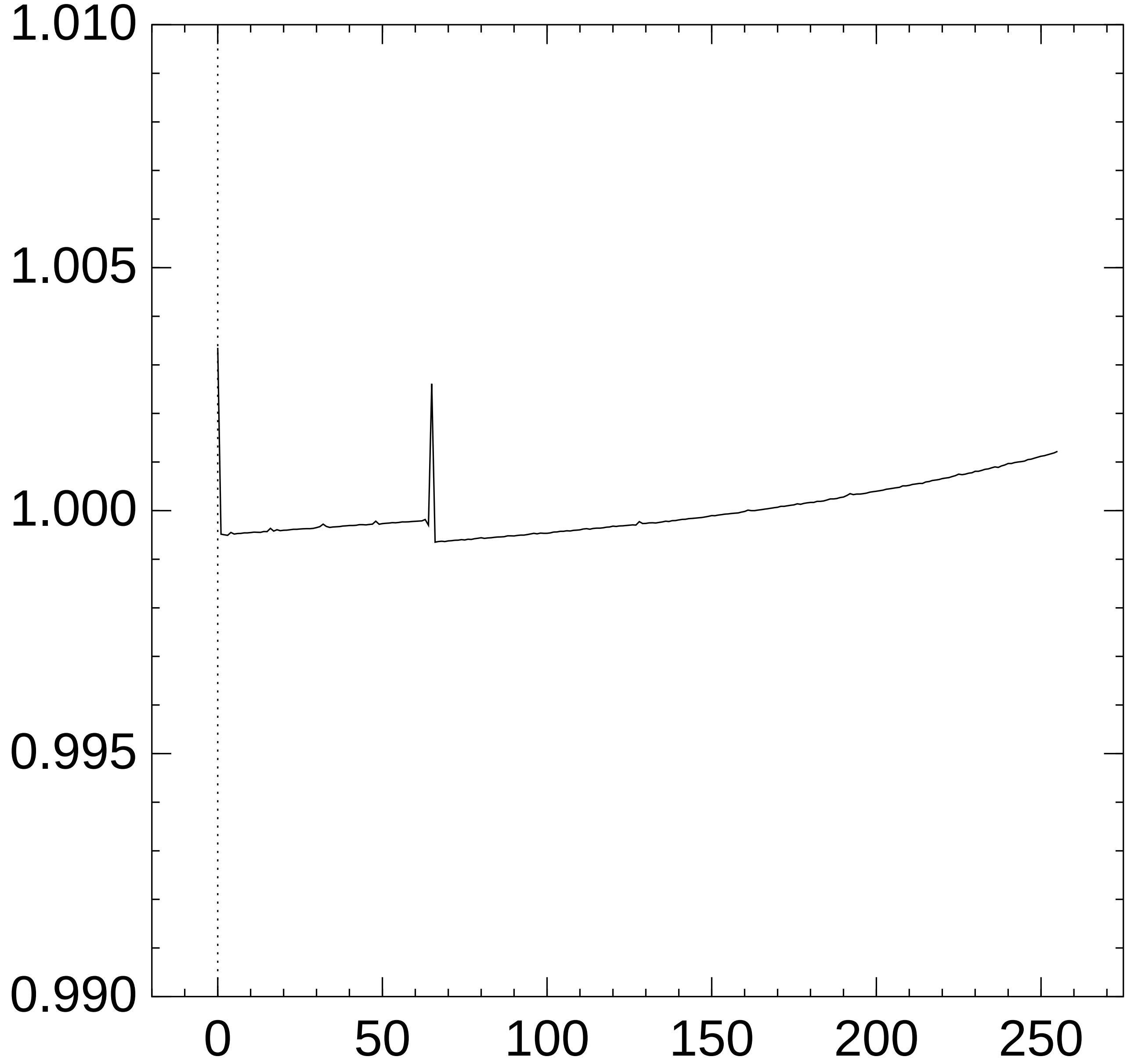
Graph of $256\,\Pr[z_{63} = x]$:



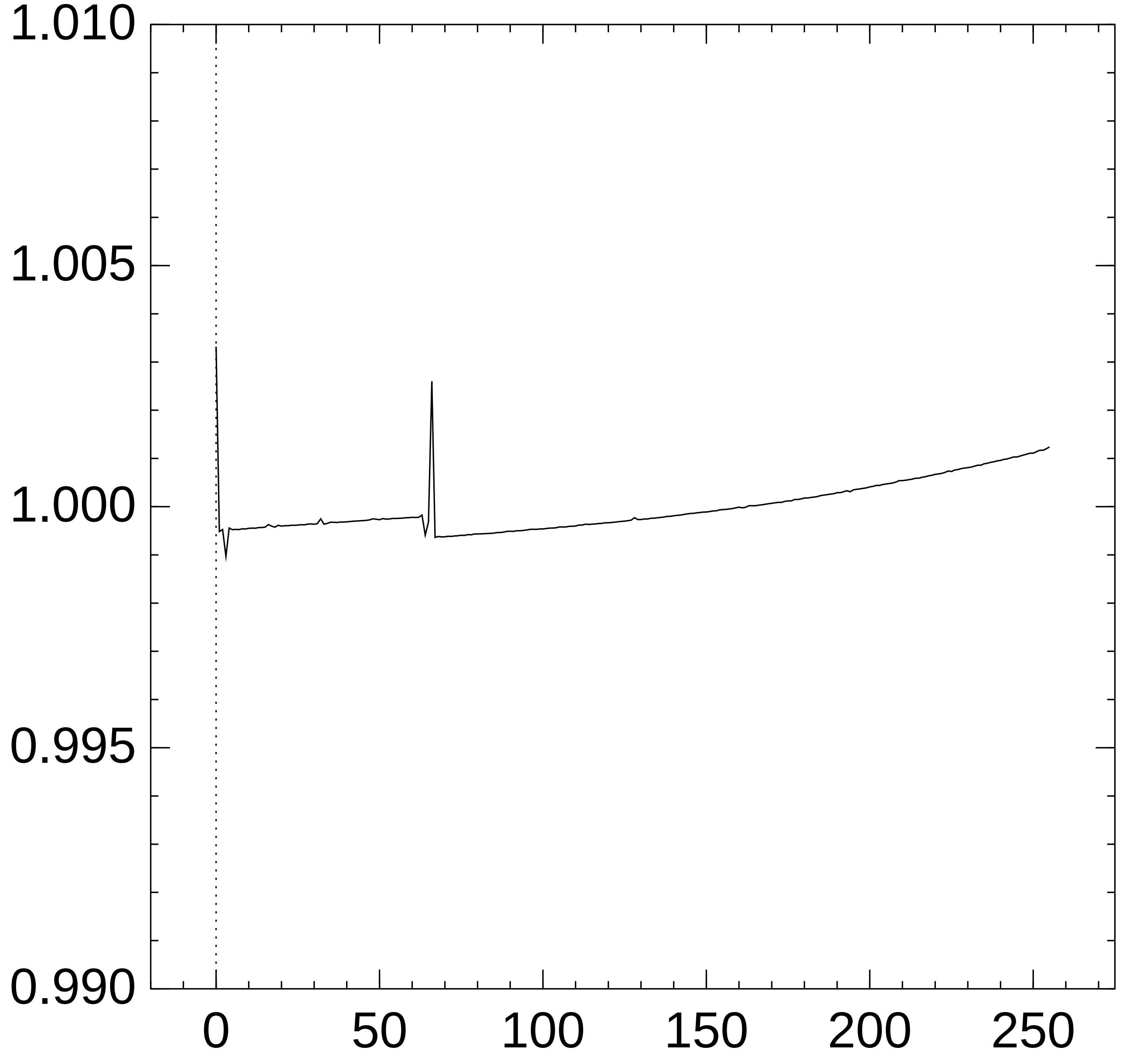
Graph of $256\,\Pr[z_{64} = x]$:



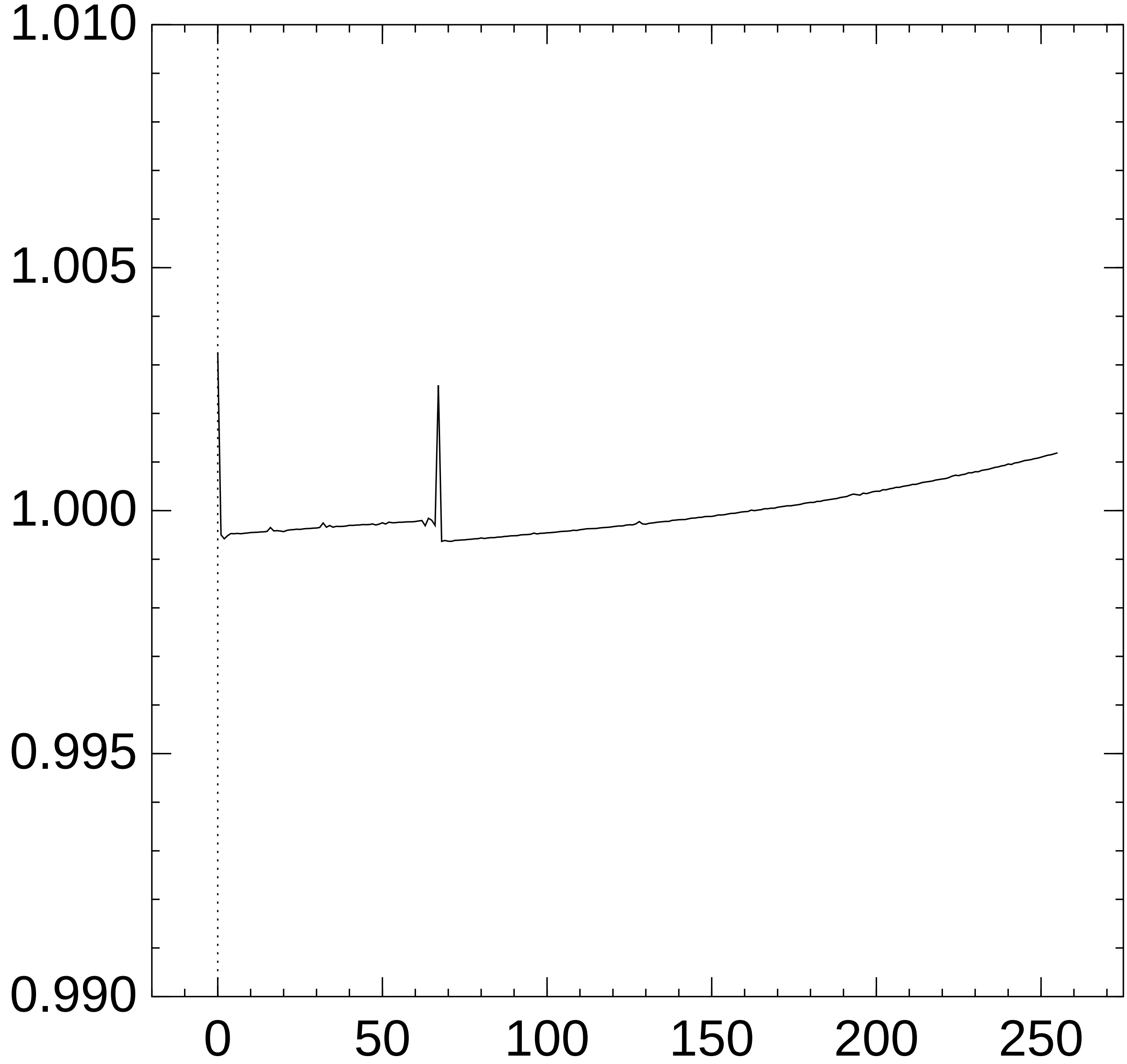
Graph of $256\,\Pr[z_{65} = x]$:



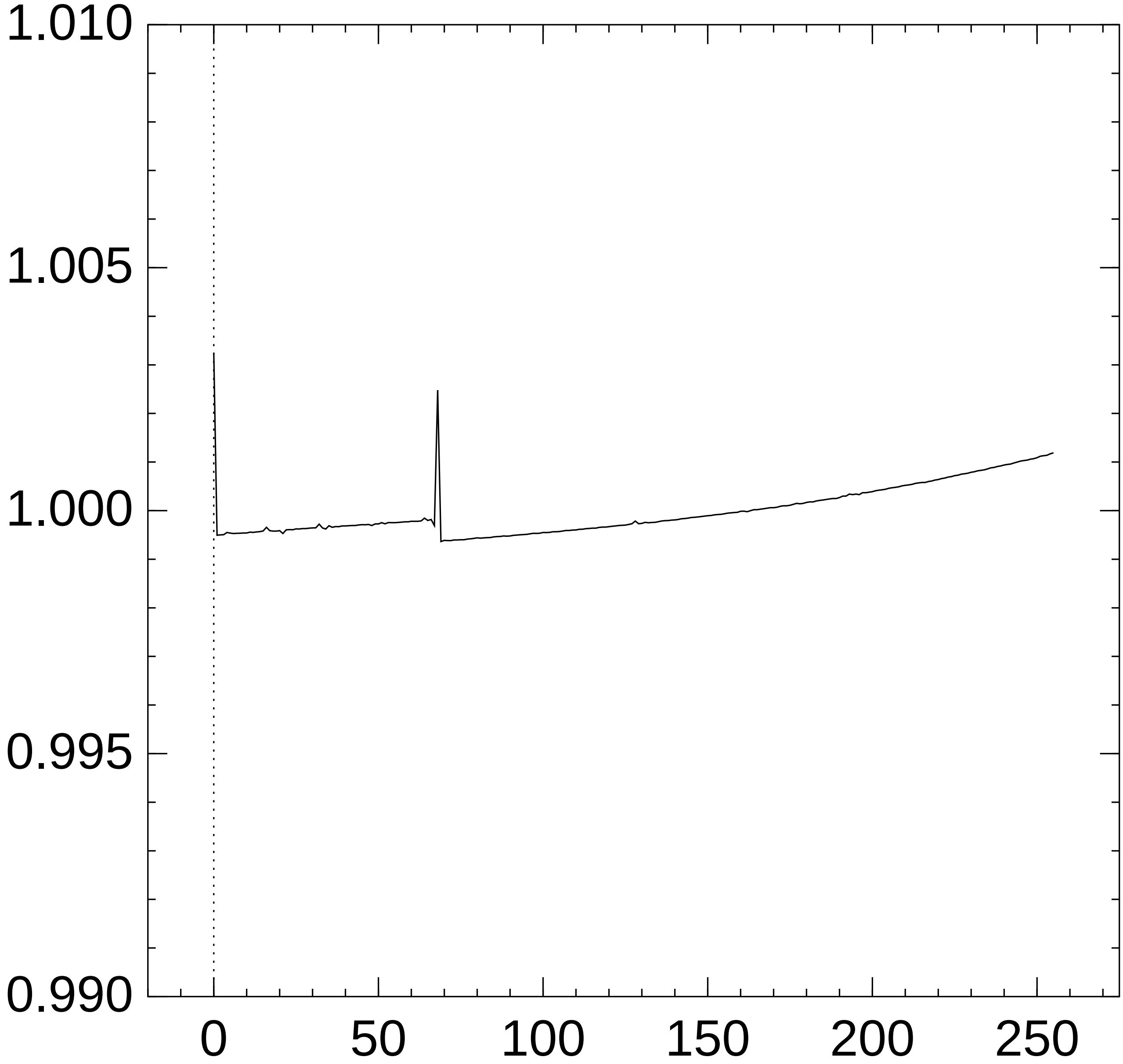
Graph of $256\,\Pr[z_{66} = x]$:



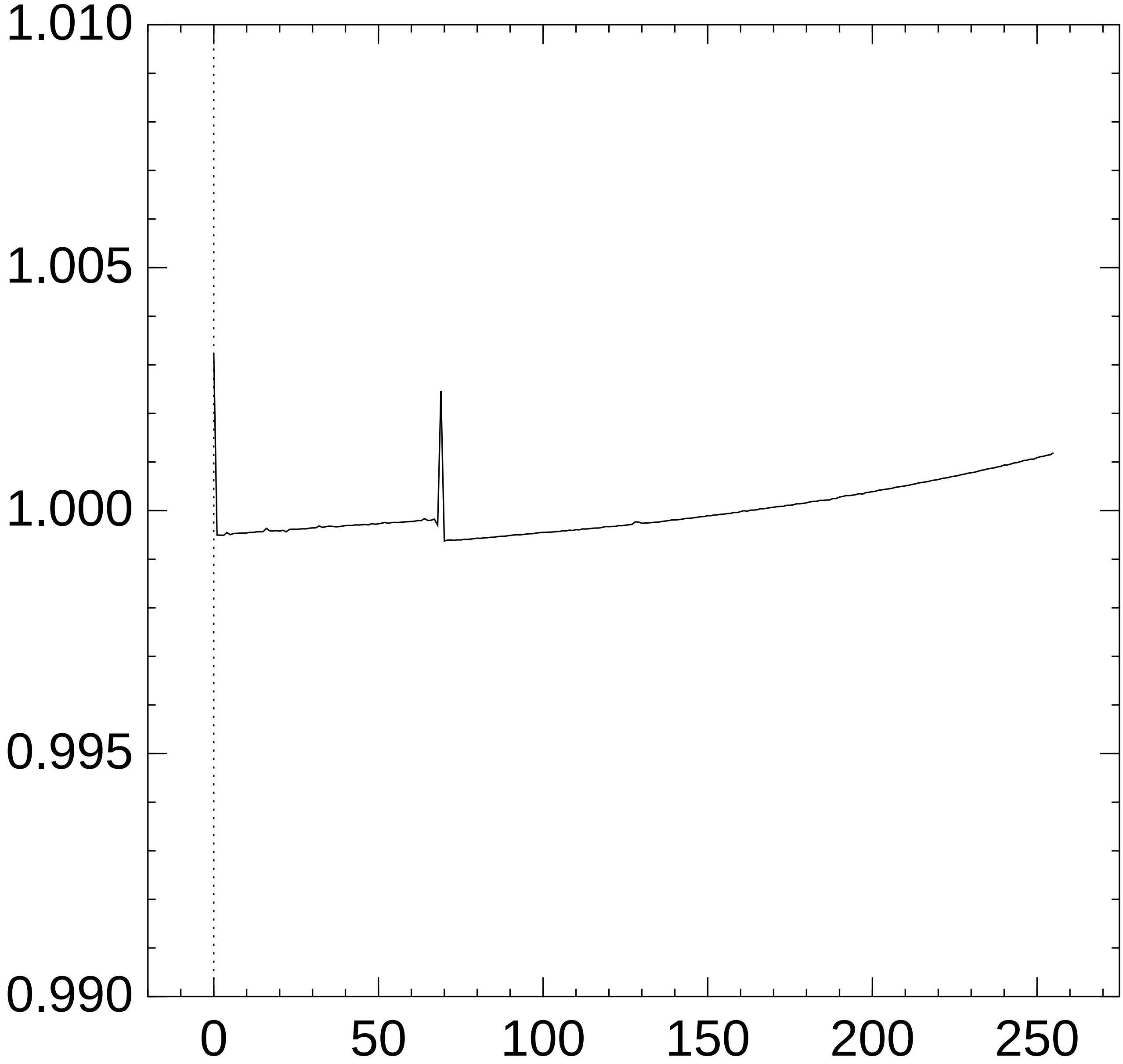
Graph of $256\,\Pr[z_{67} = x]$:



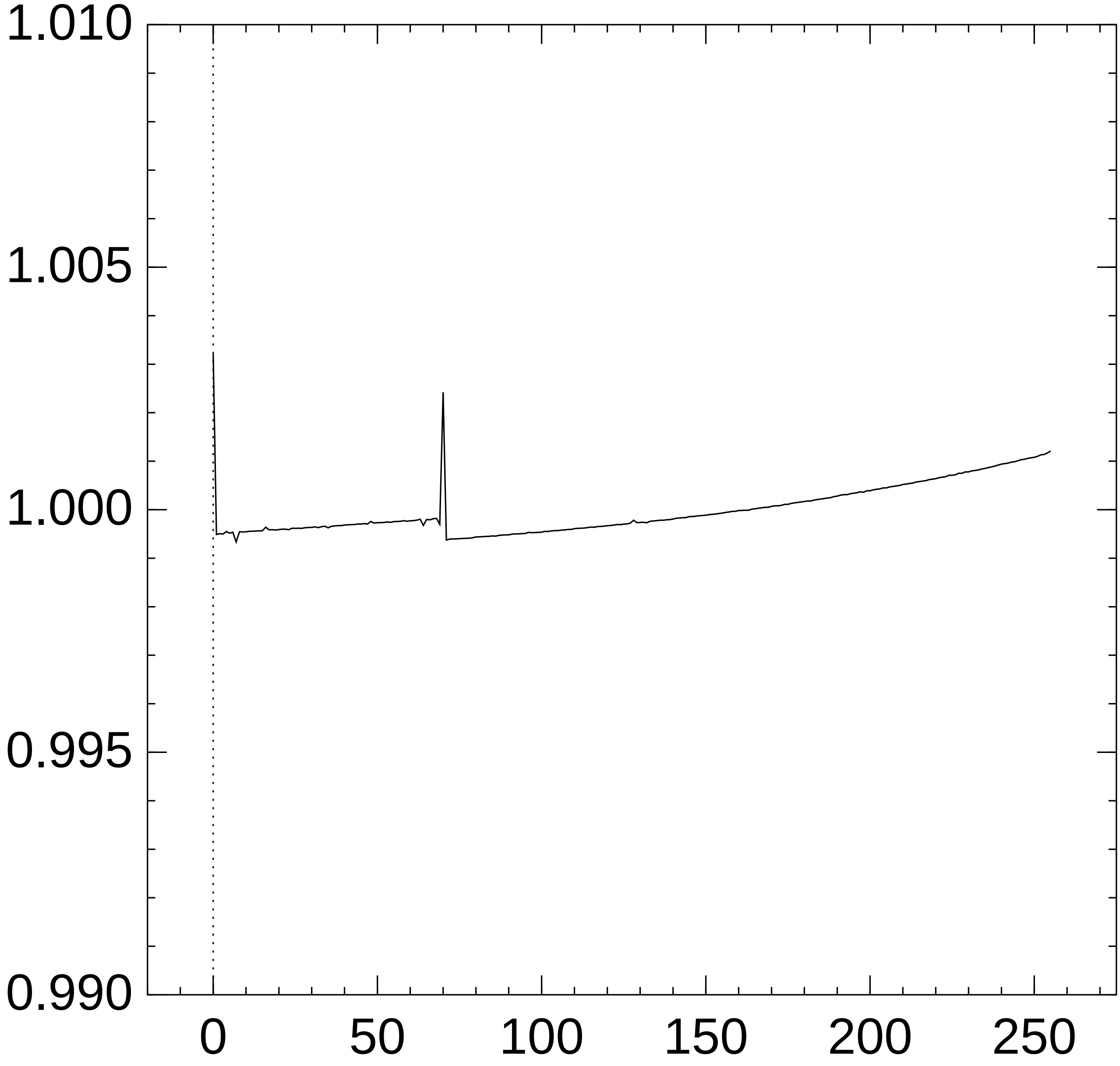
Graph of $256\,\Pr[z_{68} = x]$:



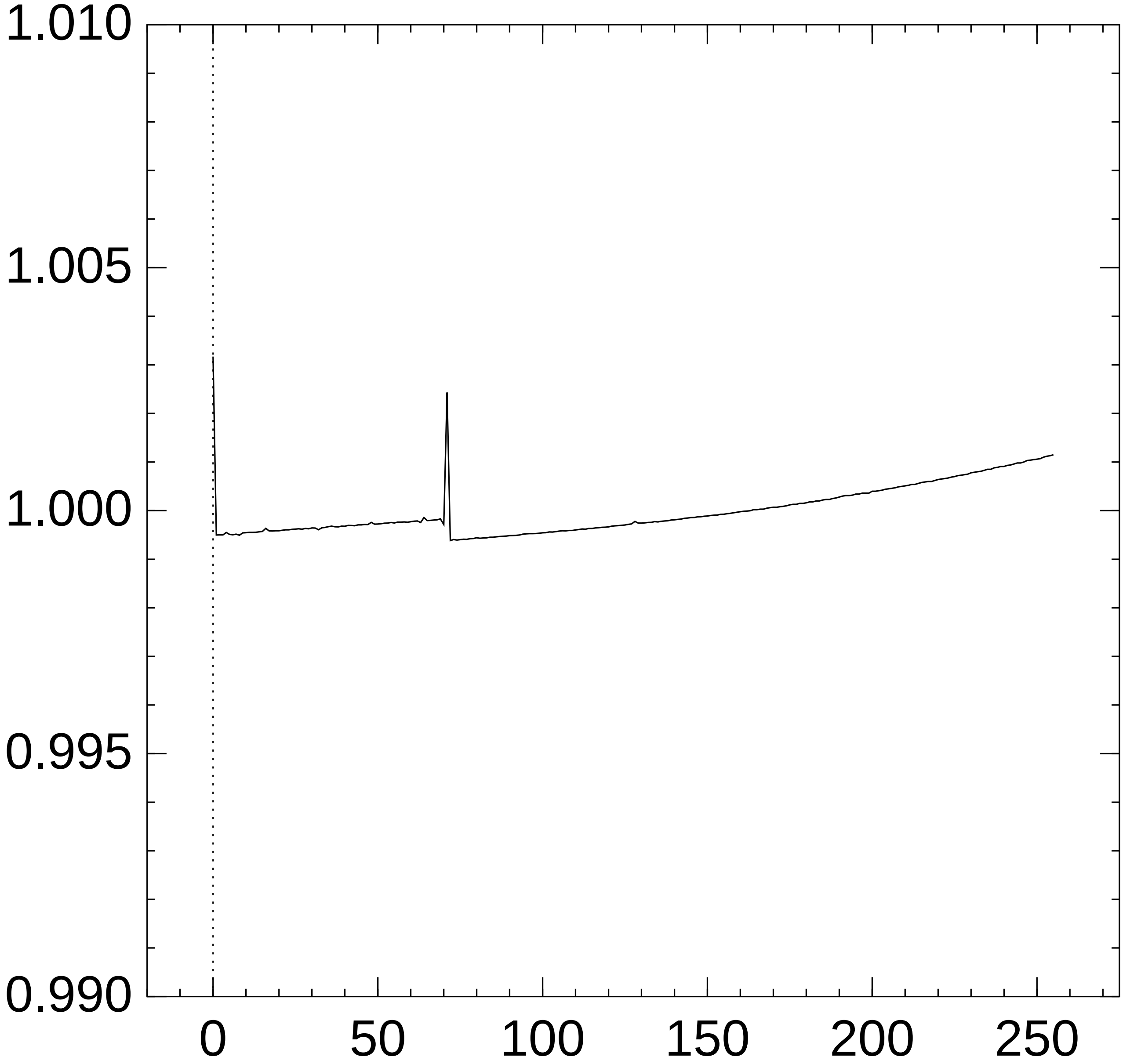
Graph of $256\,\mathrm{Pr}[z_{69} = x]$:



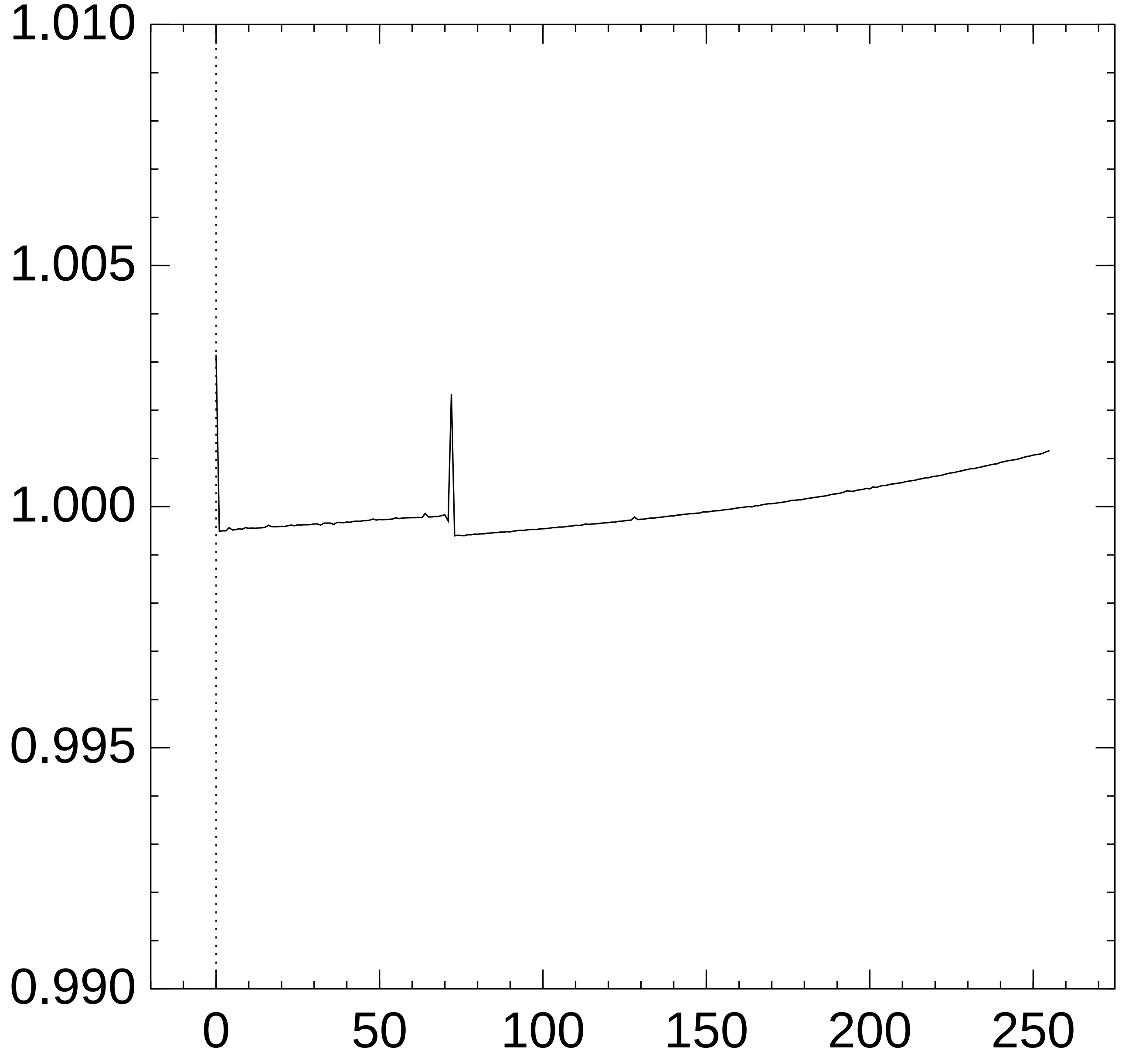
Graph of $256\,\Pr[z_{70} = x]$:



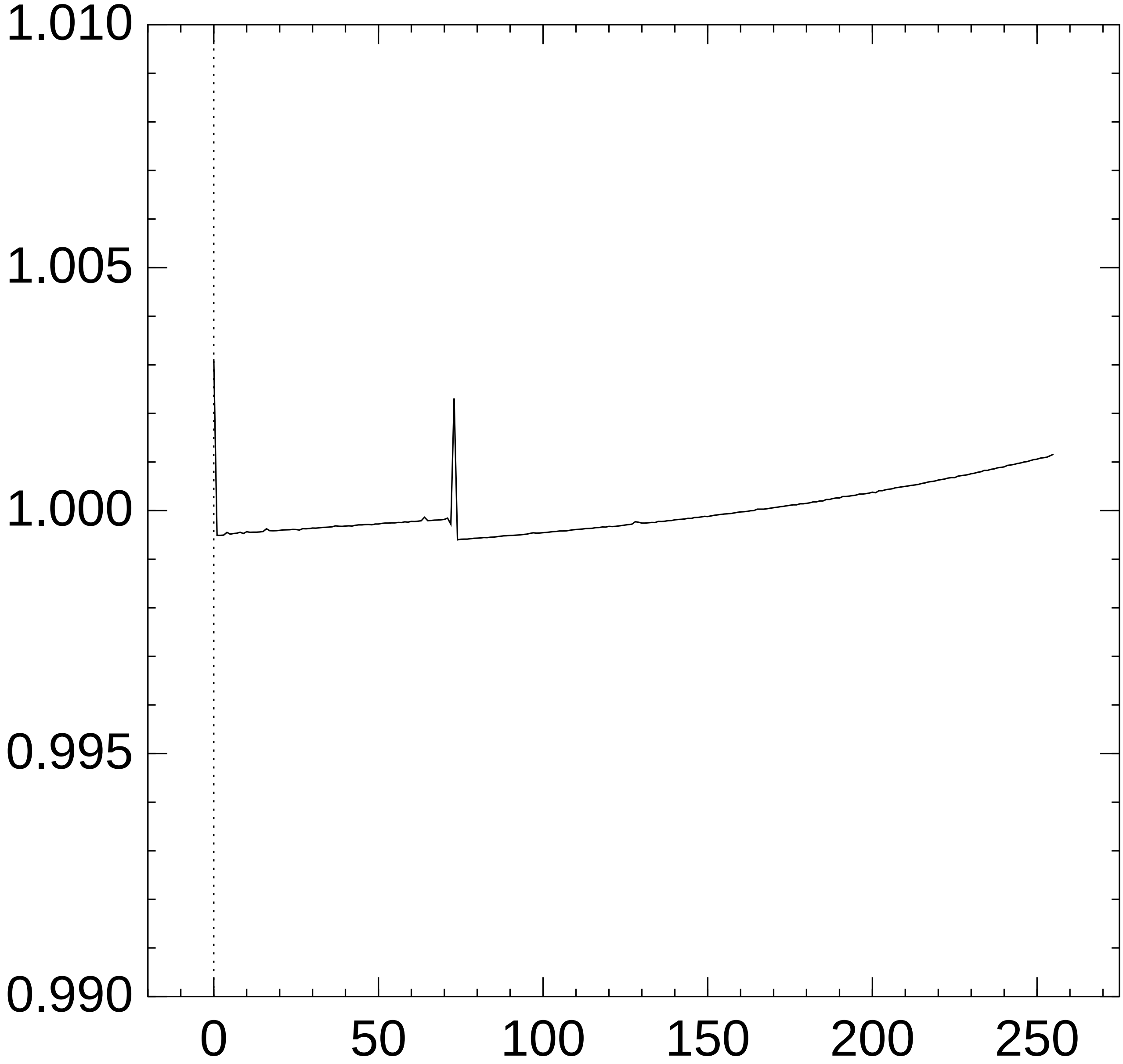
Graph of $256 \Pr[z_{71} = x]$:



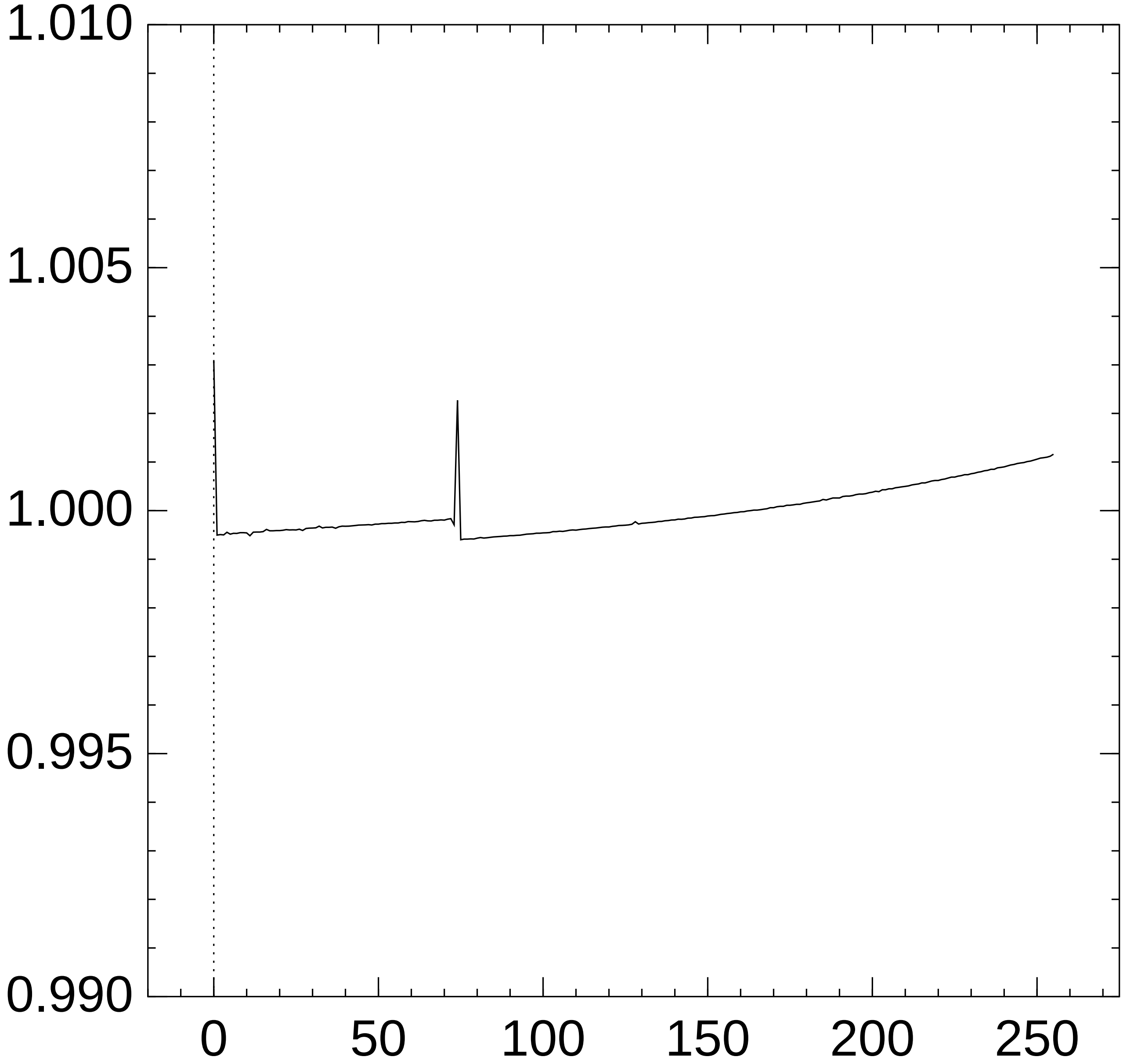
Graph of $256\,\Pr[z_{72} = x]$:



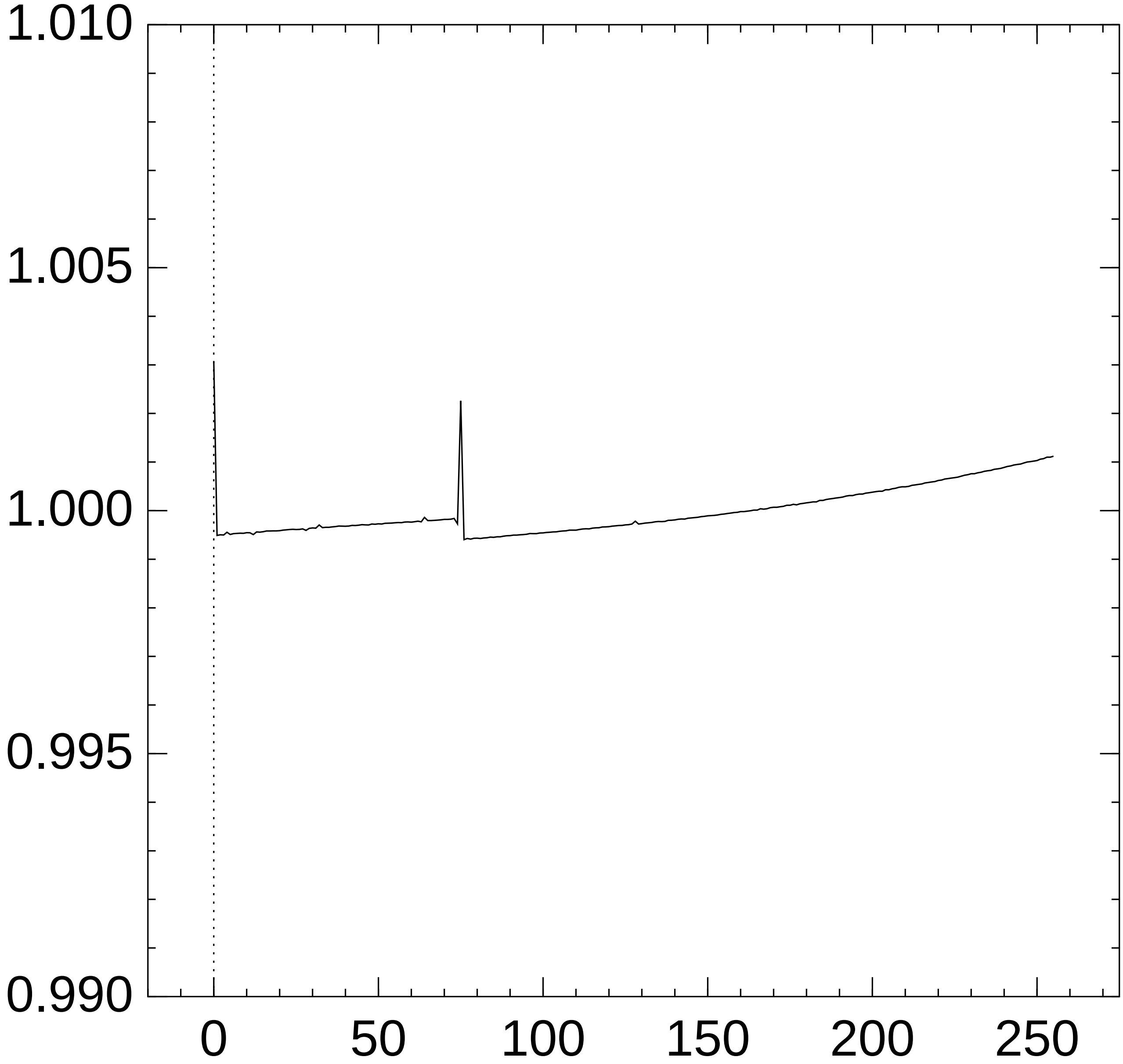
Graph of $256\,\Pr[z_{73} = x]$:



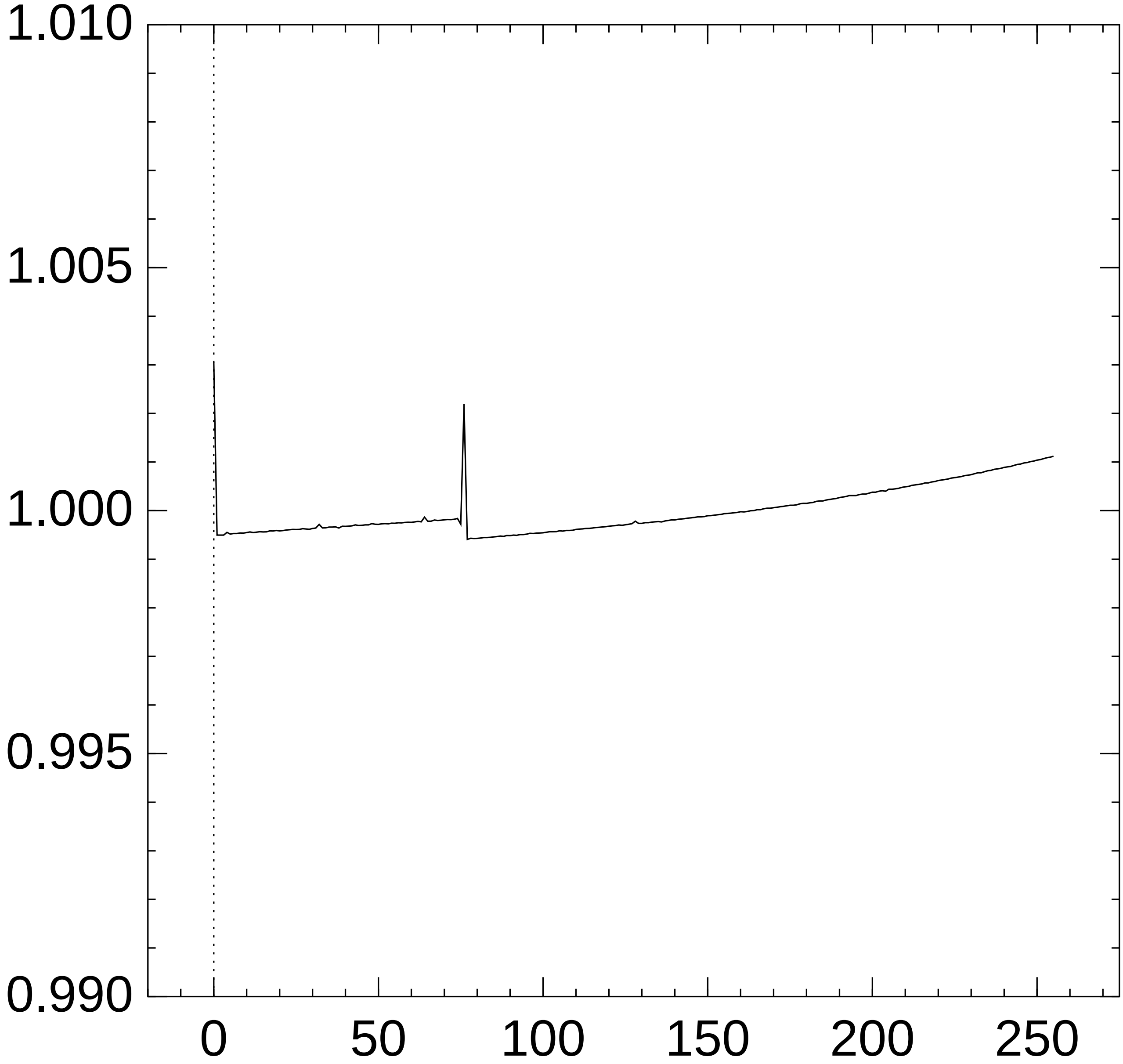
Graph of $256 \Pr[z_{74} = x]$:



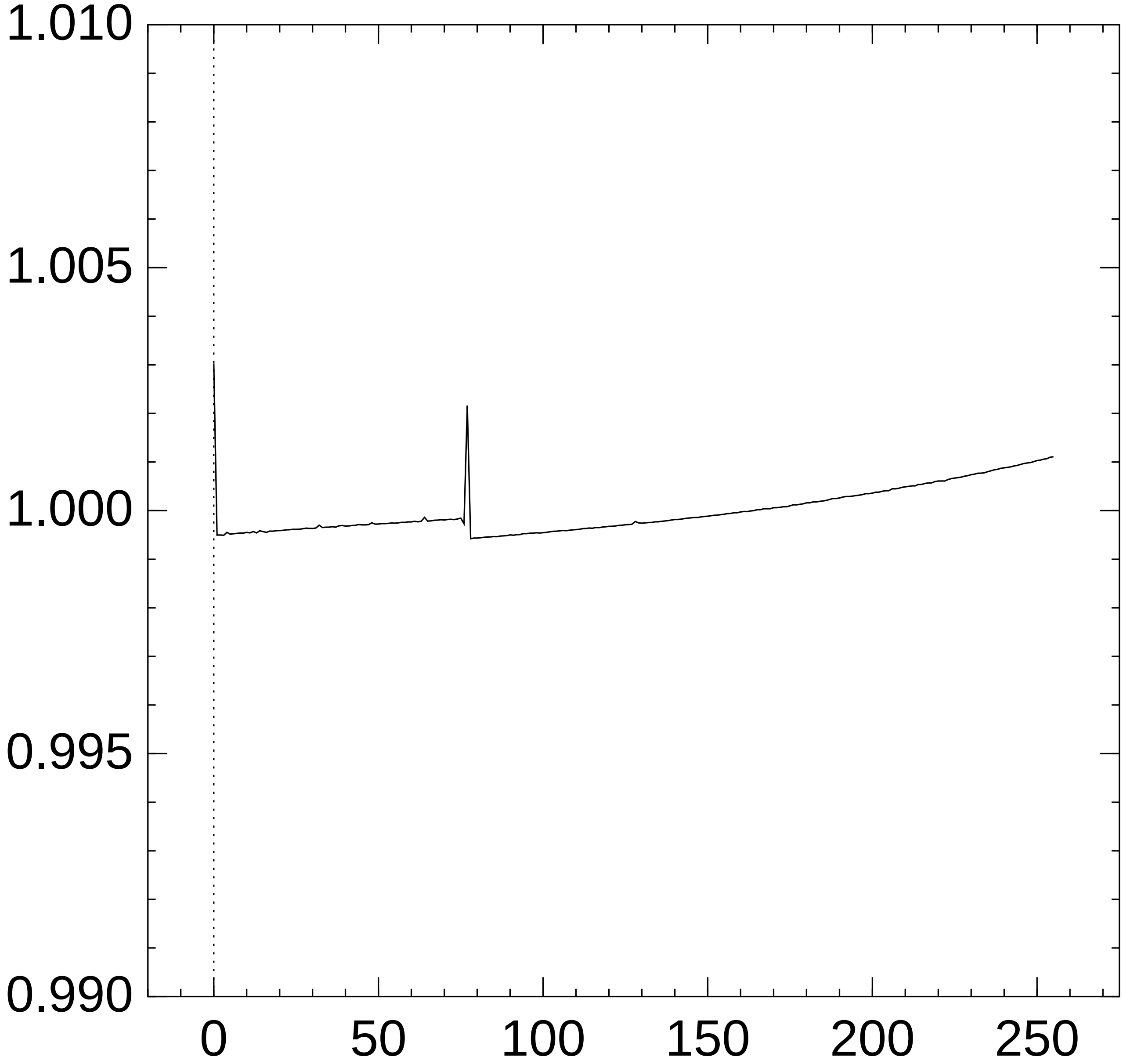
Graph of $256\,\Pr[z_{75} = x]$:



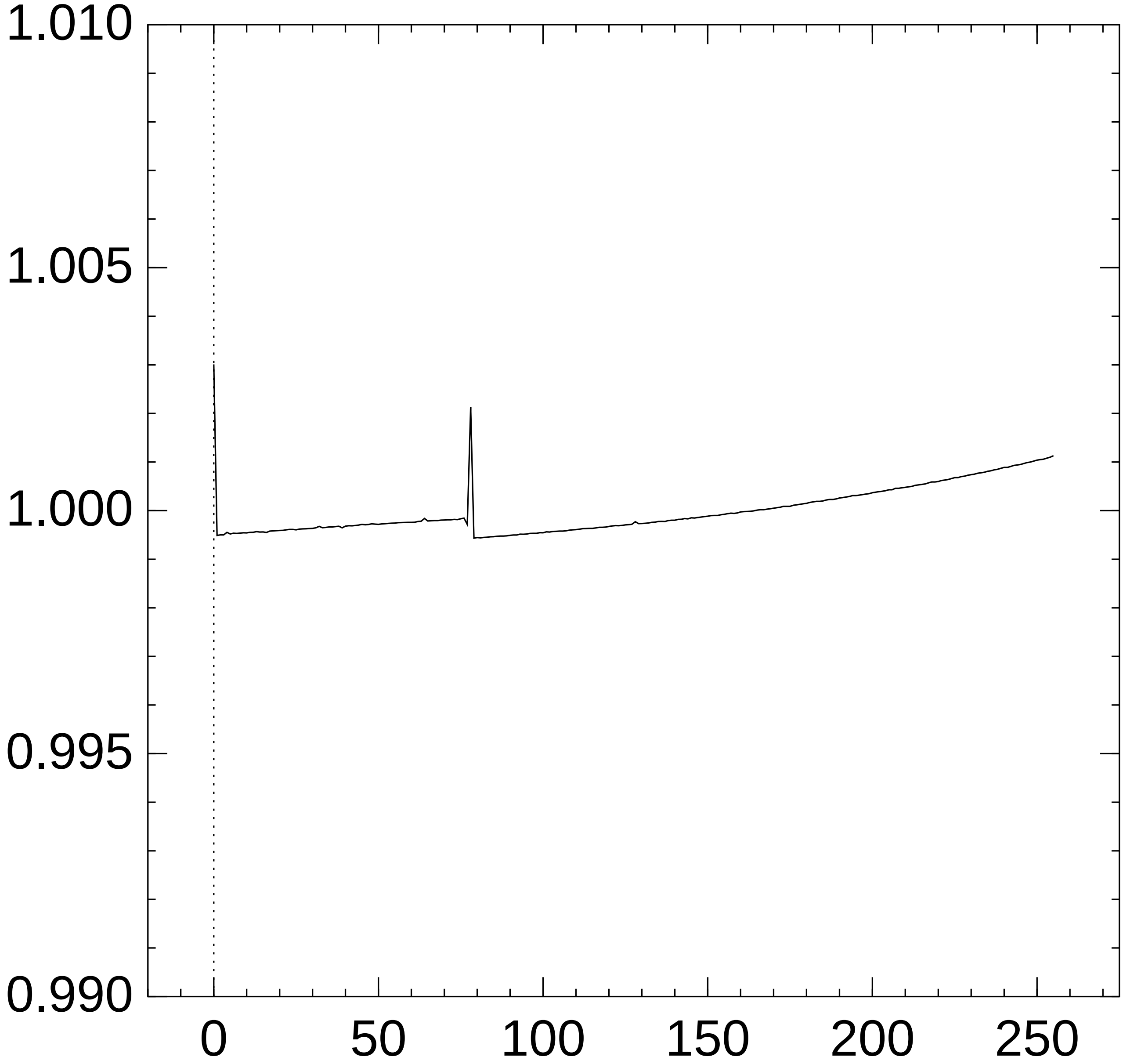
Graph of $256\,\mathsf{Pr}[z_{76} = x]$:



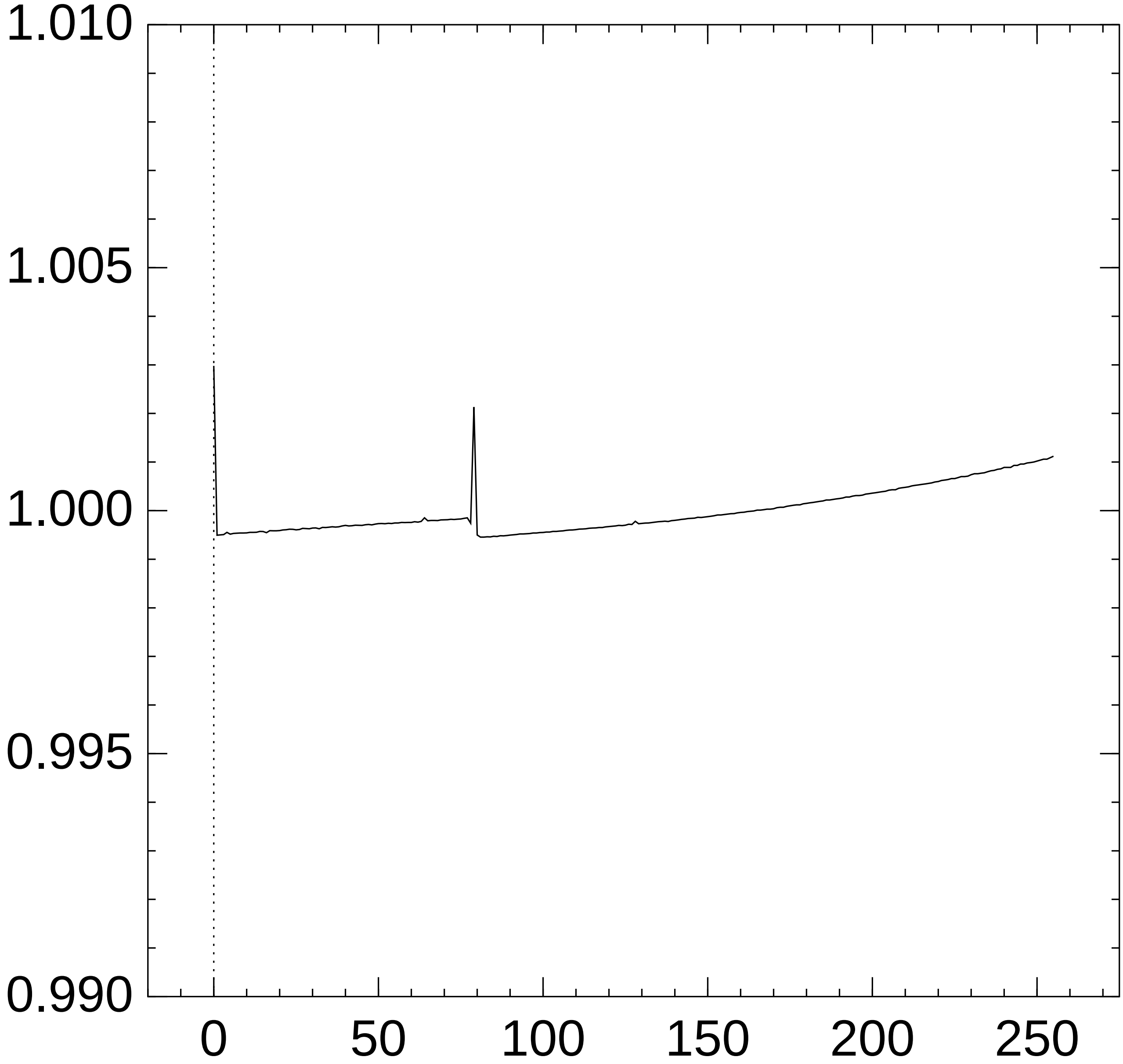
Graph of $256\,\mathrm{Pr}[z_{77} = x]$:



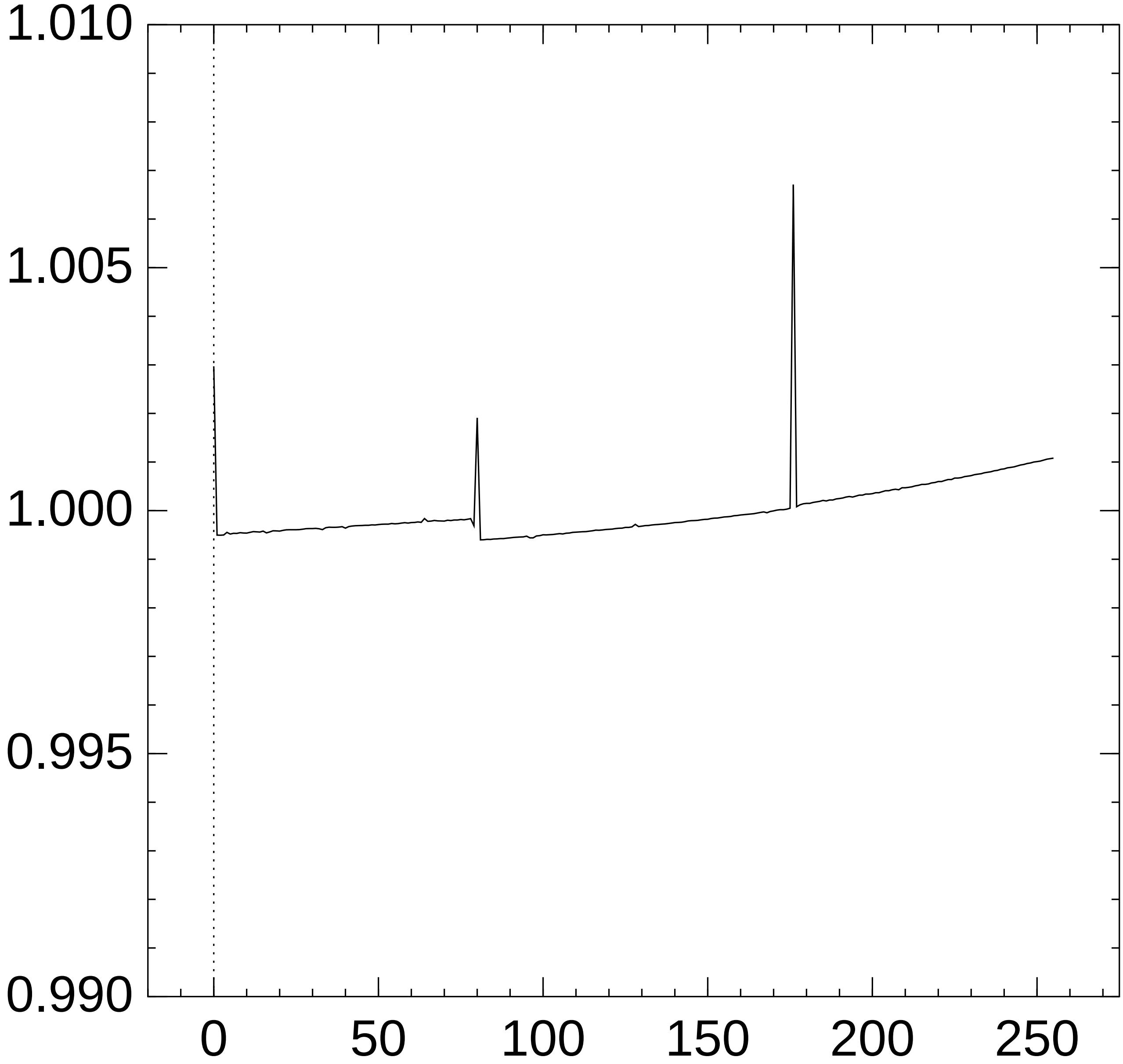
Graph of $256\,\mathrm{Pr}[z_{78} = x]$:



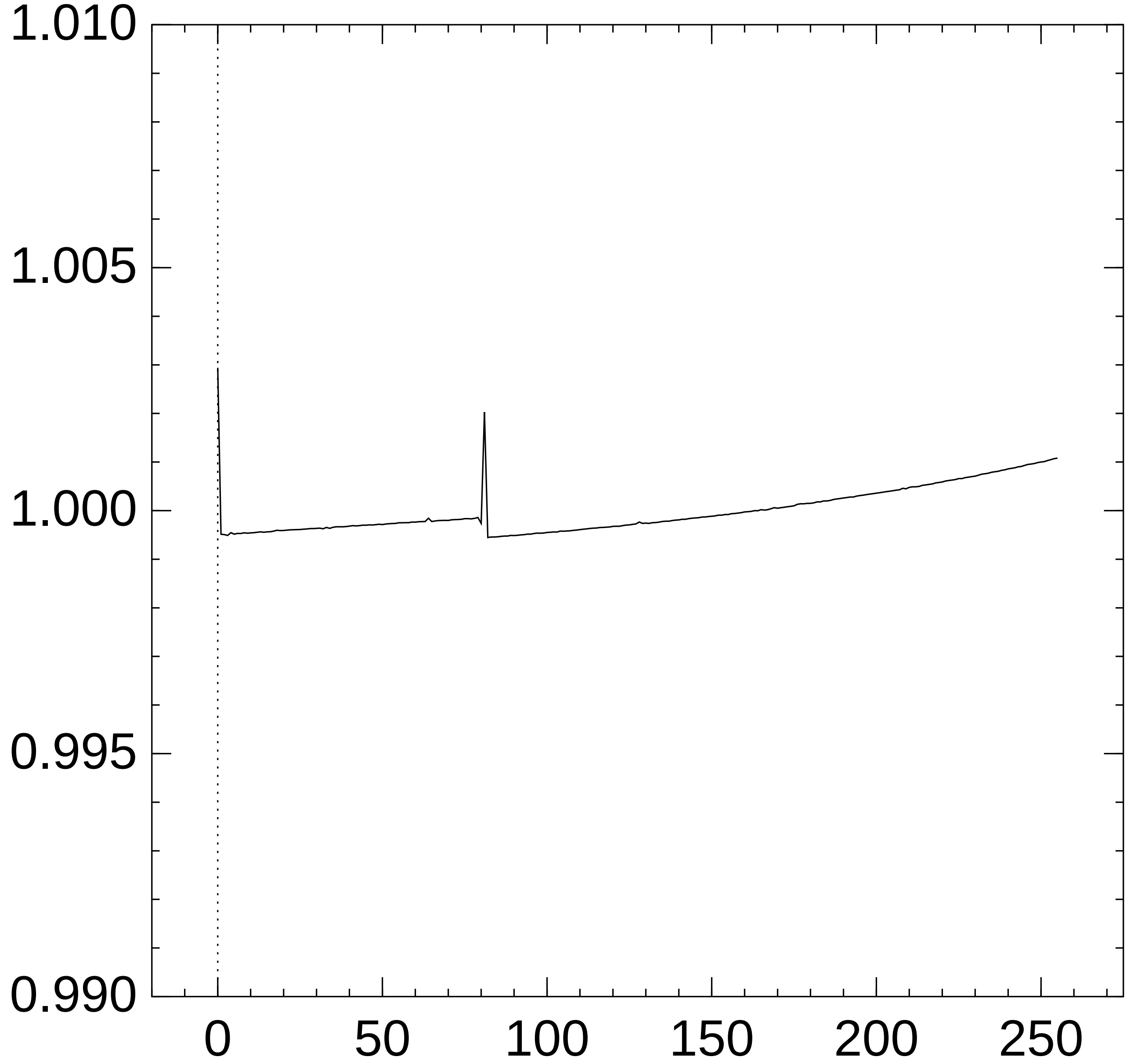
Graph of $256\,\Pr[z_{79} = x]$:



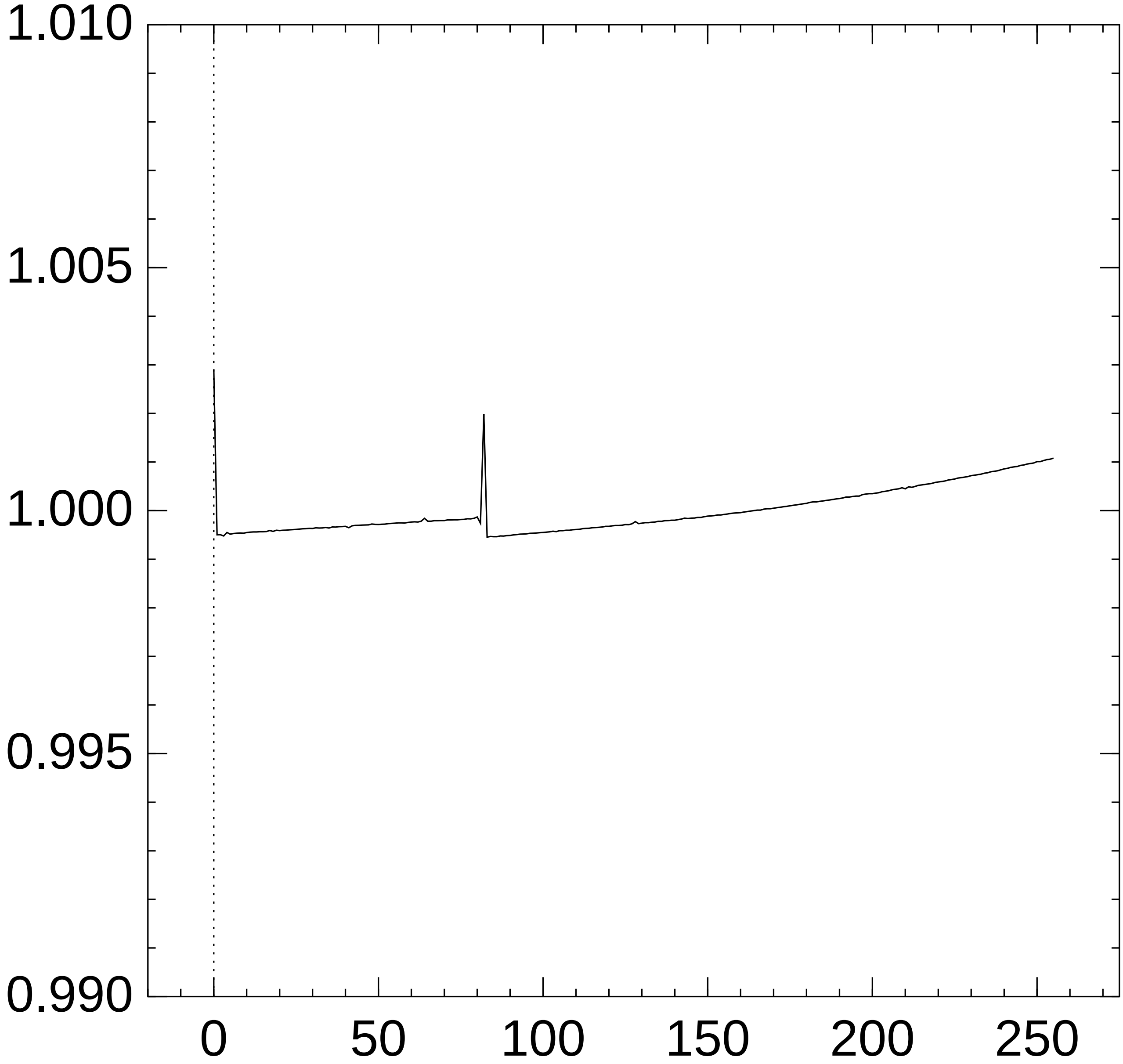
Graph of $256\,\Pr[z_{80} = x]$:



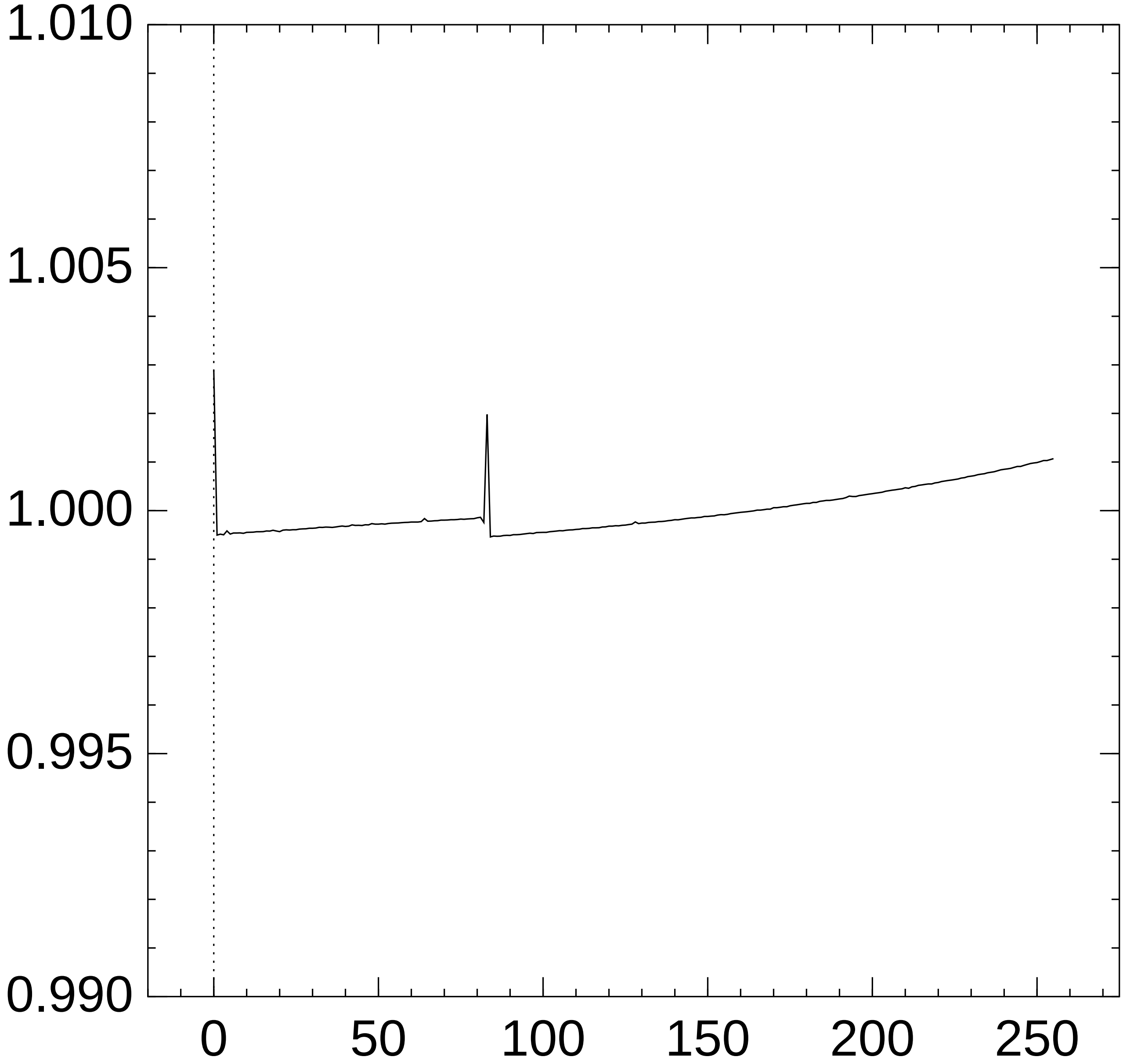
Graph of $256\,\mathrm{Pr}[z_{81} = x]$:



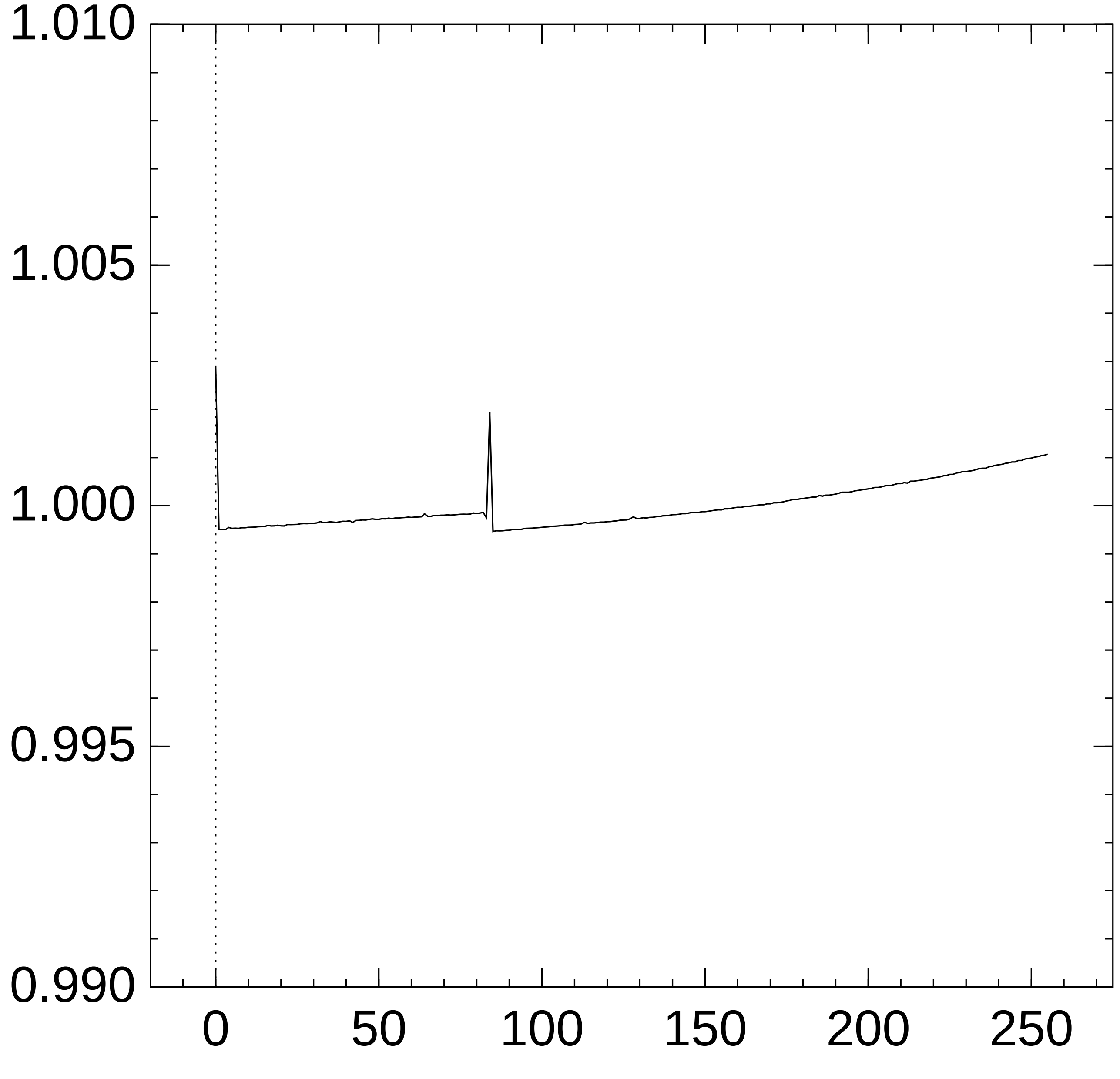
Graph of $256\,\Pr[z_{82} = x]$:



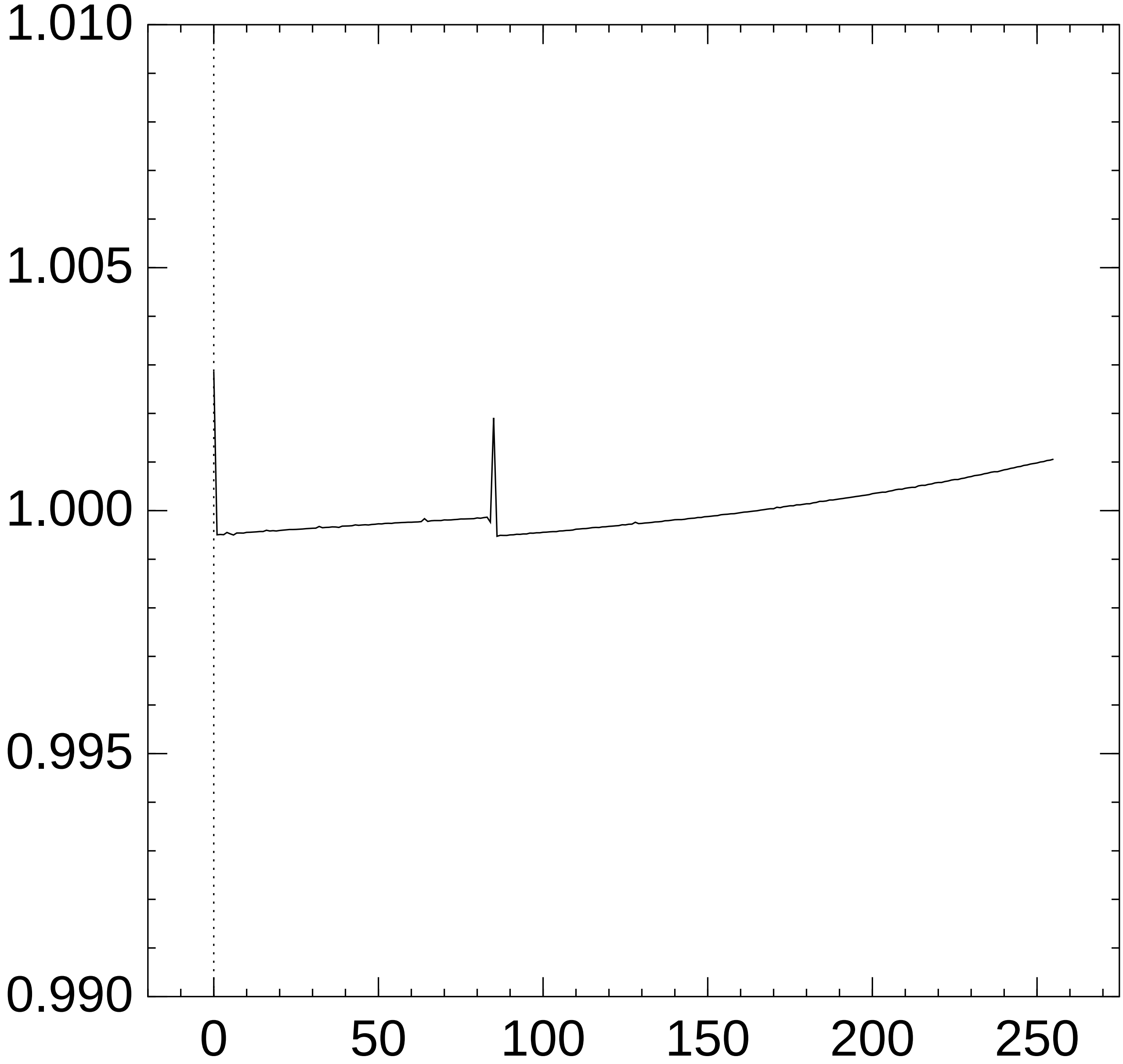
Graph of $256\,\mathrm{Pr}[z_{83} = x]$:



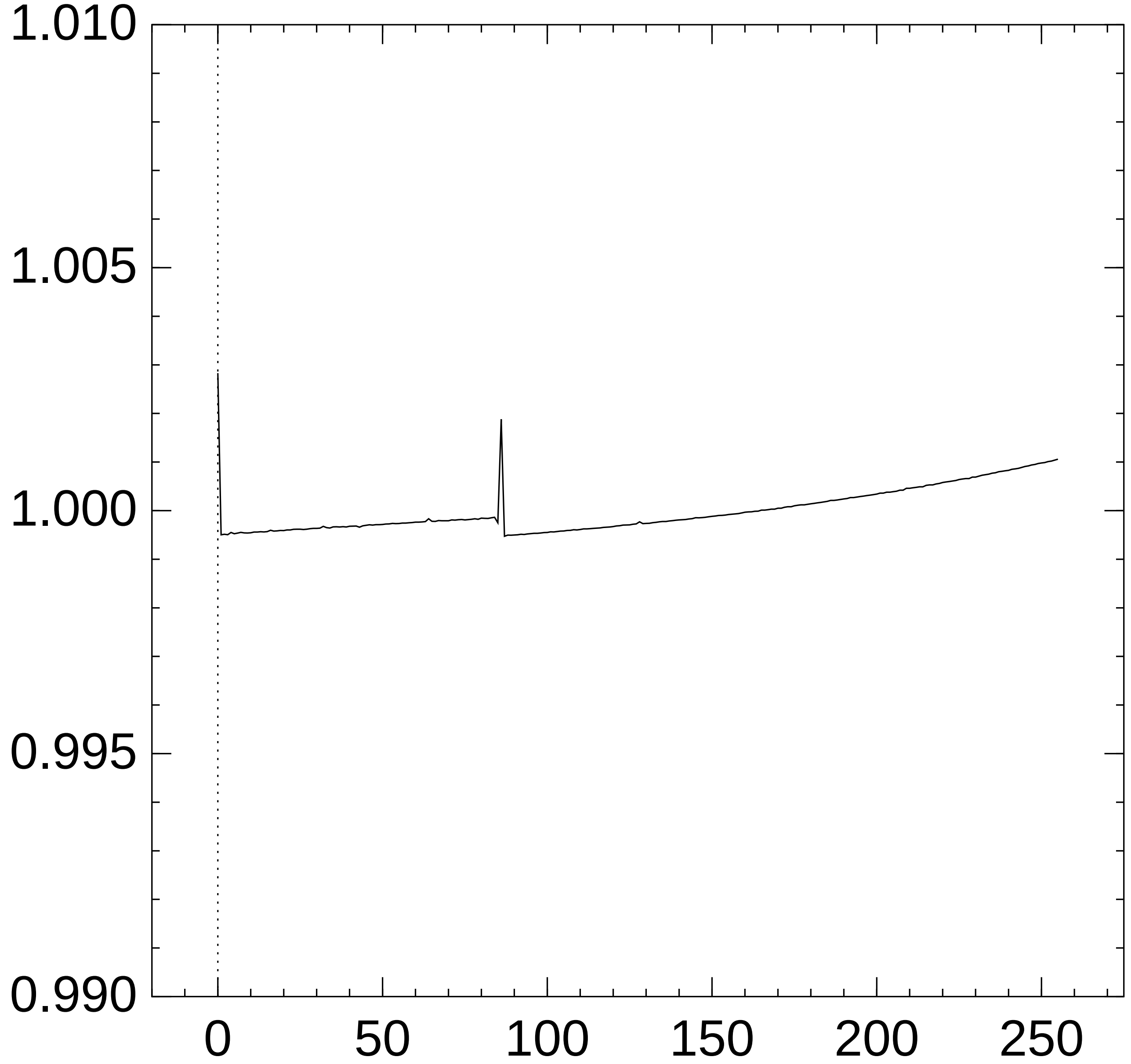
Graph of $256\,\Pr[z_{84} = x]$:



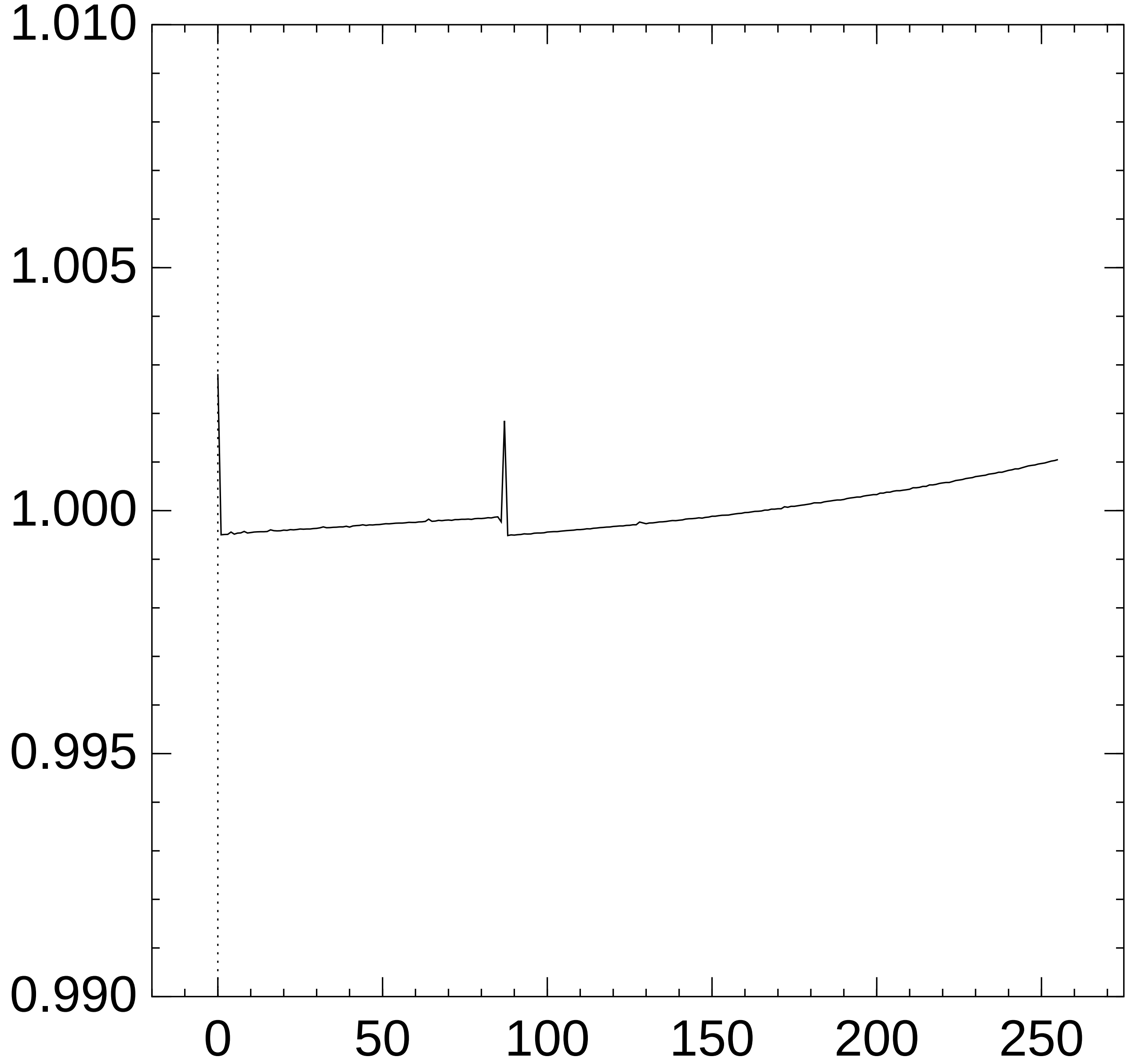
Graph of $256\,\Pr[z_{85} = x]$:



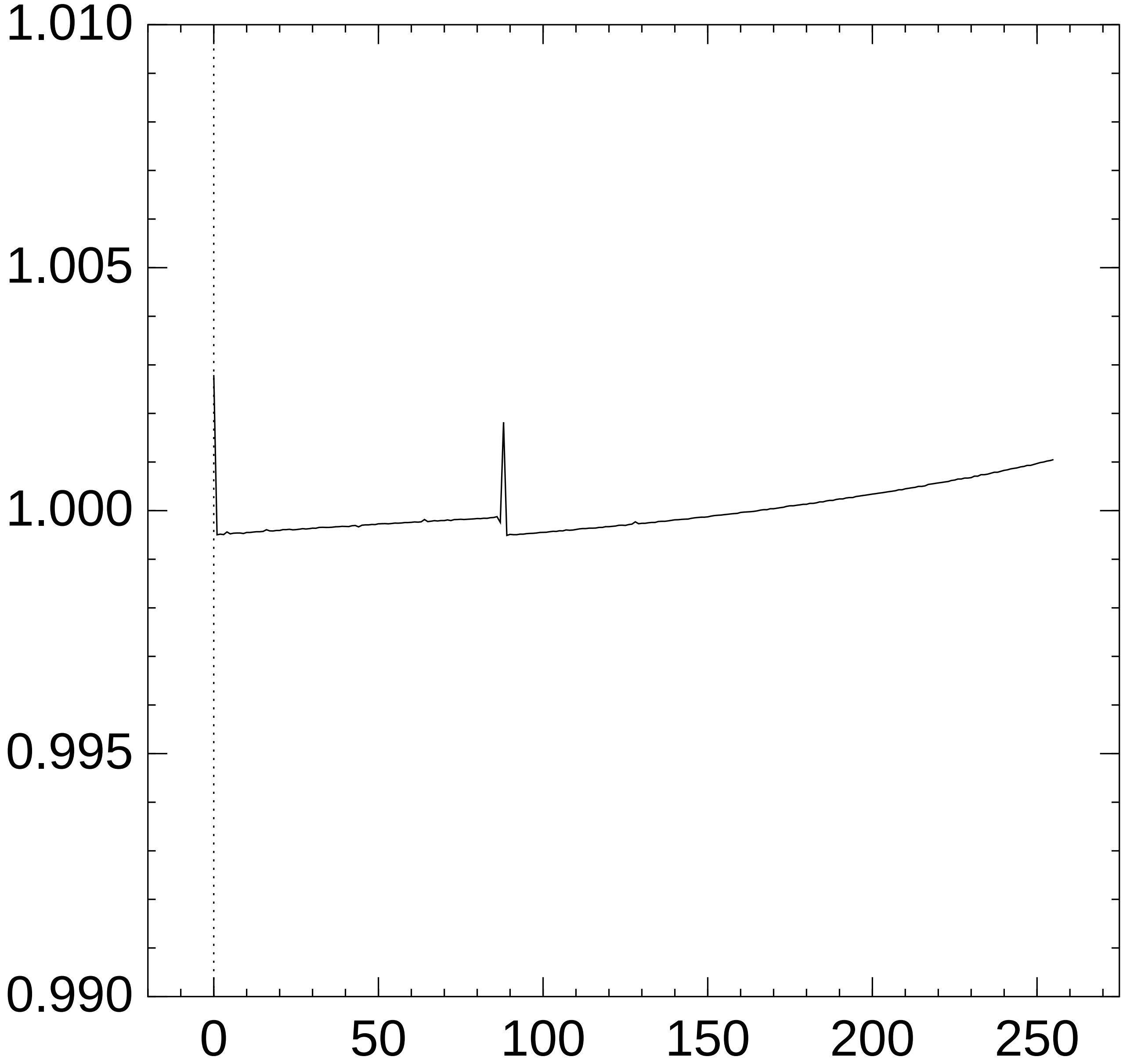
Graph of $256\,\mathrm{Pr}[z_{86} = x]$:



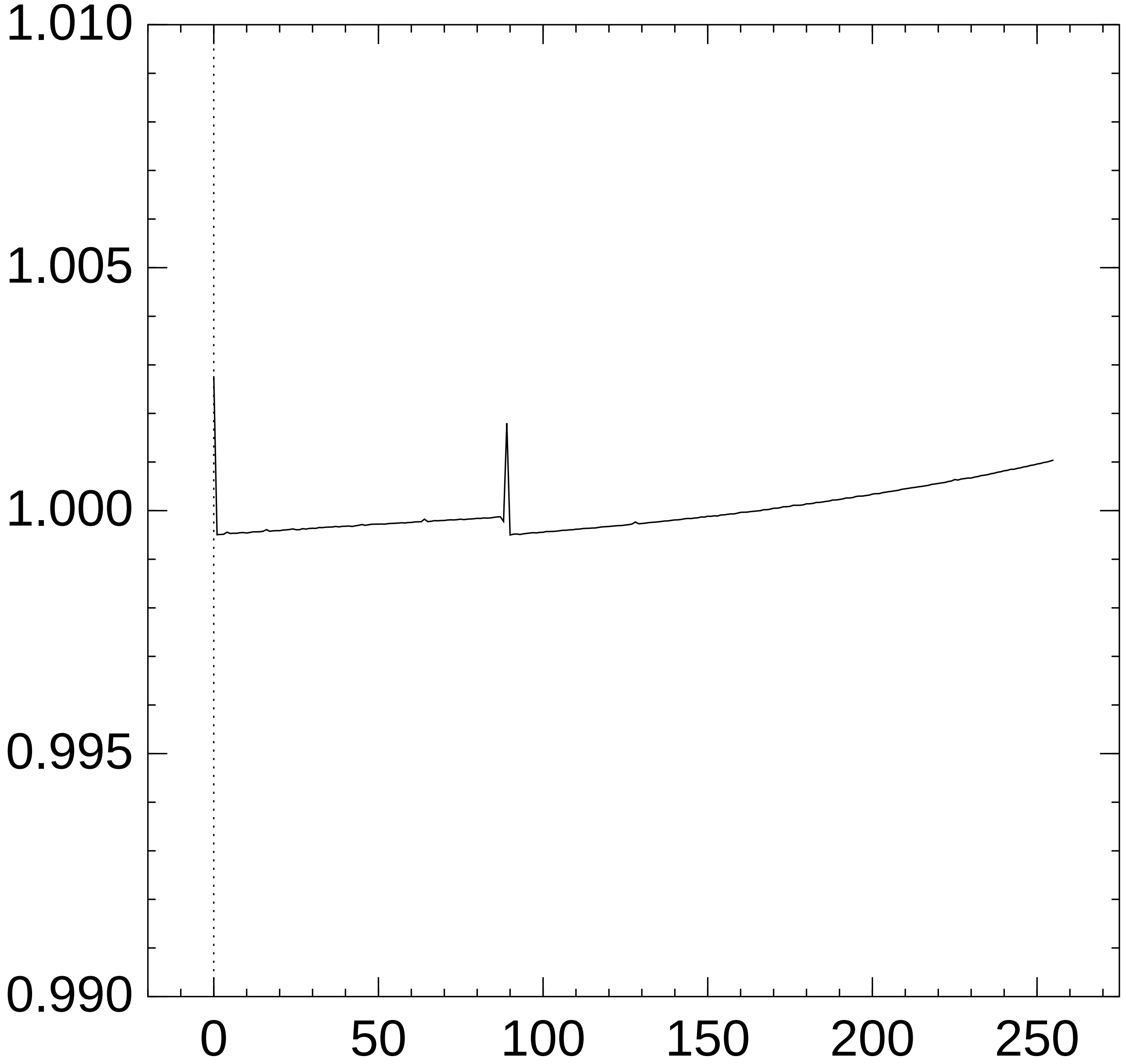
Graph of $256\,\Pr[z_{87} = x]$:



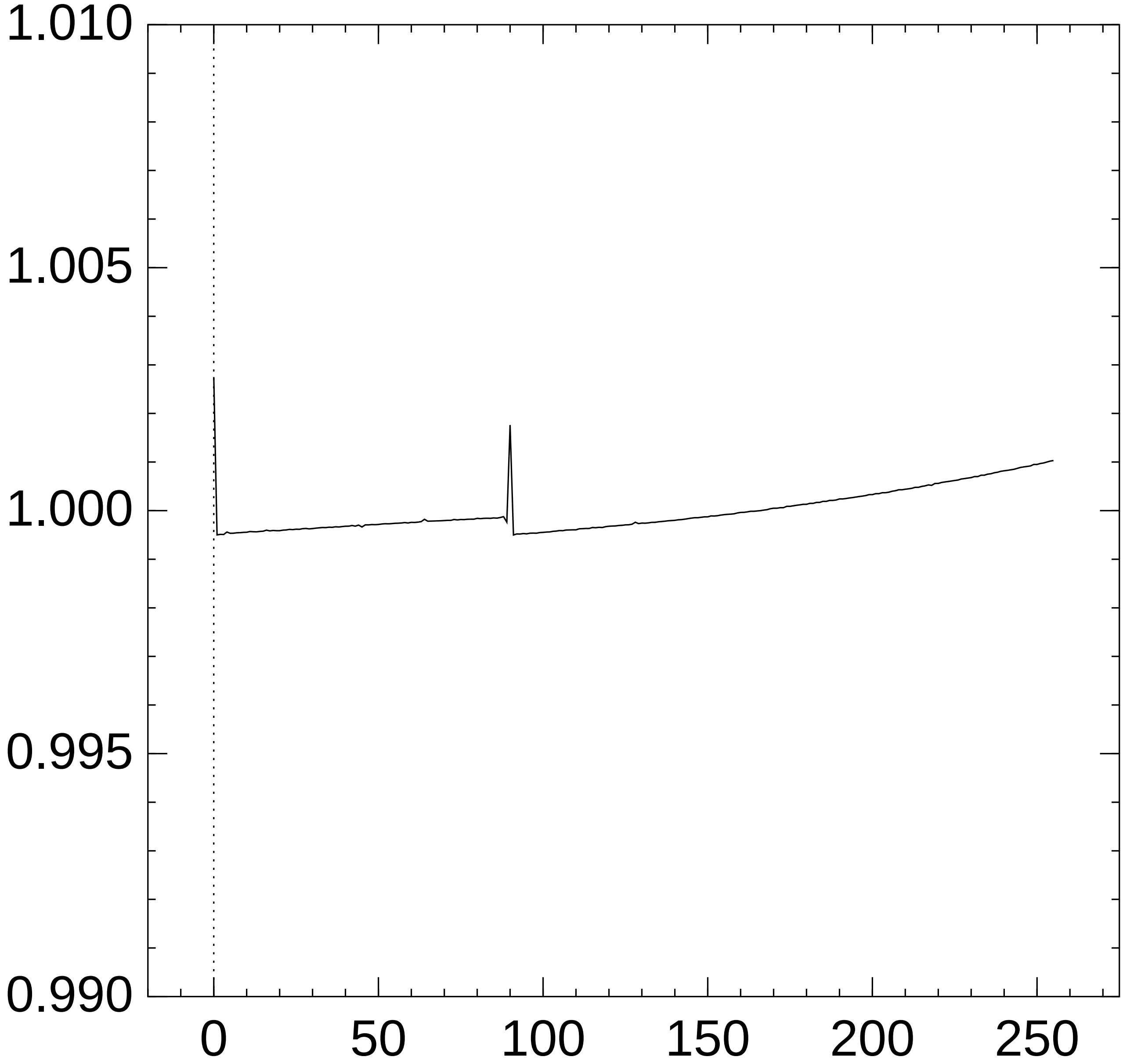
Graph of $256\,\Pr[z_{88} = x]$:



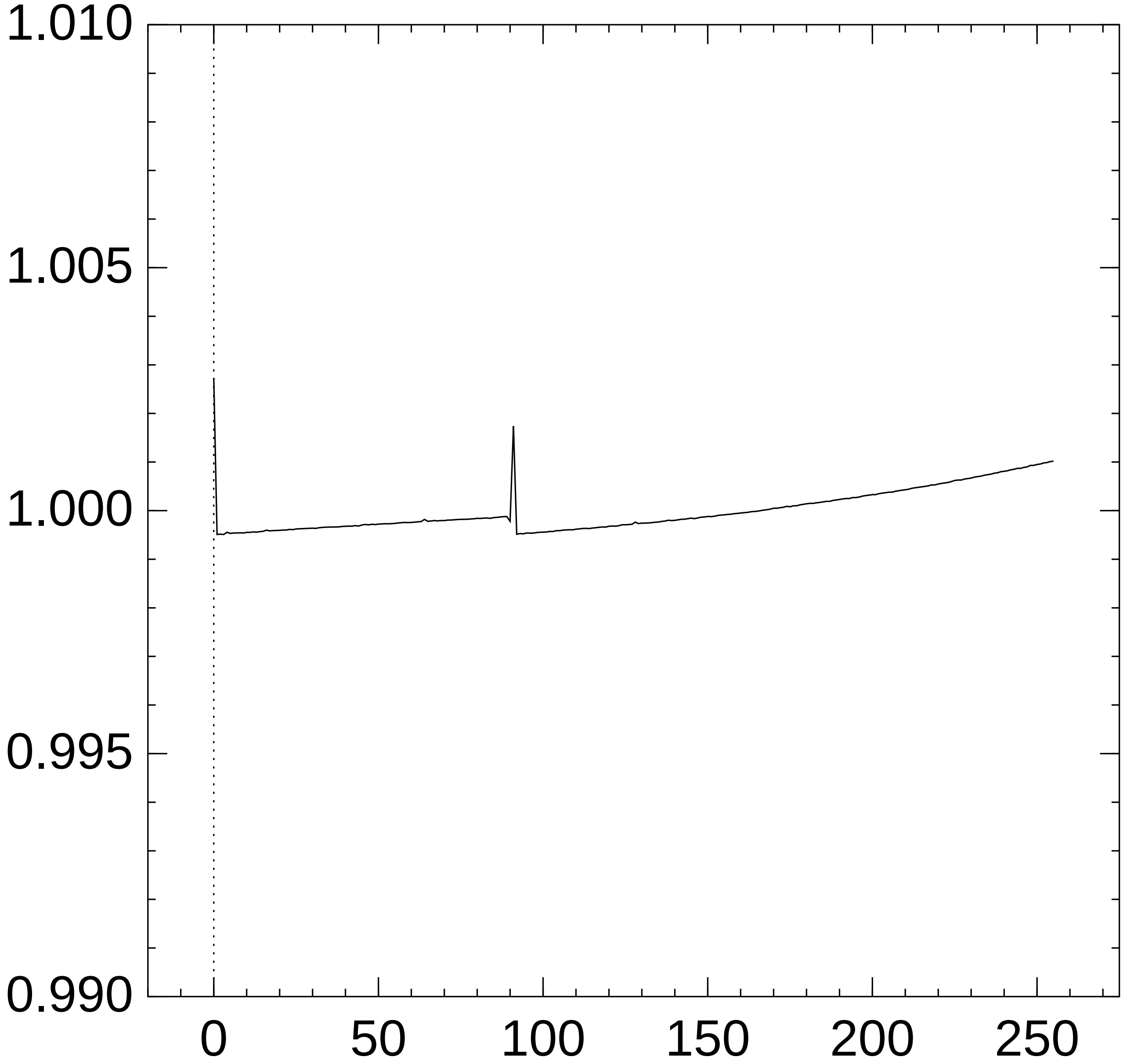
Graph of $256\,\Pr[z_{89} = x]$:



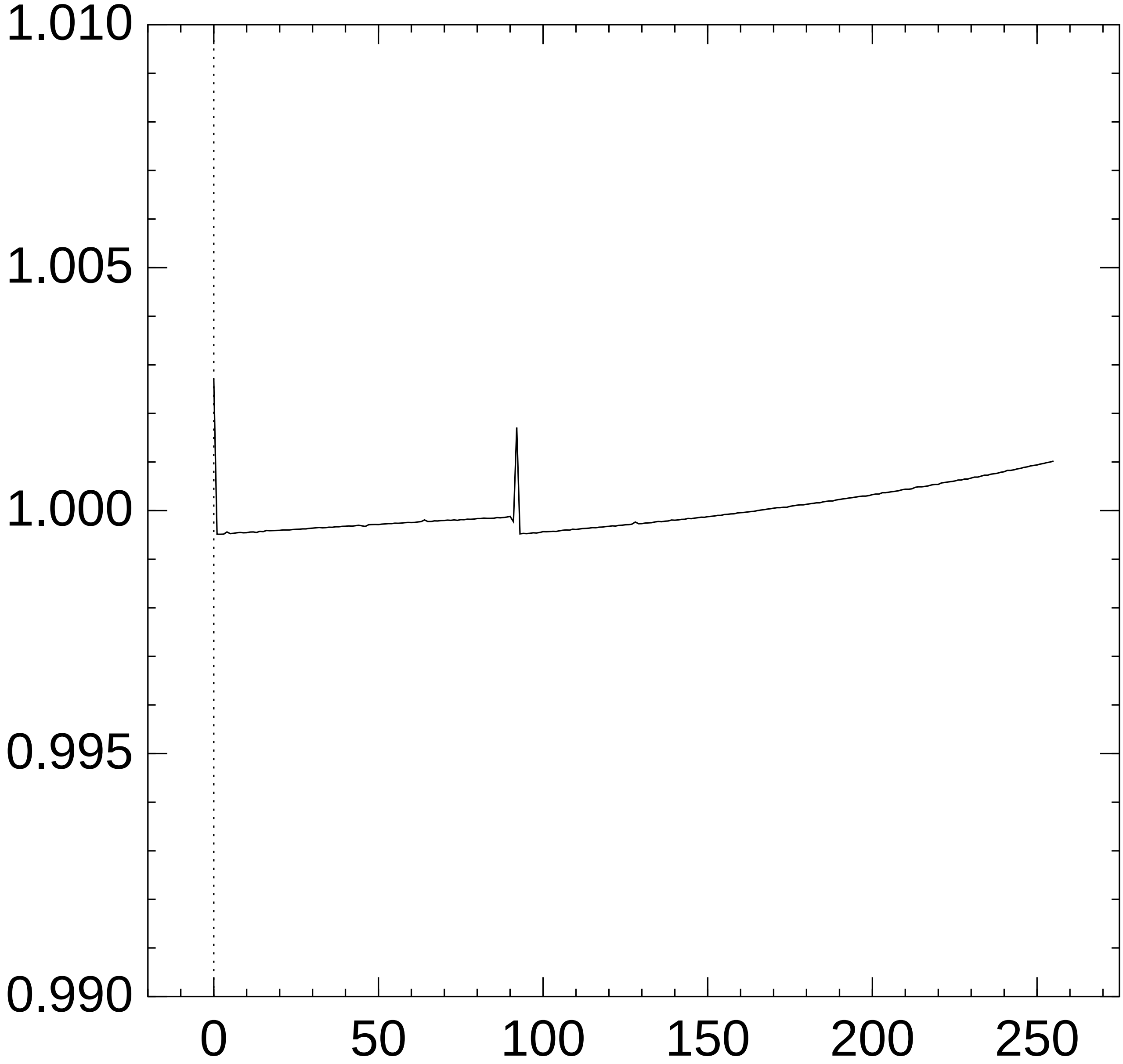
Graph of $256\,\Pr[z_{90} = x]$:



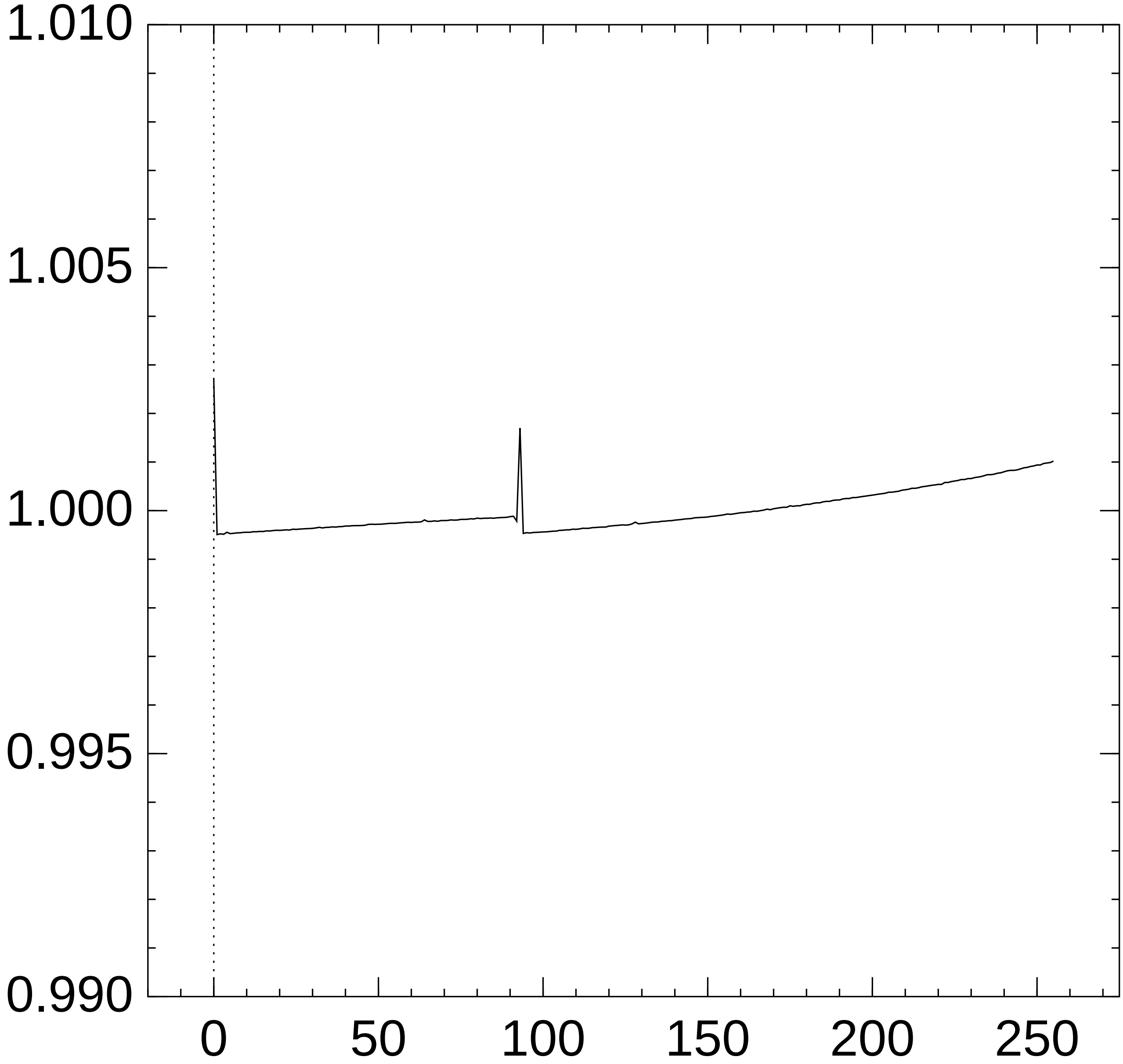
Graph of $256\,\Pr[z_{91} = x]$:



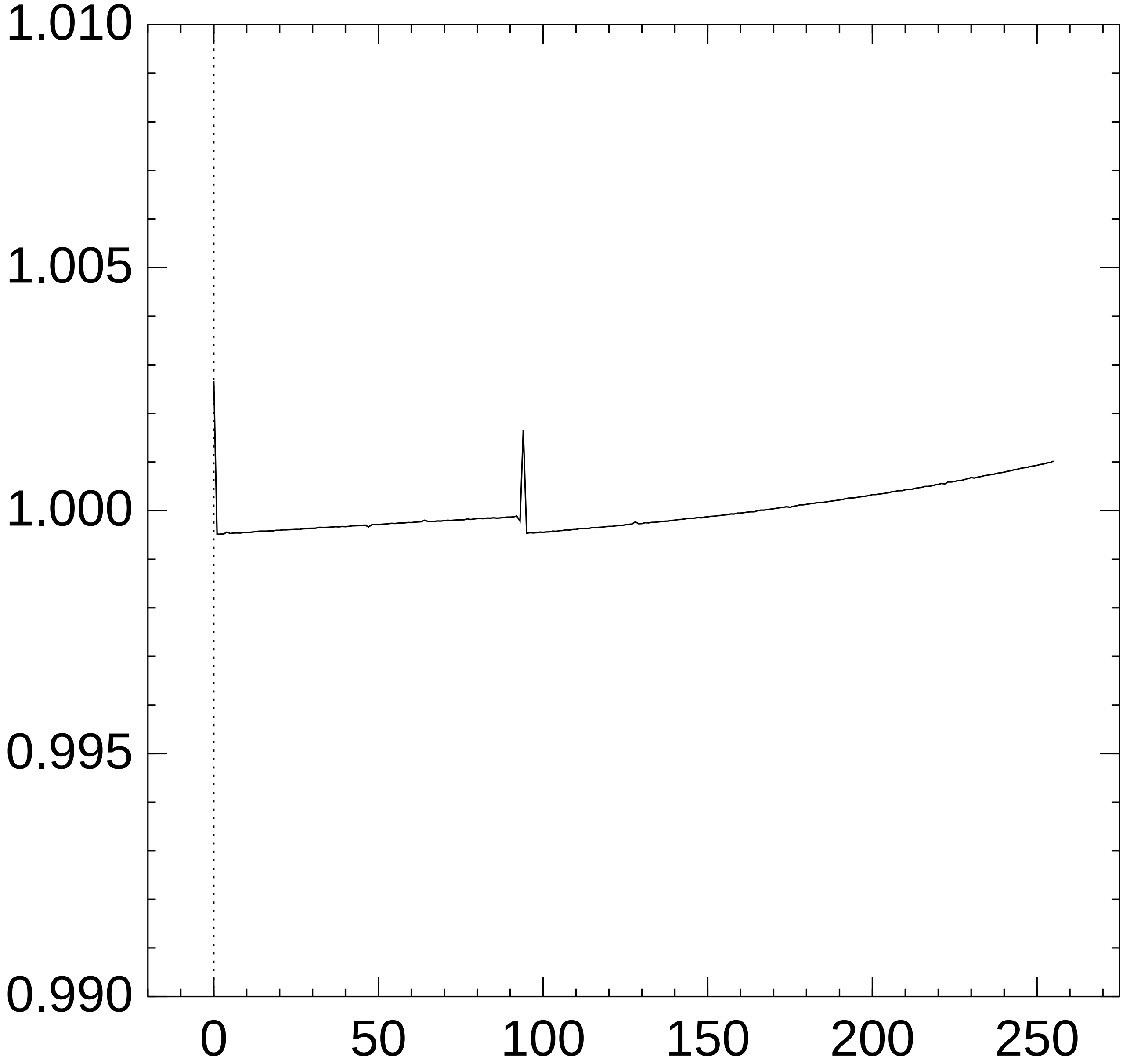
Graph of $256\,\Pr[z_{92} = x]$:



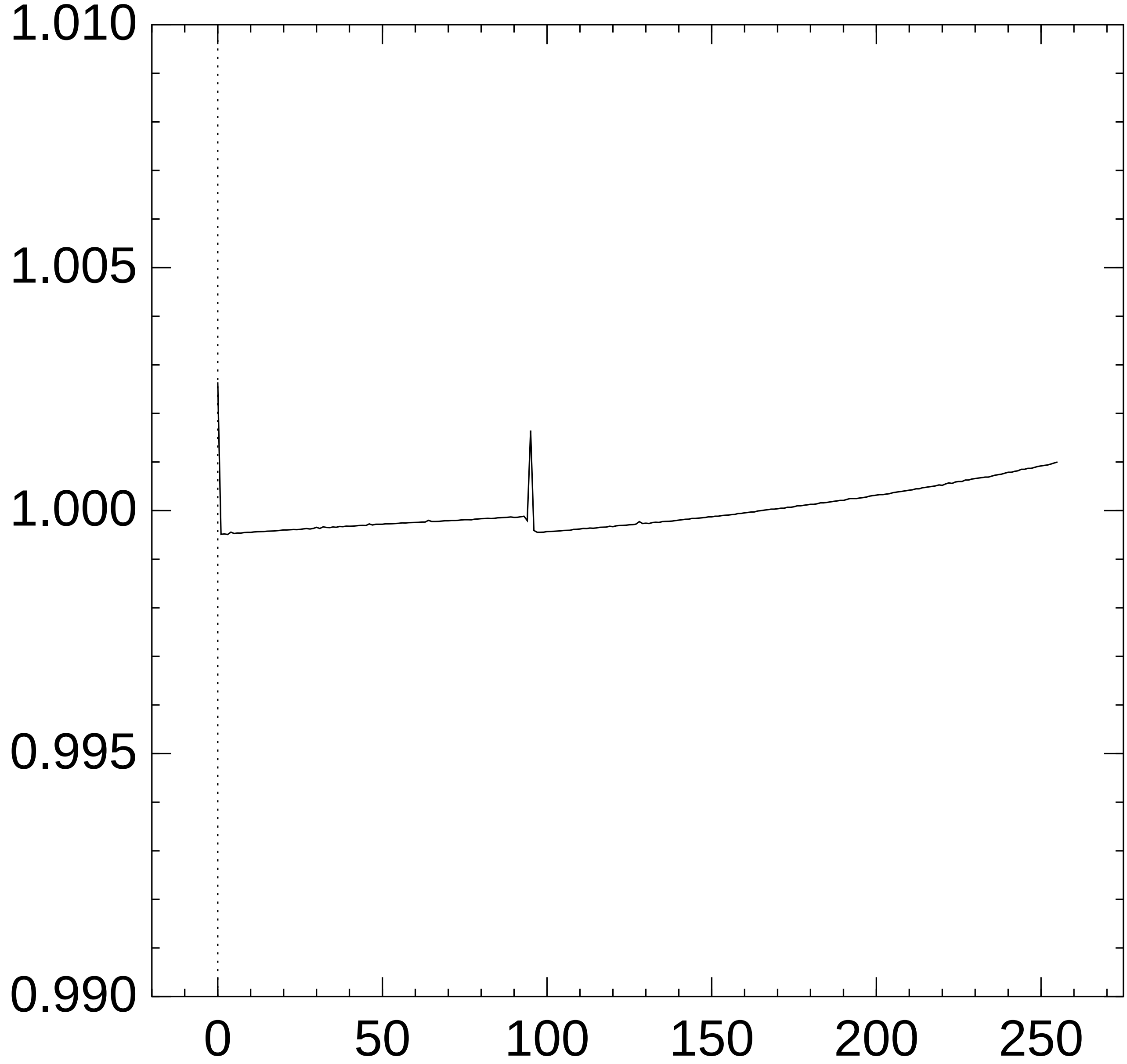
Graph of $256 \Pr[z_{93} = x]$:



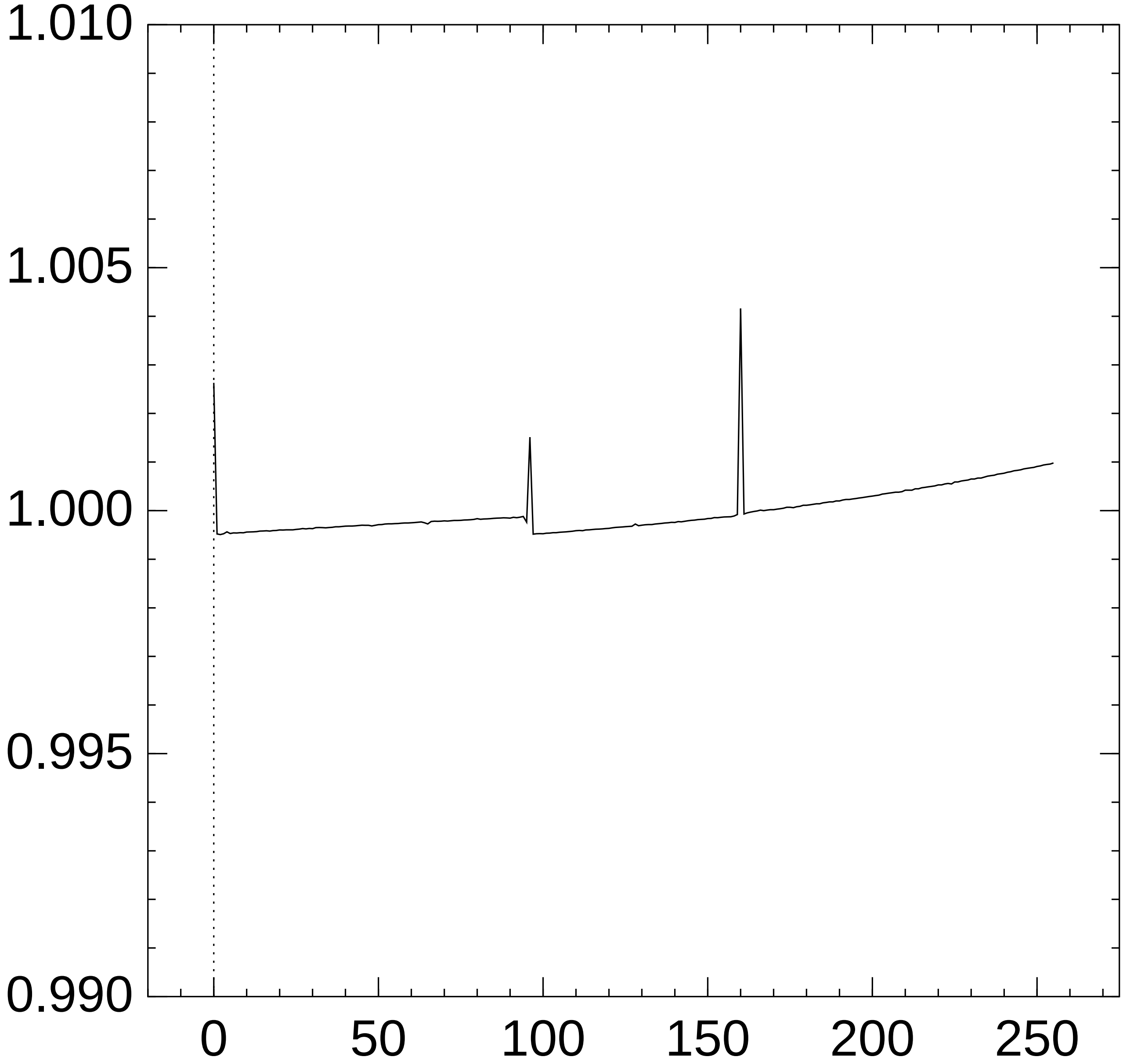
Graph of $256\,\Pr[z_{94} = x]$:



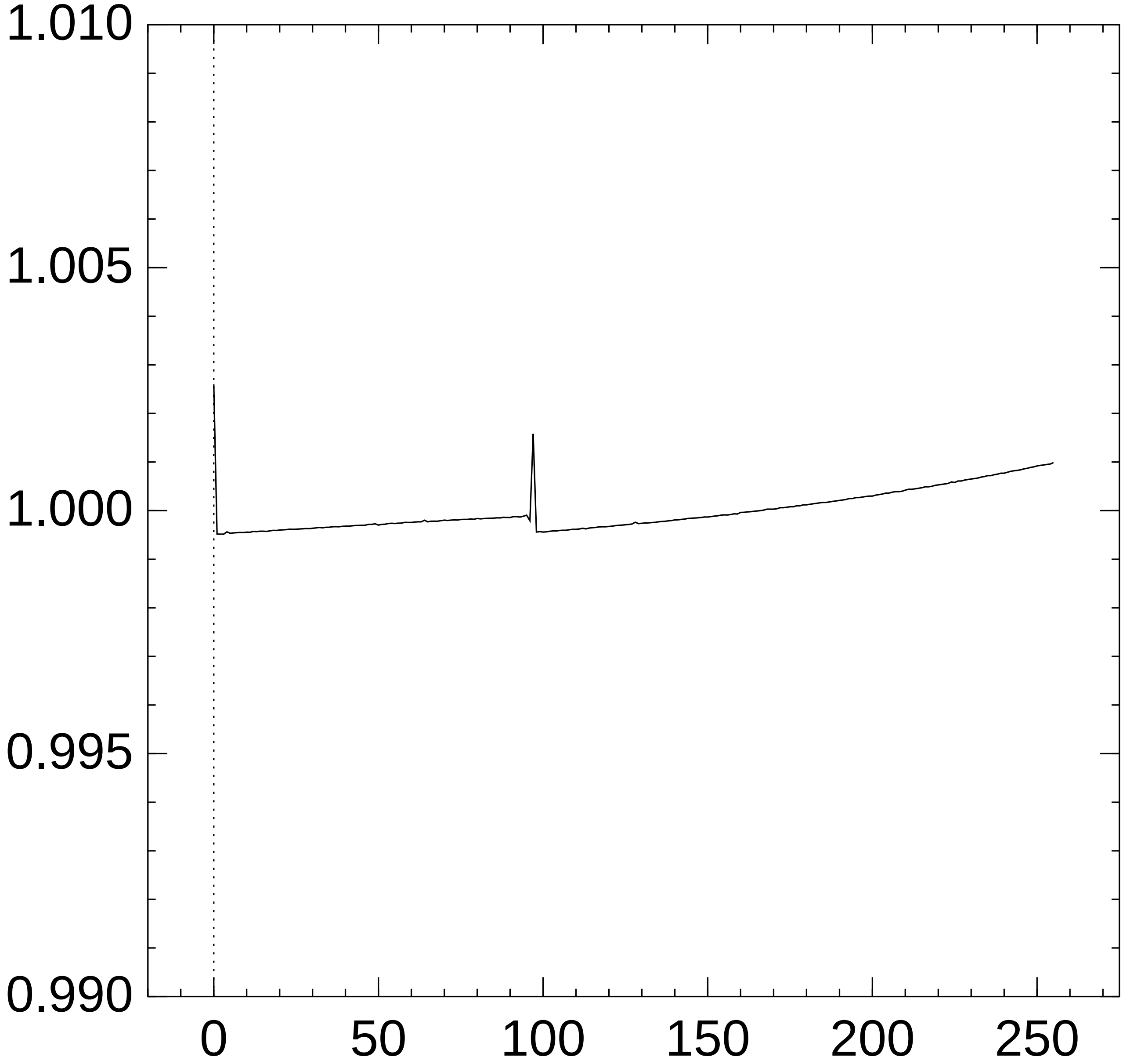
Graph of $256\,\Pr[z_{95} = x]$:



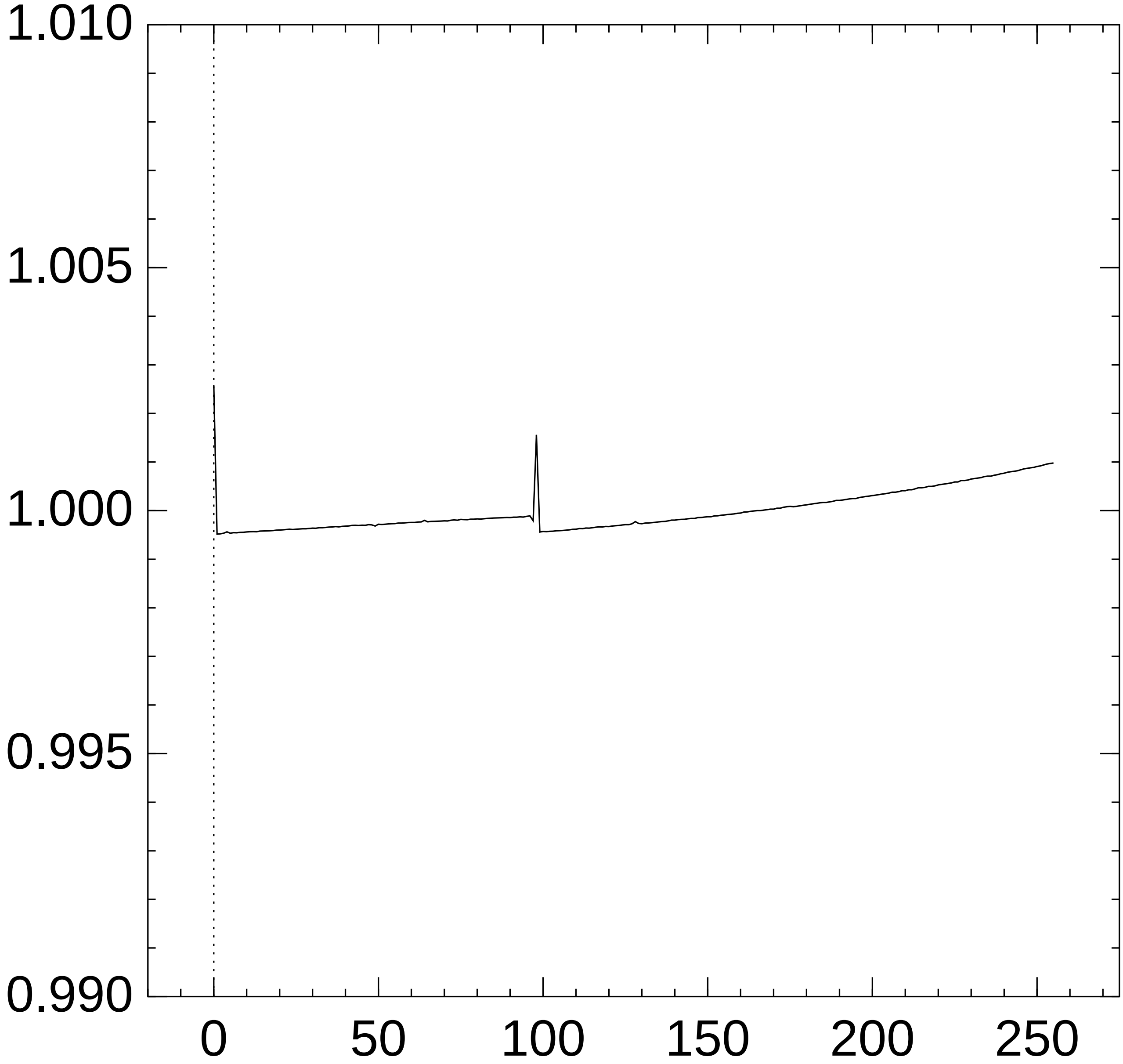
Graph of $256\,\Pr[z_{96} = x]$:



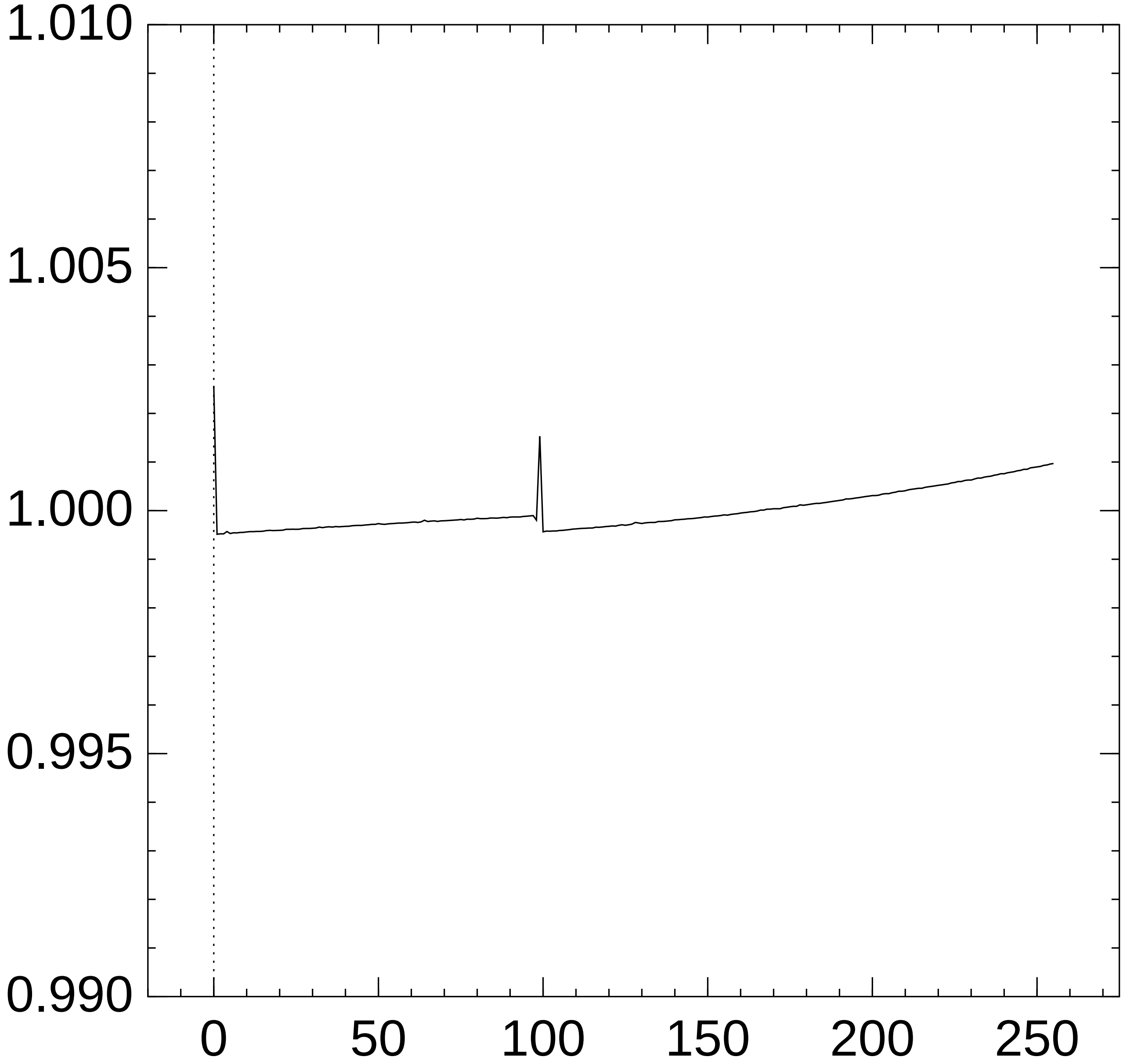
Graph of $256\,\Pr[z_{97} = x]$:



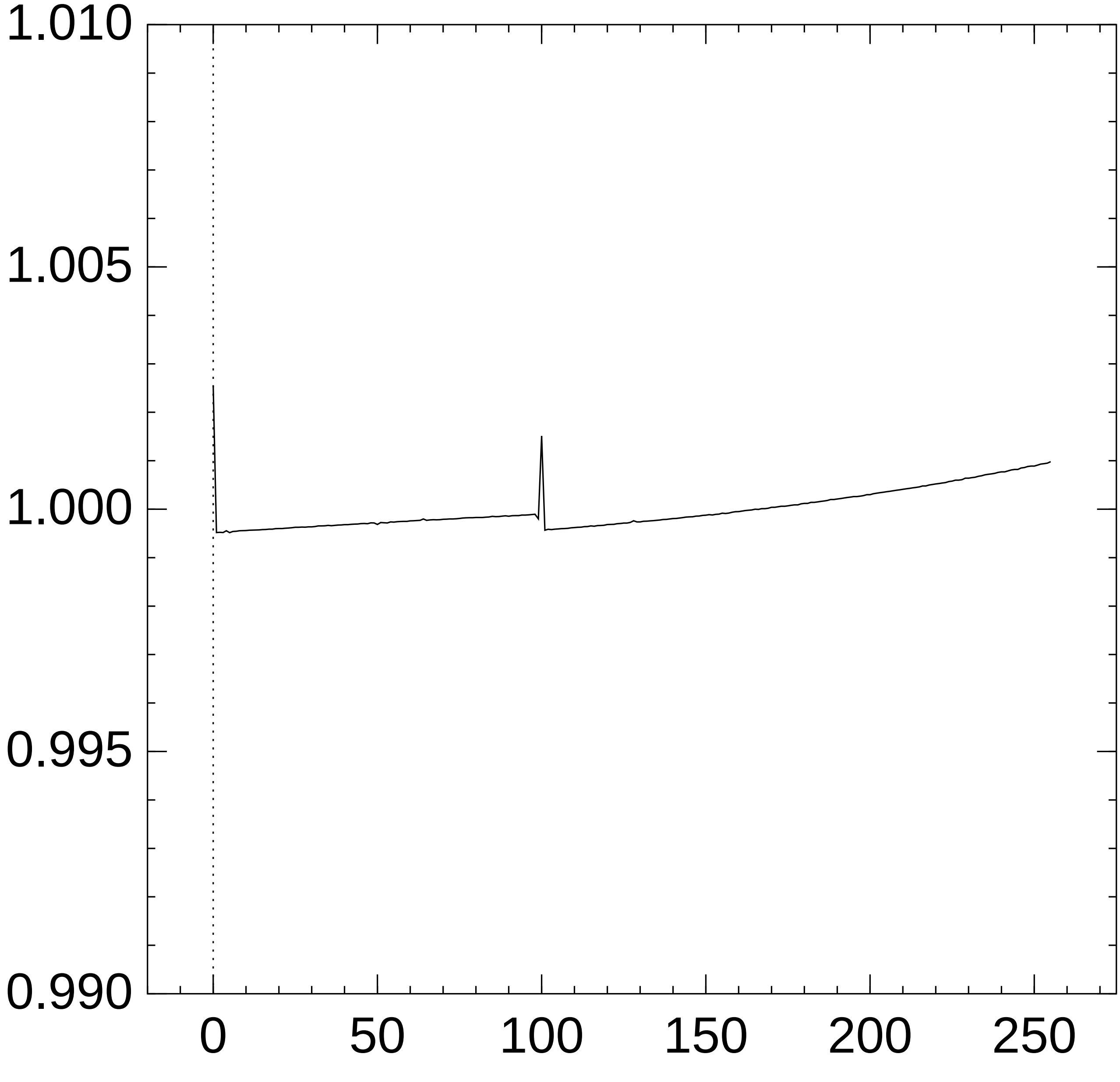
Graph of $256\,\mathrm{Pr}[z_{98} = x]$:



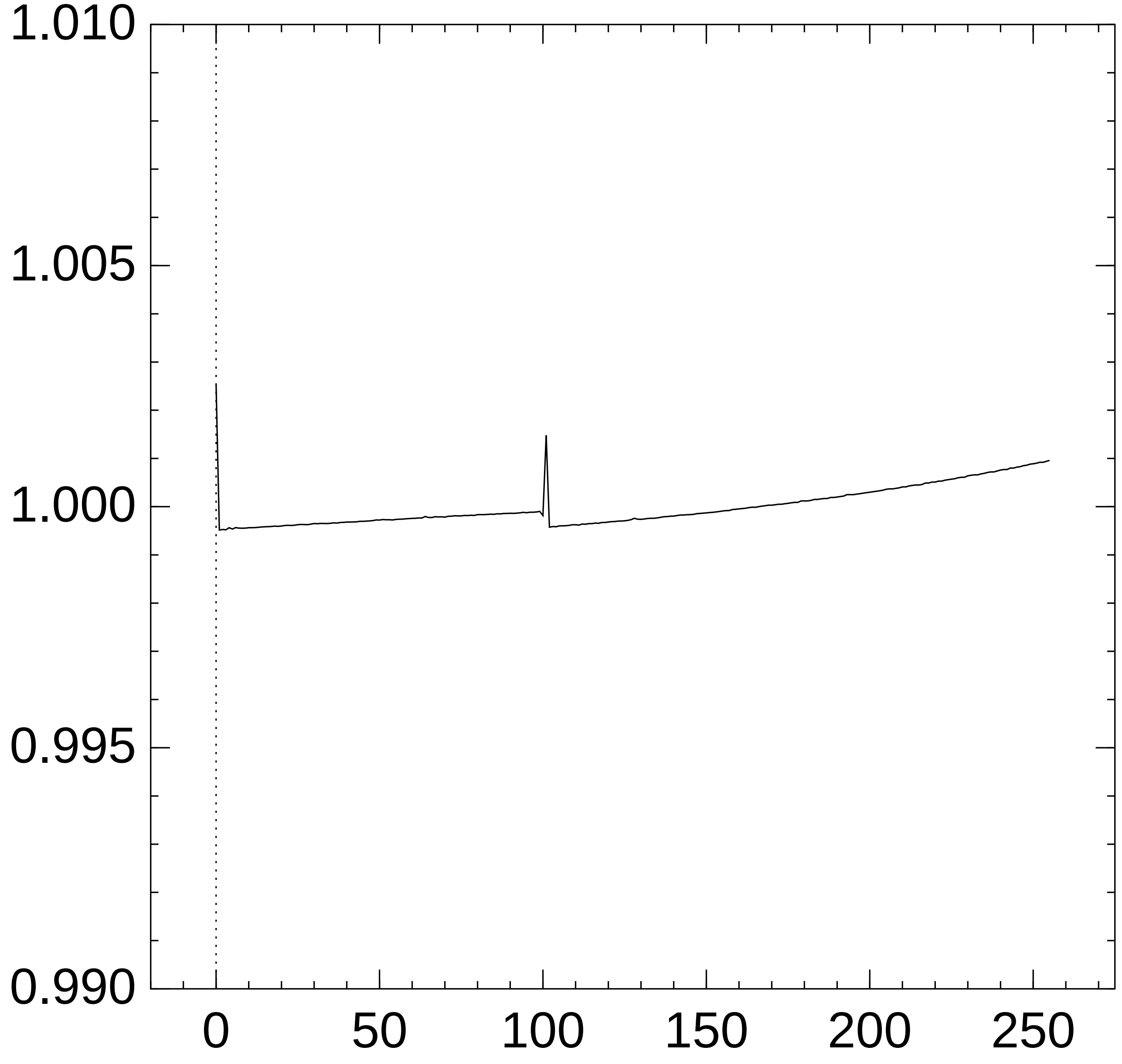
Graph of $256\,\Pr[z_{99} = x]$:



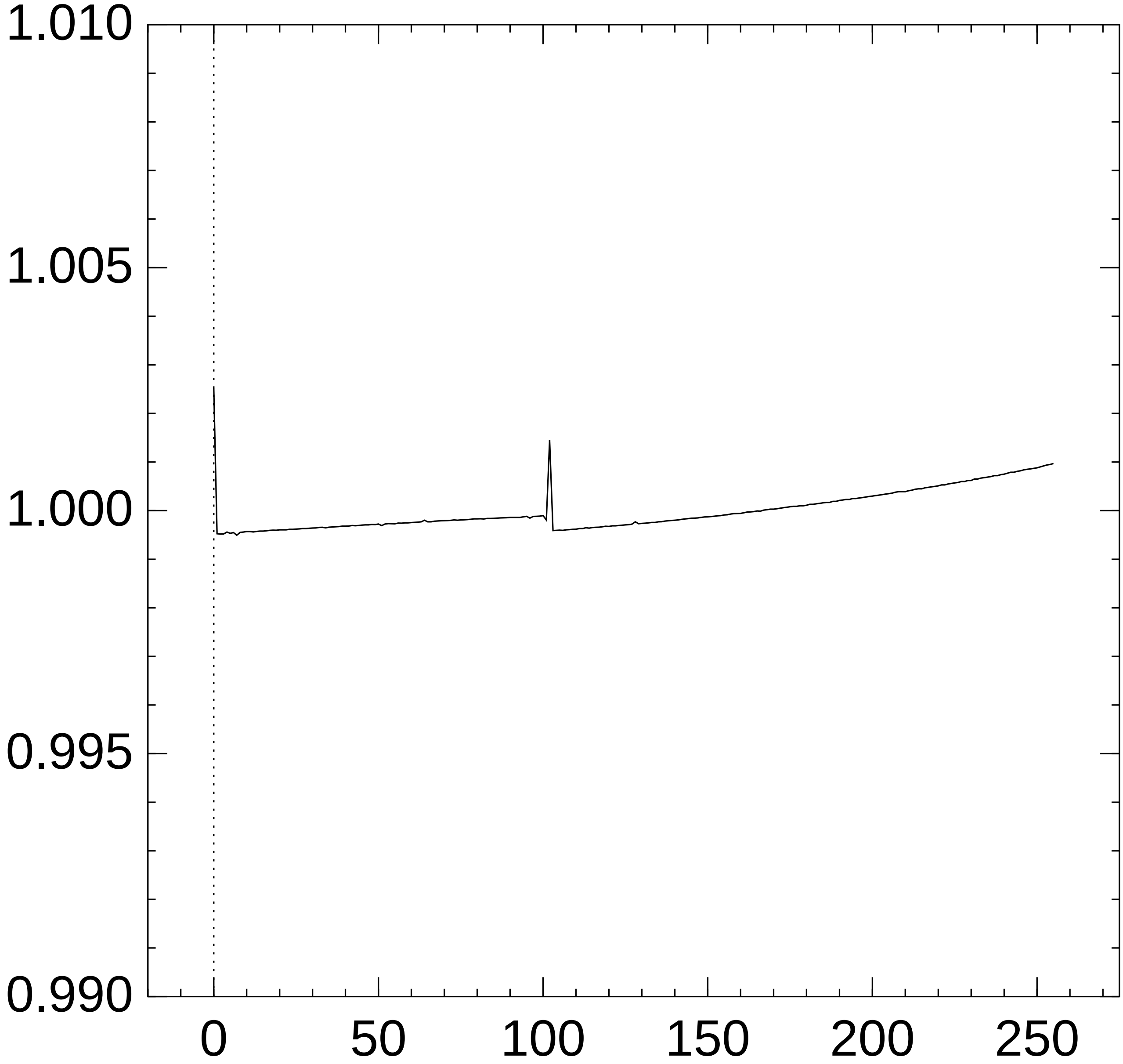
Graph of $256\,\Pr[z_{100} = x]$:



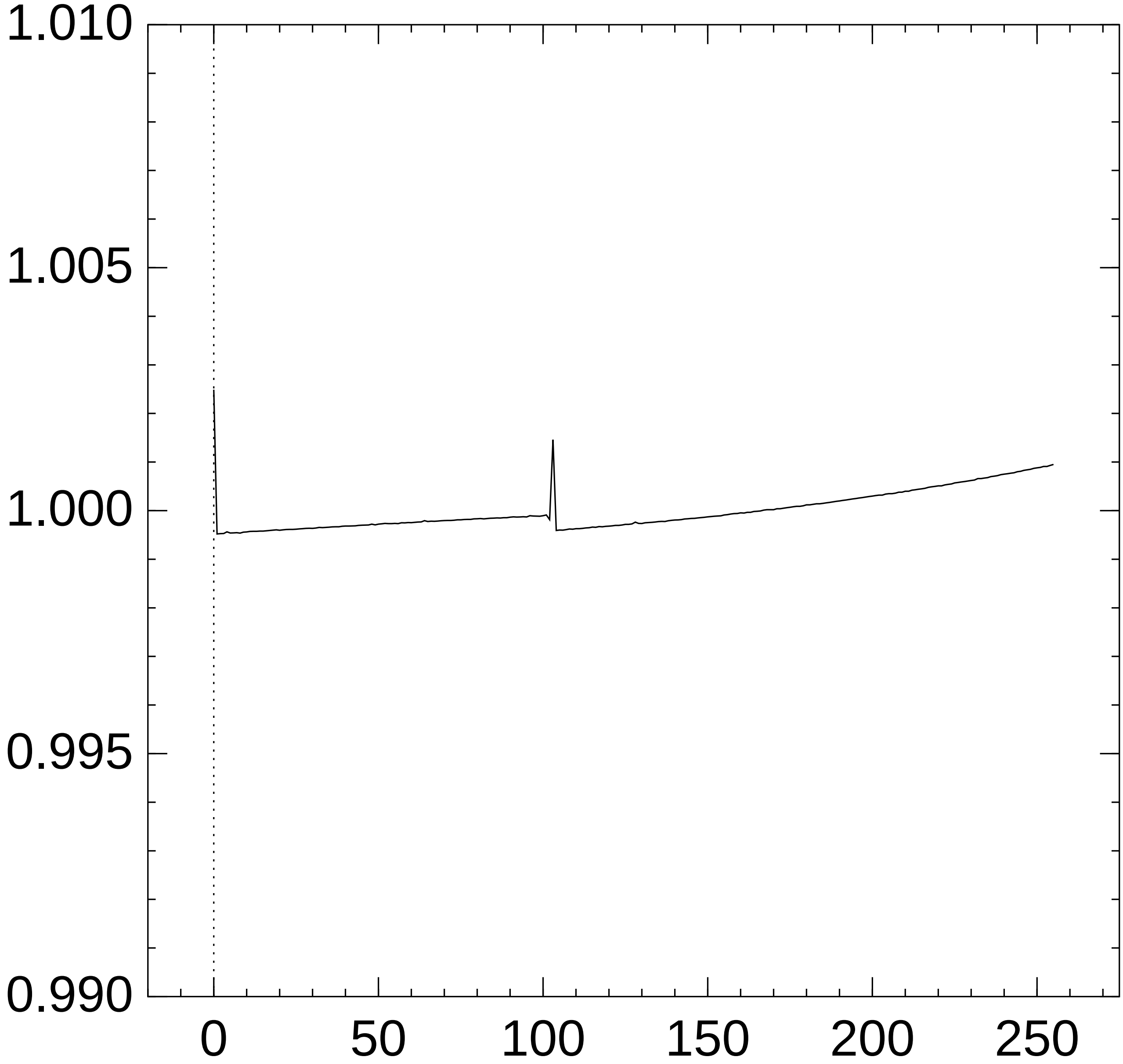
Graph of $256\,\Pr[z_{101} = x]$:



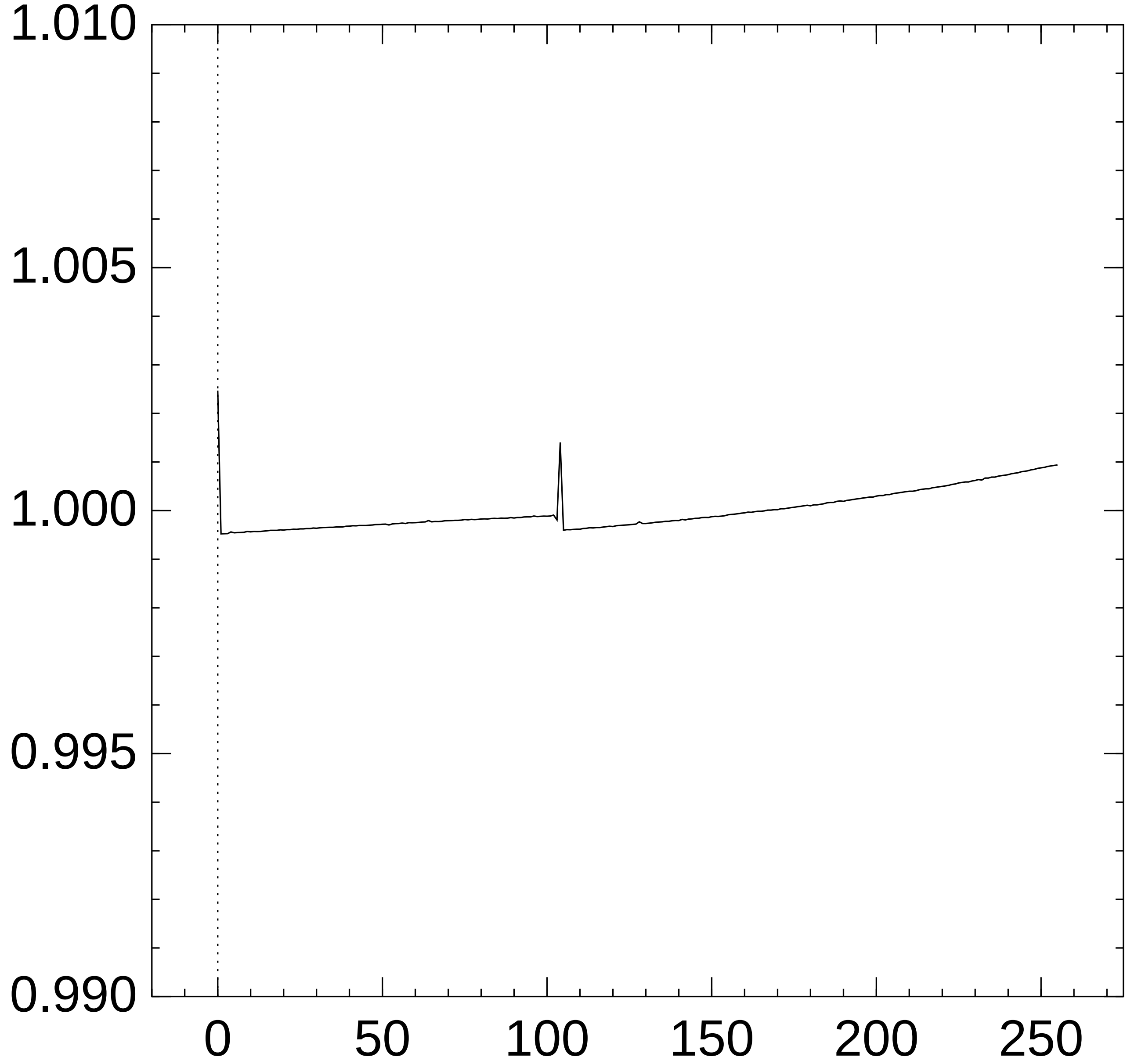
Graph of $256\,\mathrm{Pr}[z_{102} = x]$:



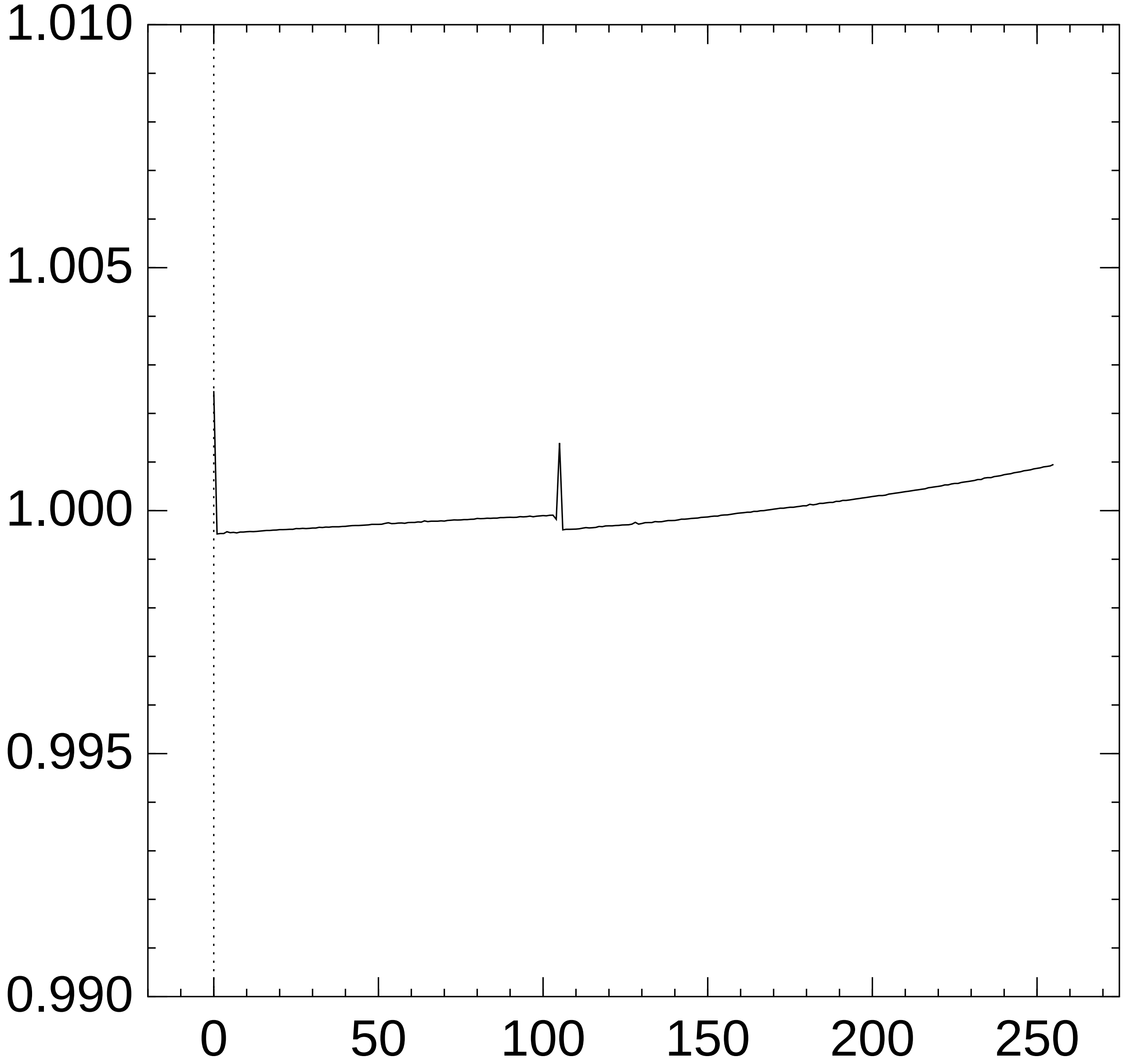
Graph of $256\,\mathrm{Pr}[z_{103} = x]$:



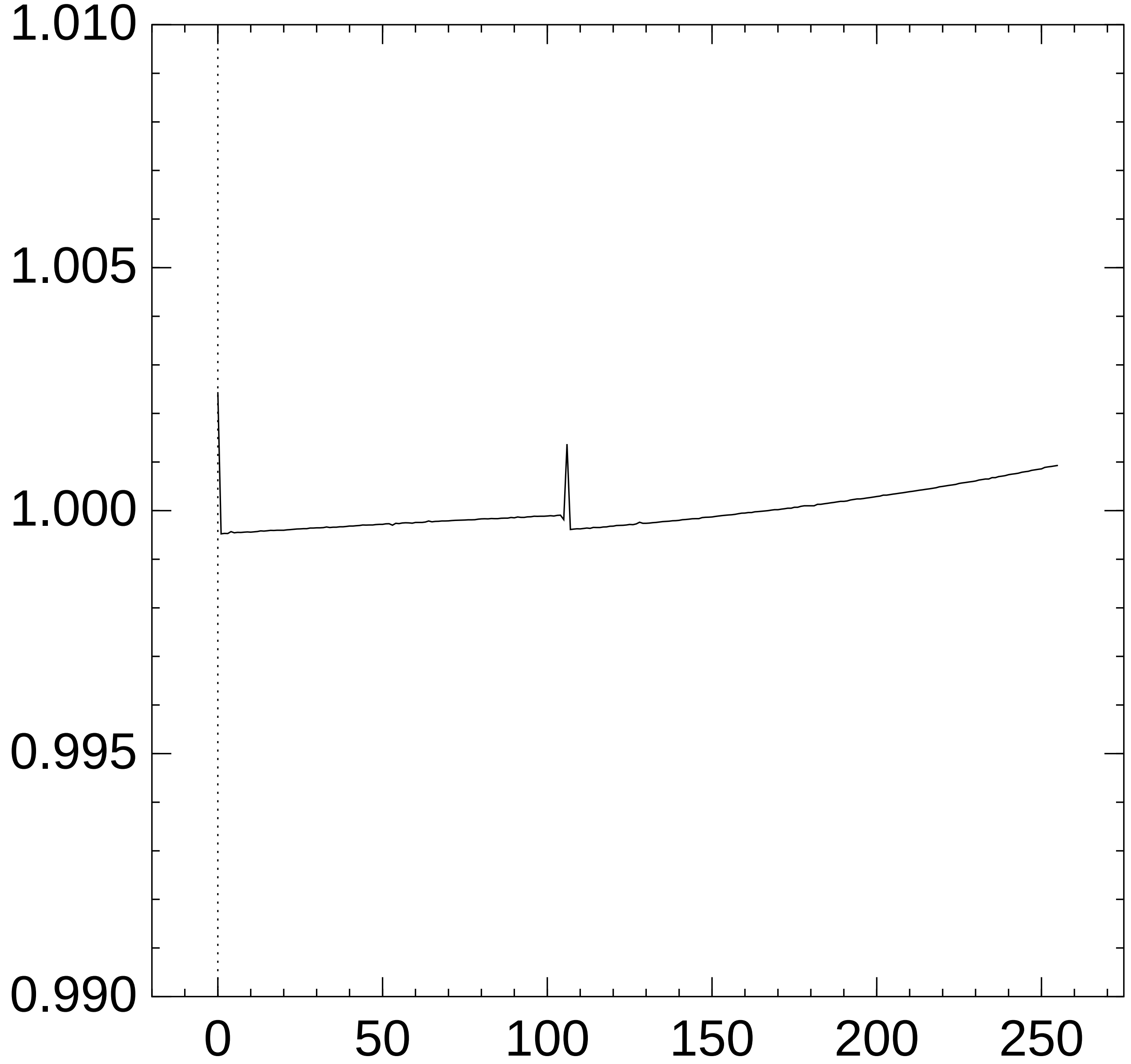
Graph of $256 \Pr[z_{104} = x]$:



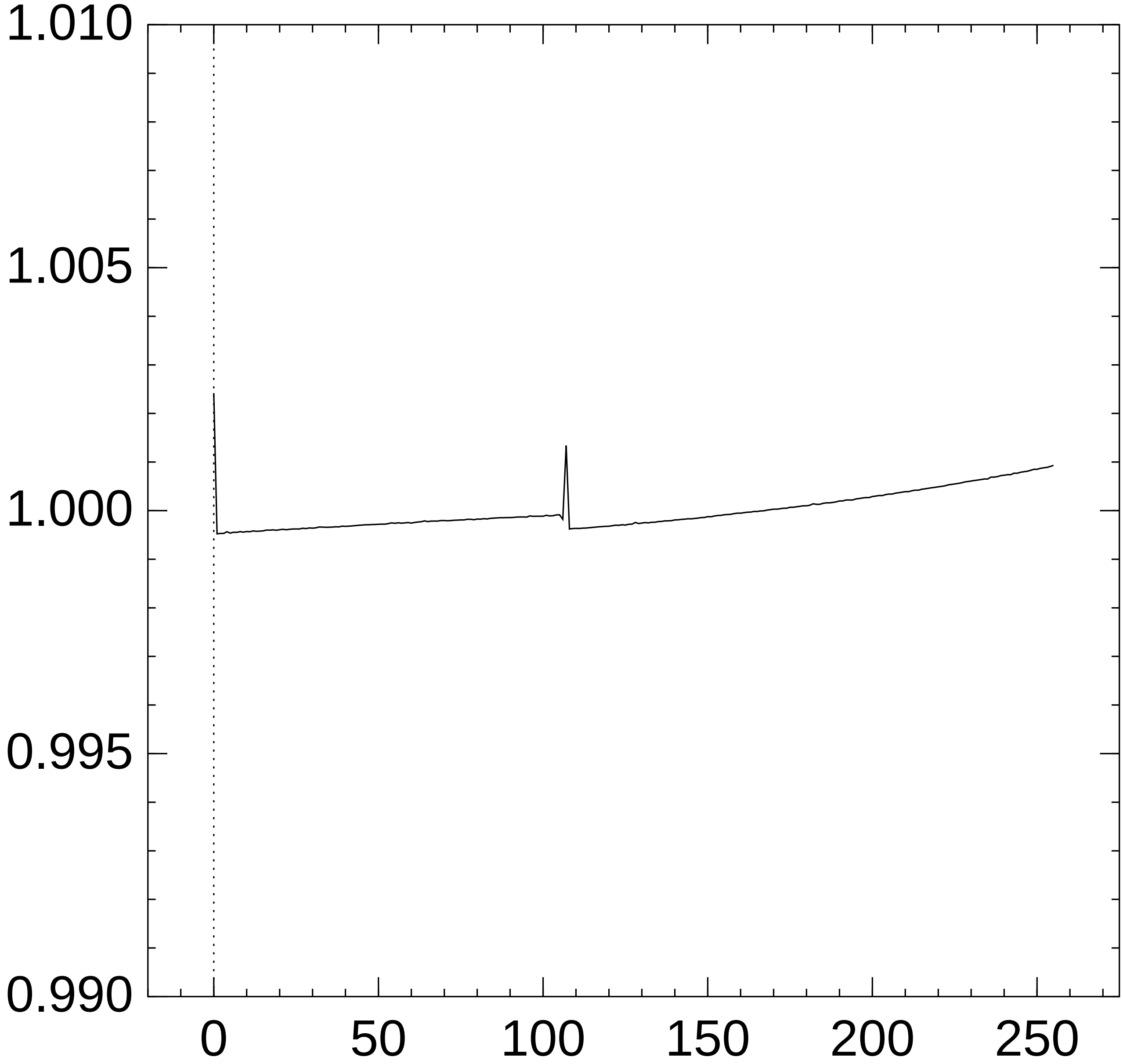
Graph of $256\,\mathrm{Pr}[z_{105} = x]$:



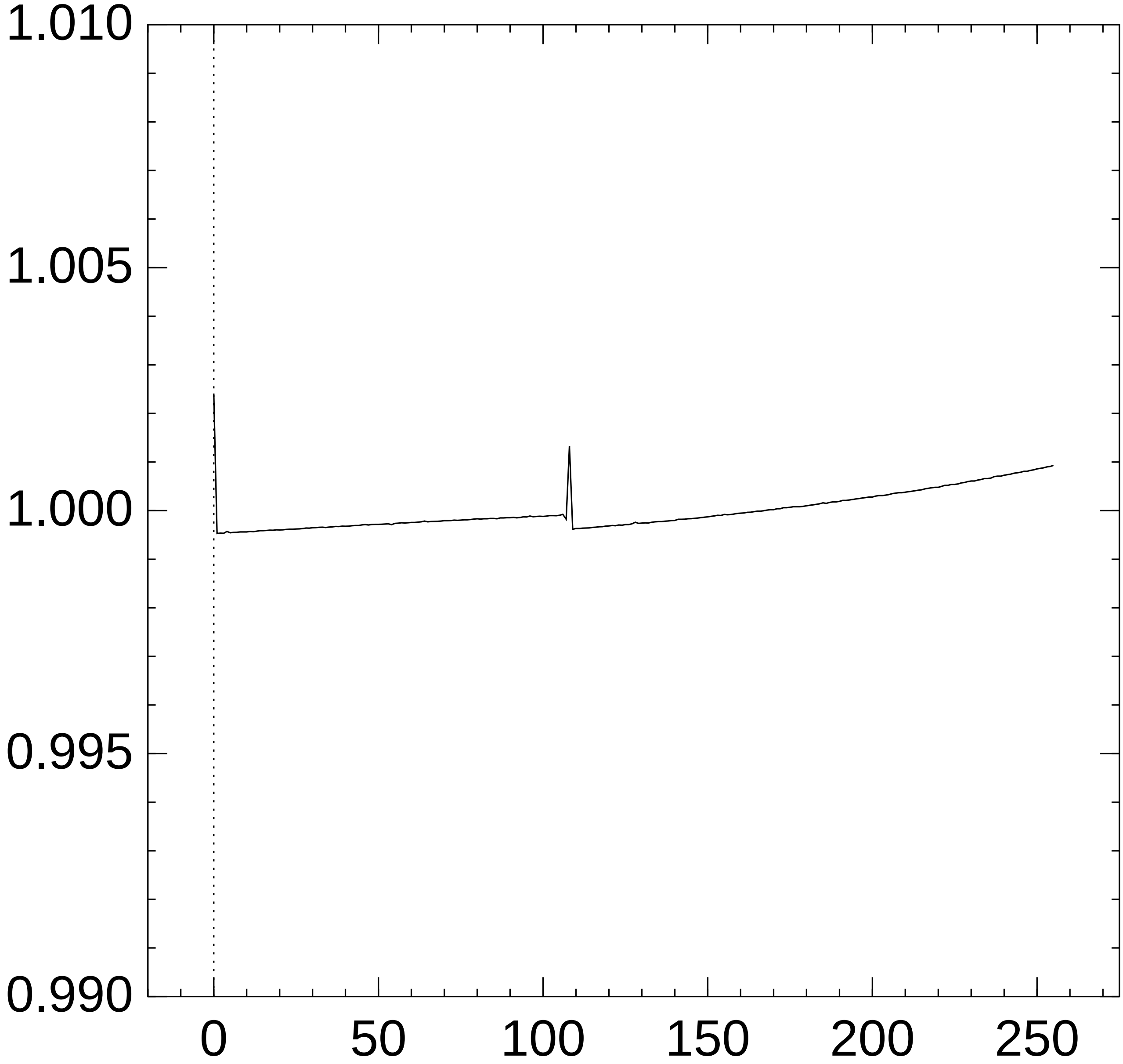
Graph of $256\,\Pr[z_{106} = x]$:



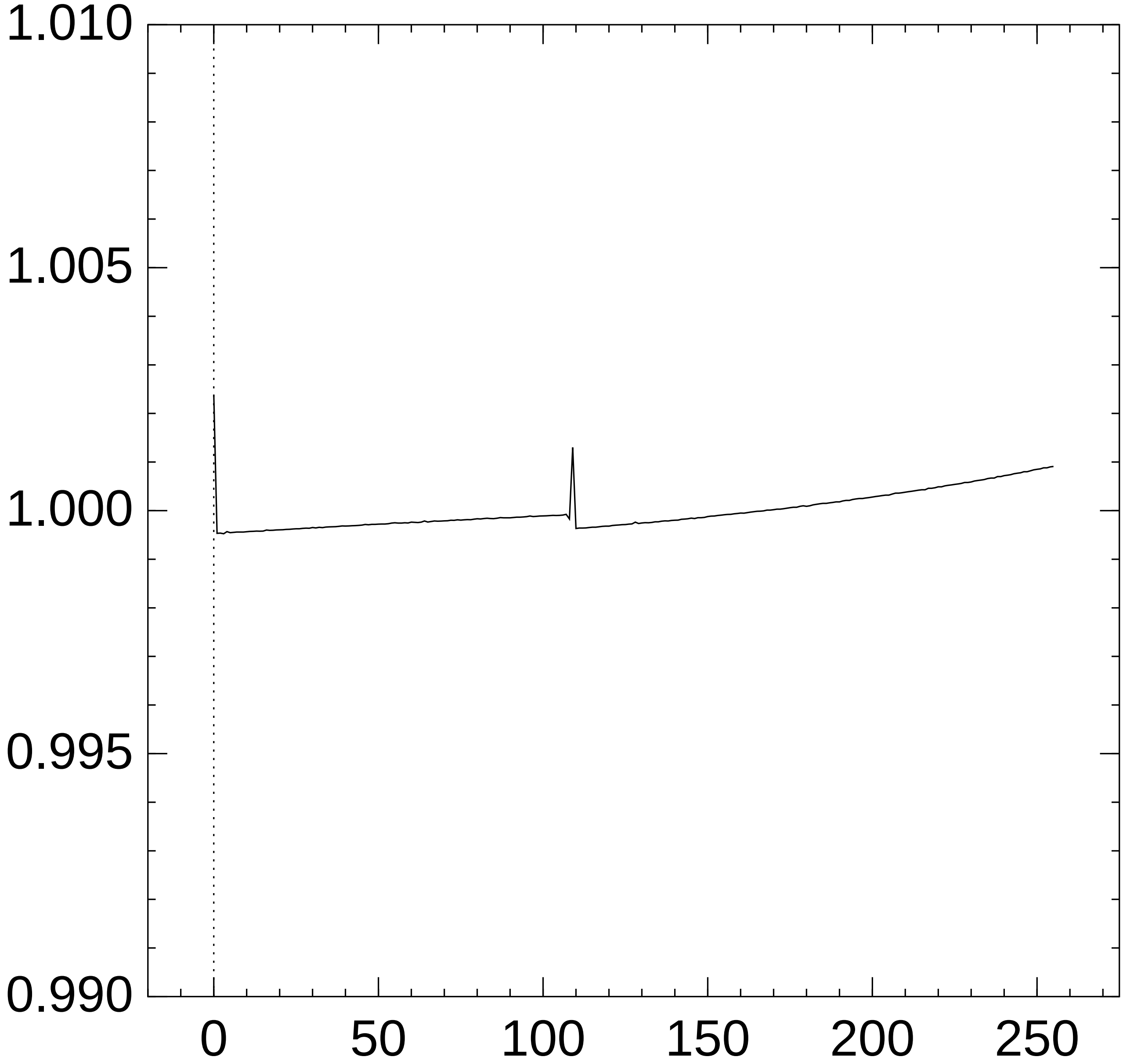
Graph of $256\,\Pr[z_{107} = x]$:



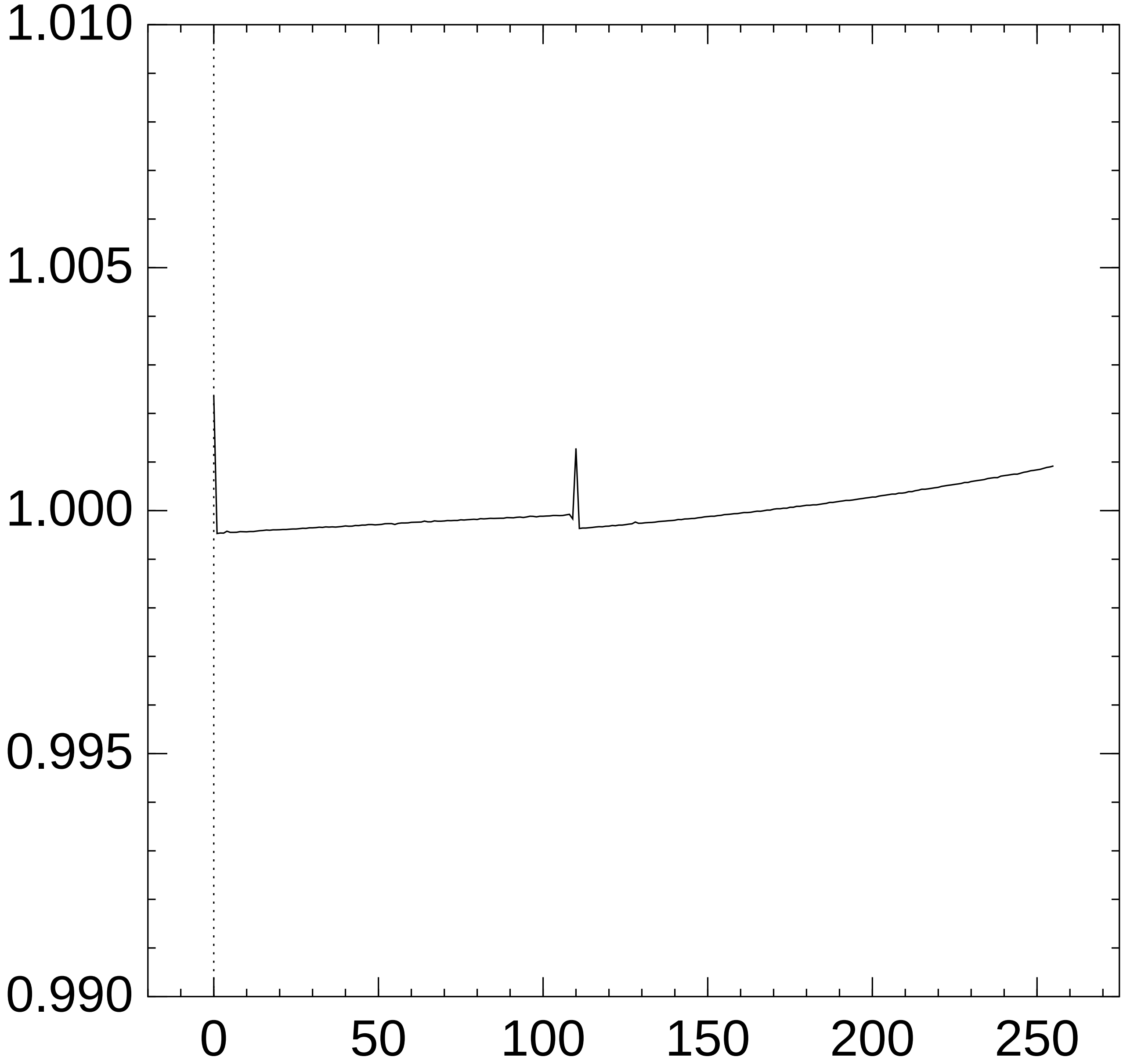
Graph of $256 \Pr[z_{108} = x]$:



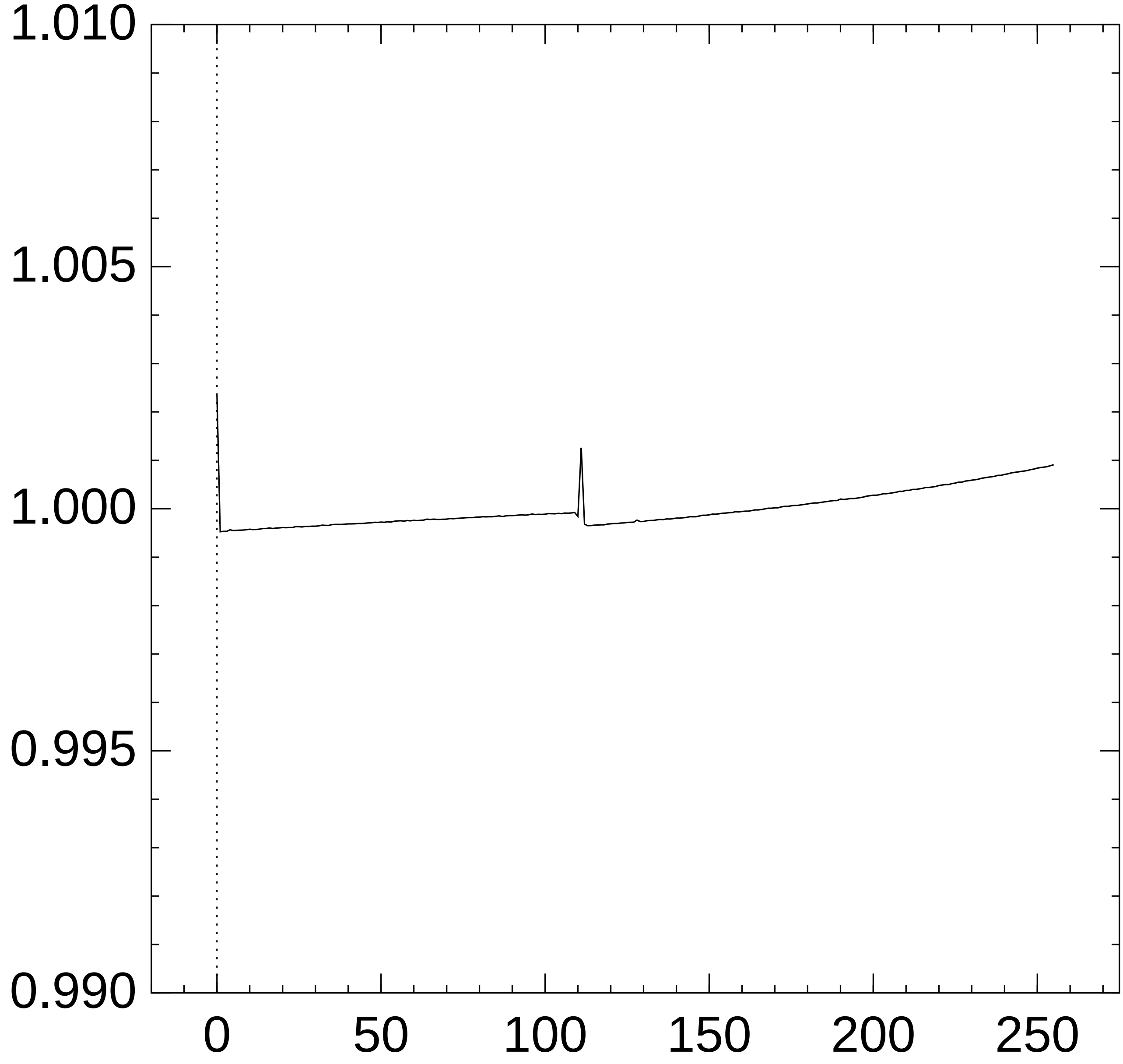
Graph of $256\,\Pr[z_{109} = x]$:



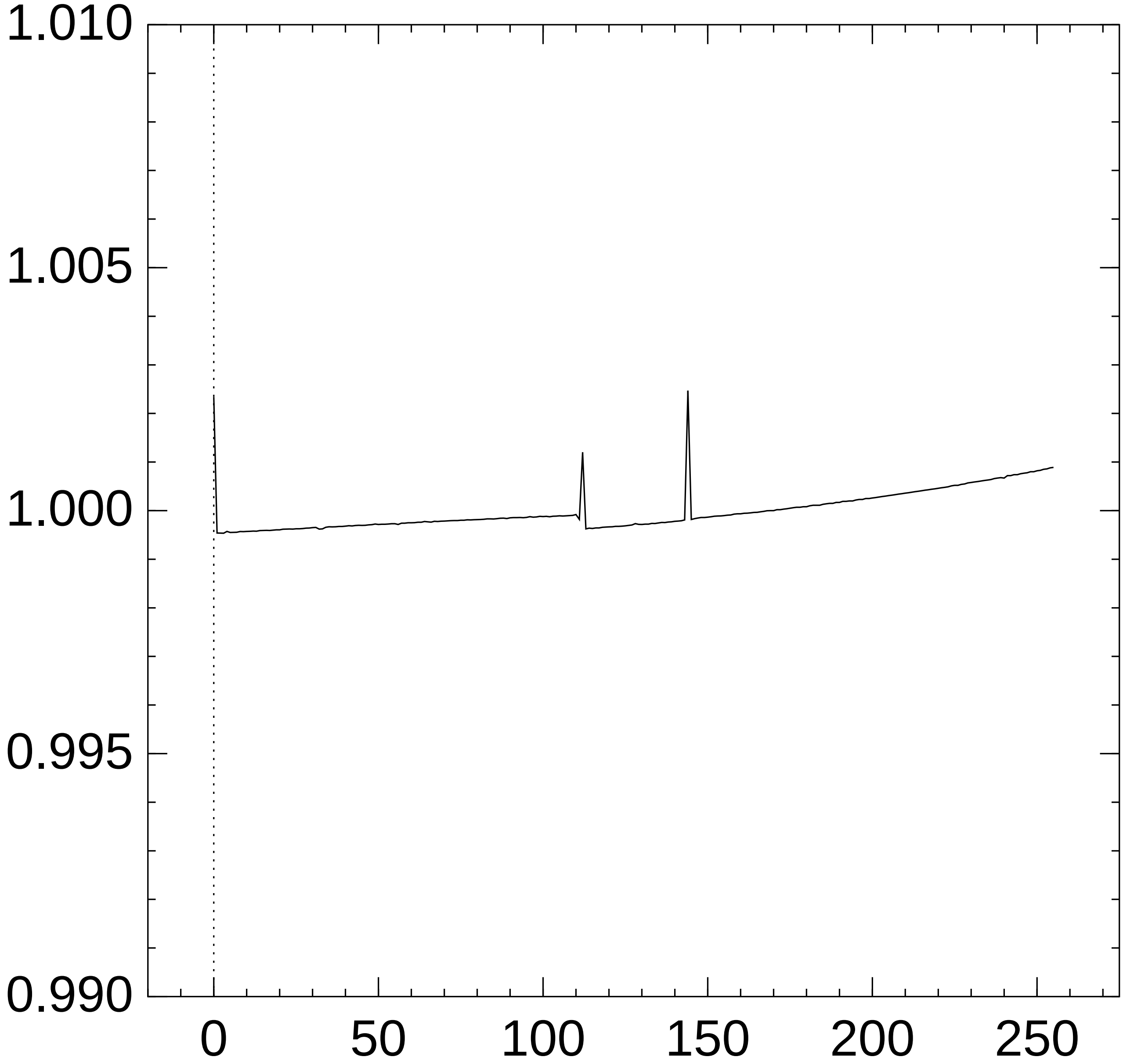
Graph of $256\,\Pr[z_{110} = x]$:



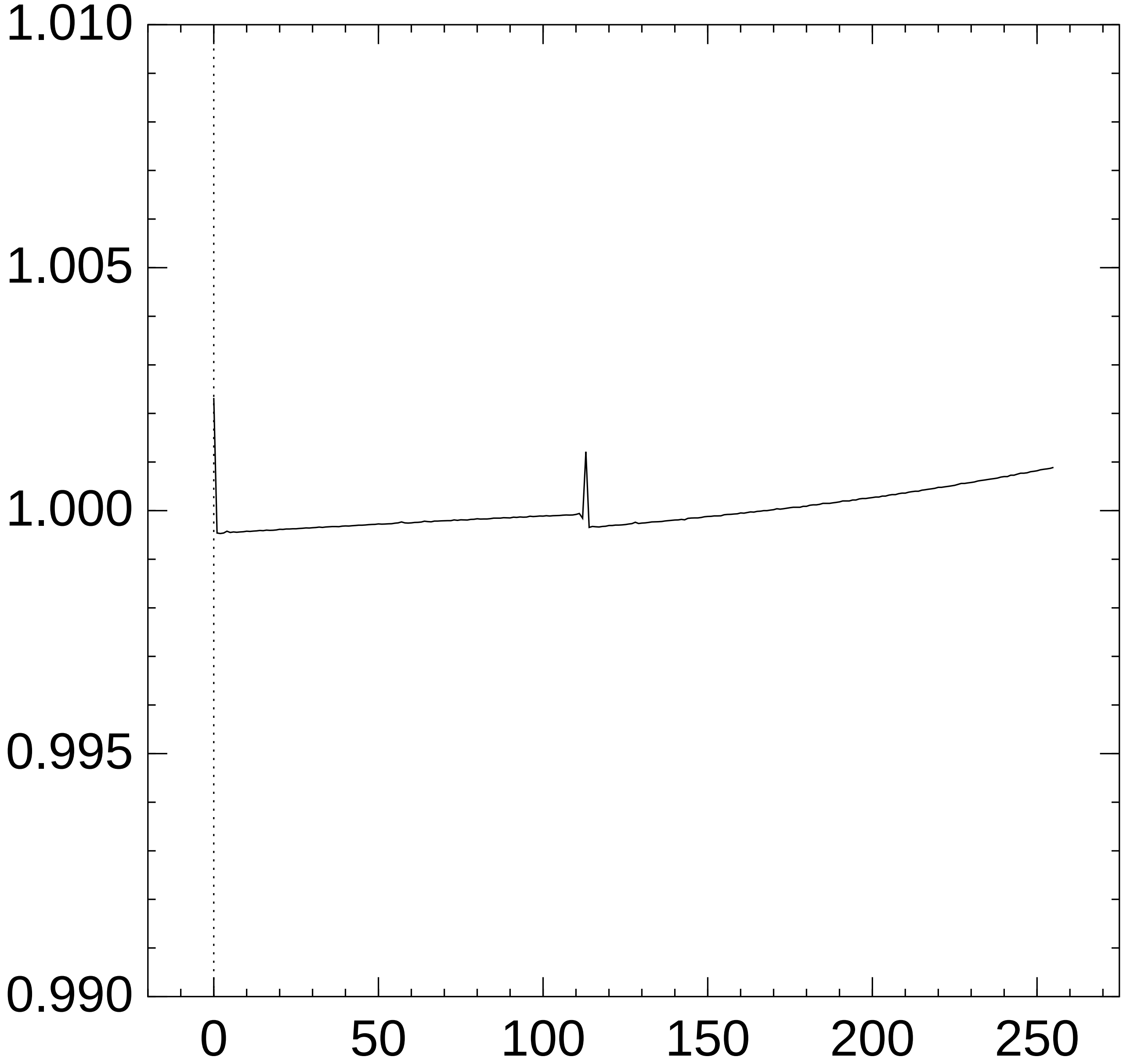
Graph of $256\,\Pr[z_{111} = x]$:



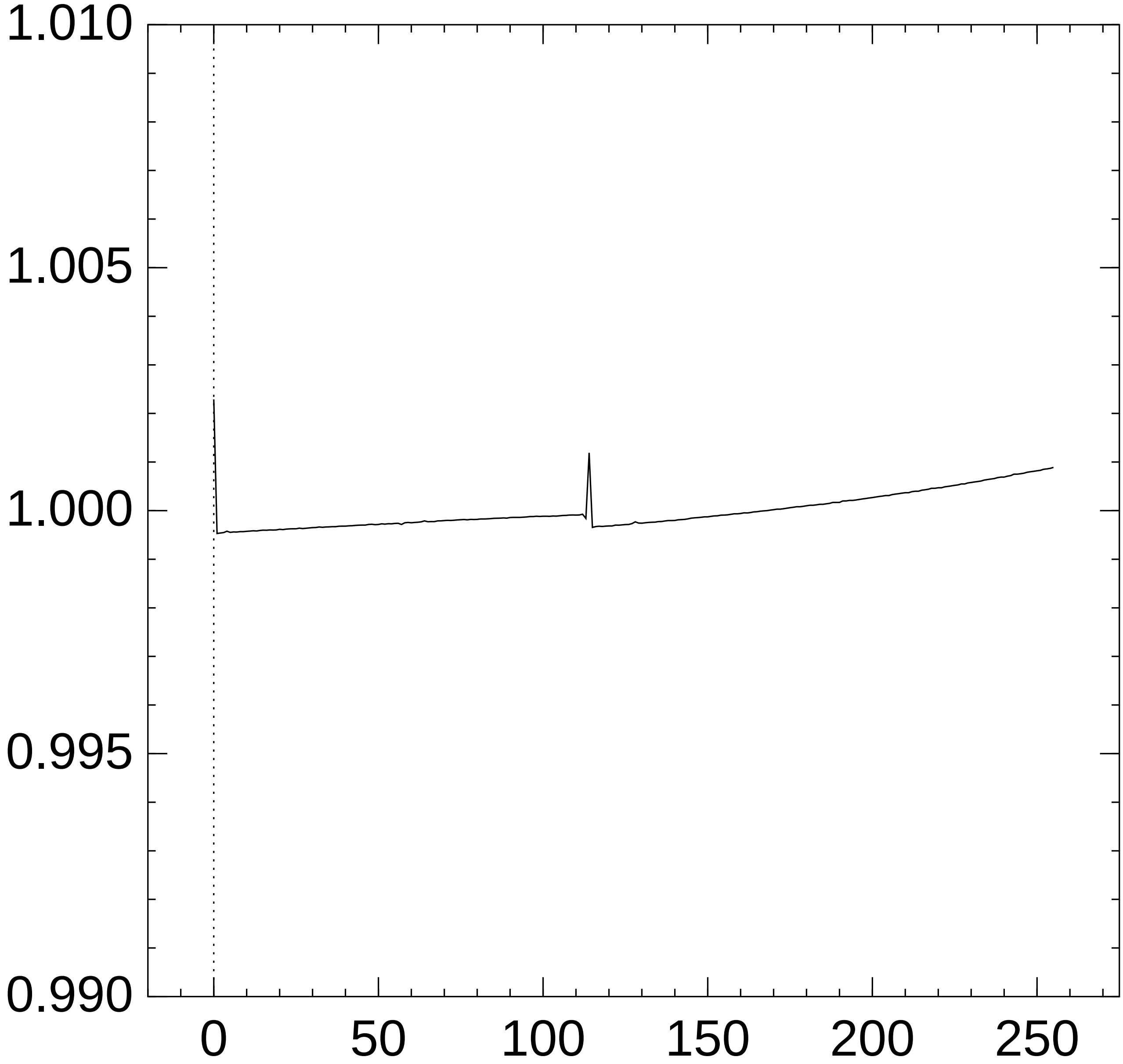
Graph of $256\,\Pr[z_{112} = x]$:



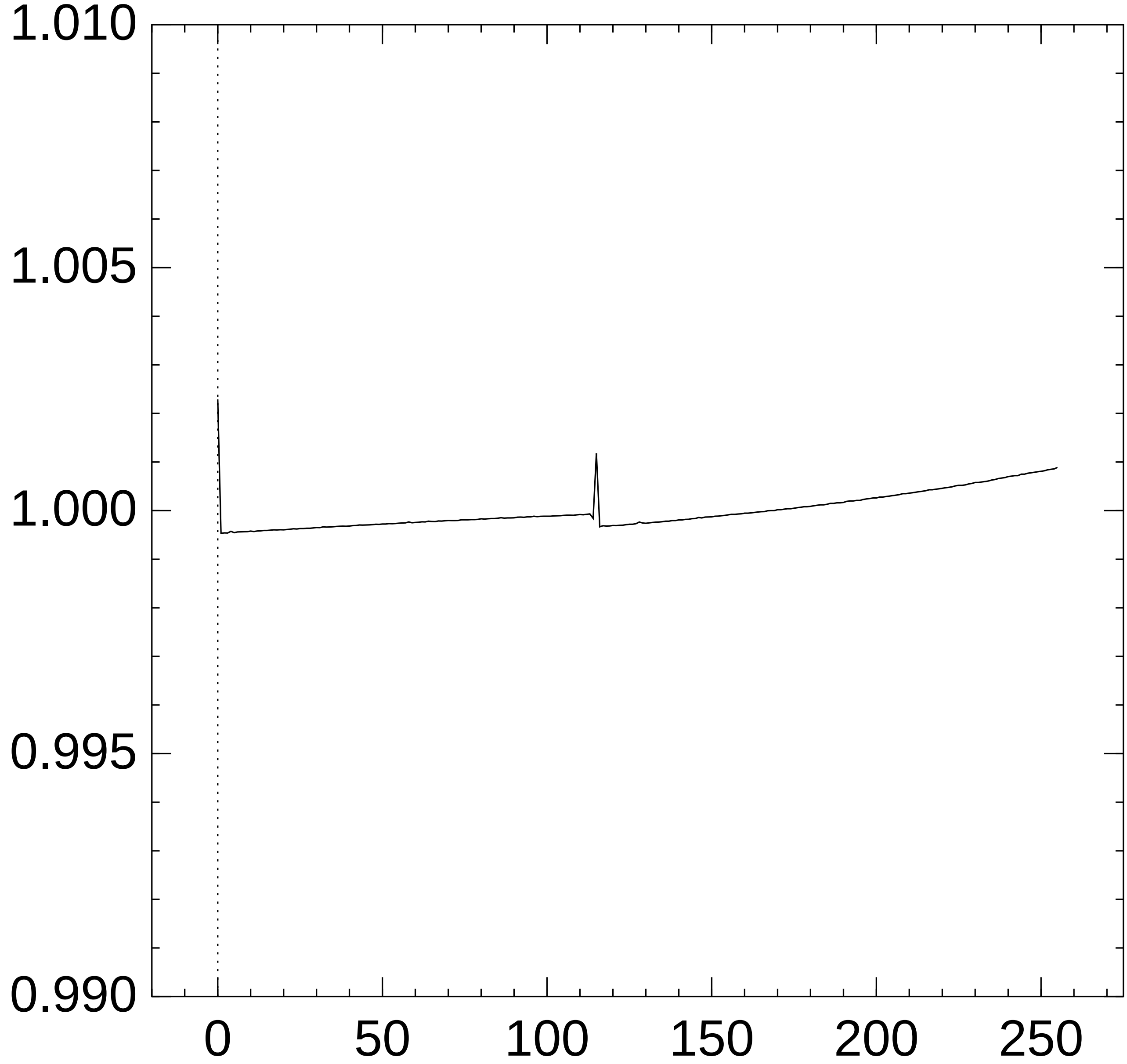
Graph of $256\,\Pr[z_{113} = x]$:



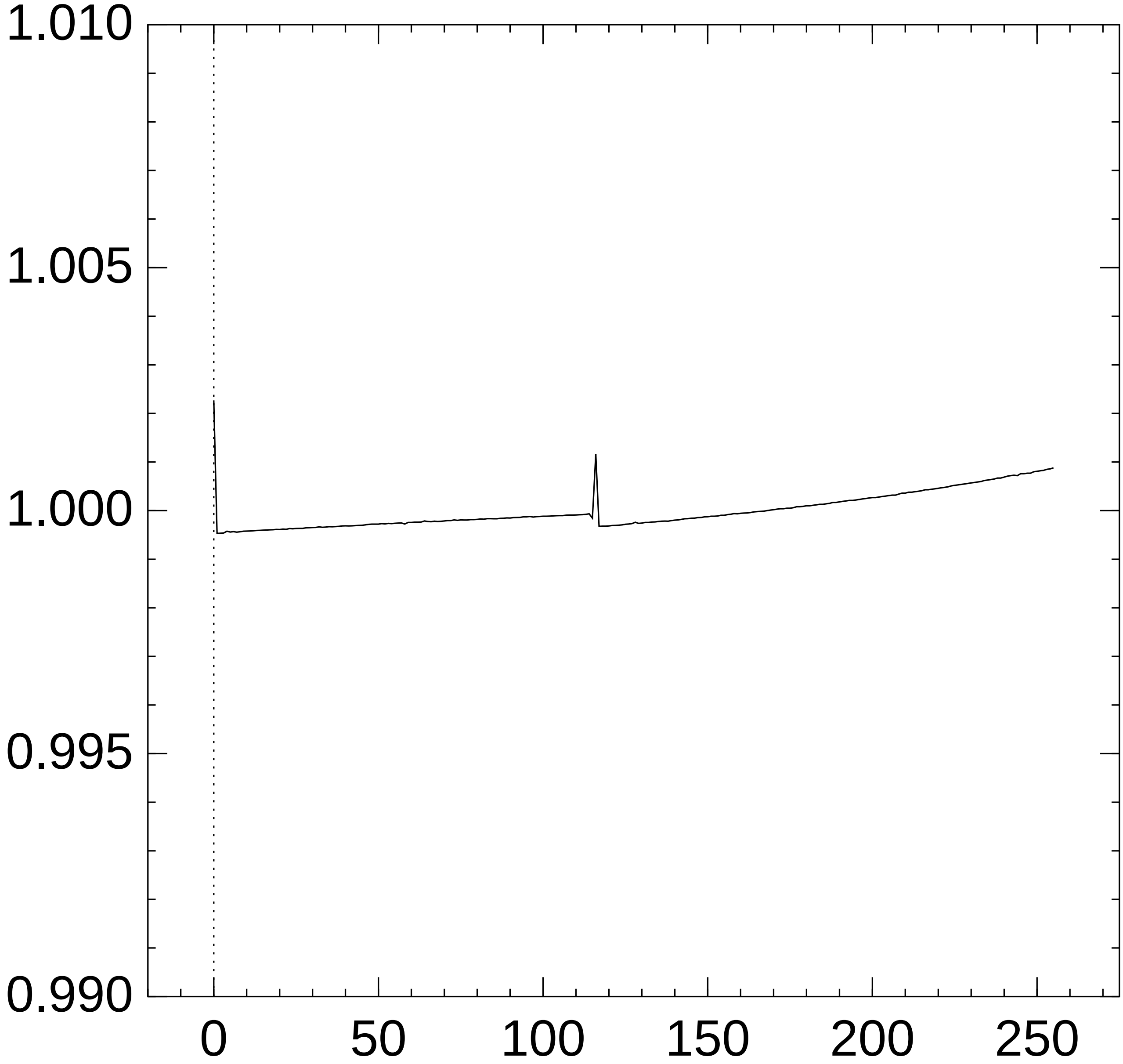
Graph of $256\,\mathrm{Pr}[z_{114} = x]$:



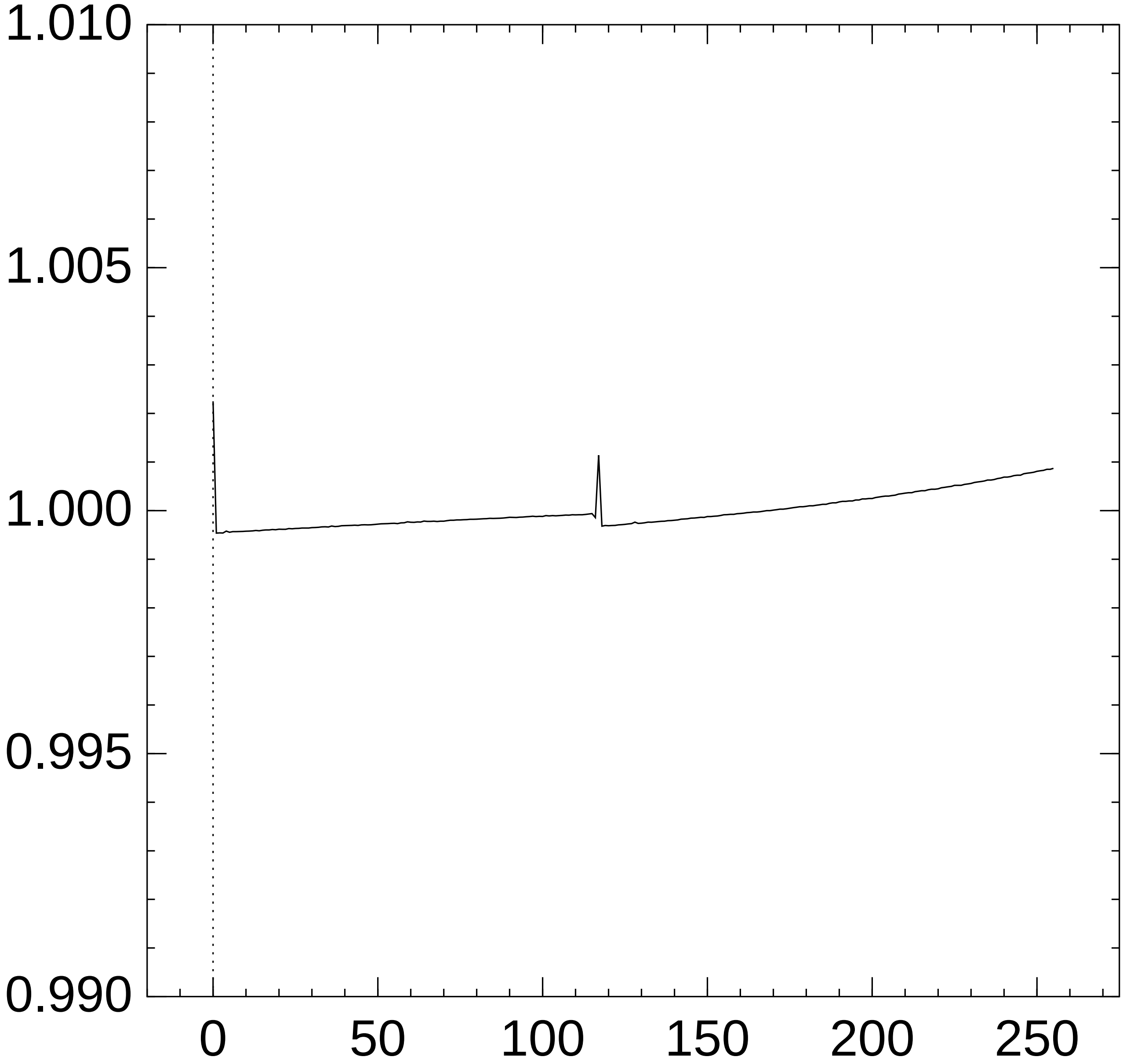
Graph of $256\,\mathrm{Pr}[z_{115} = x]$:



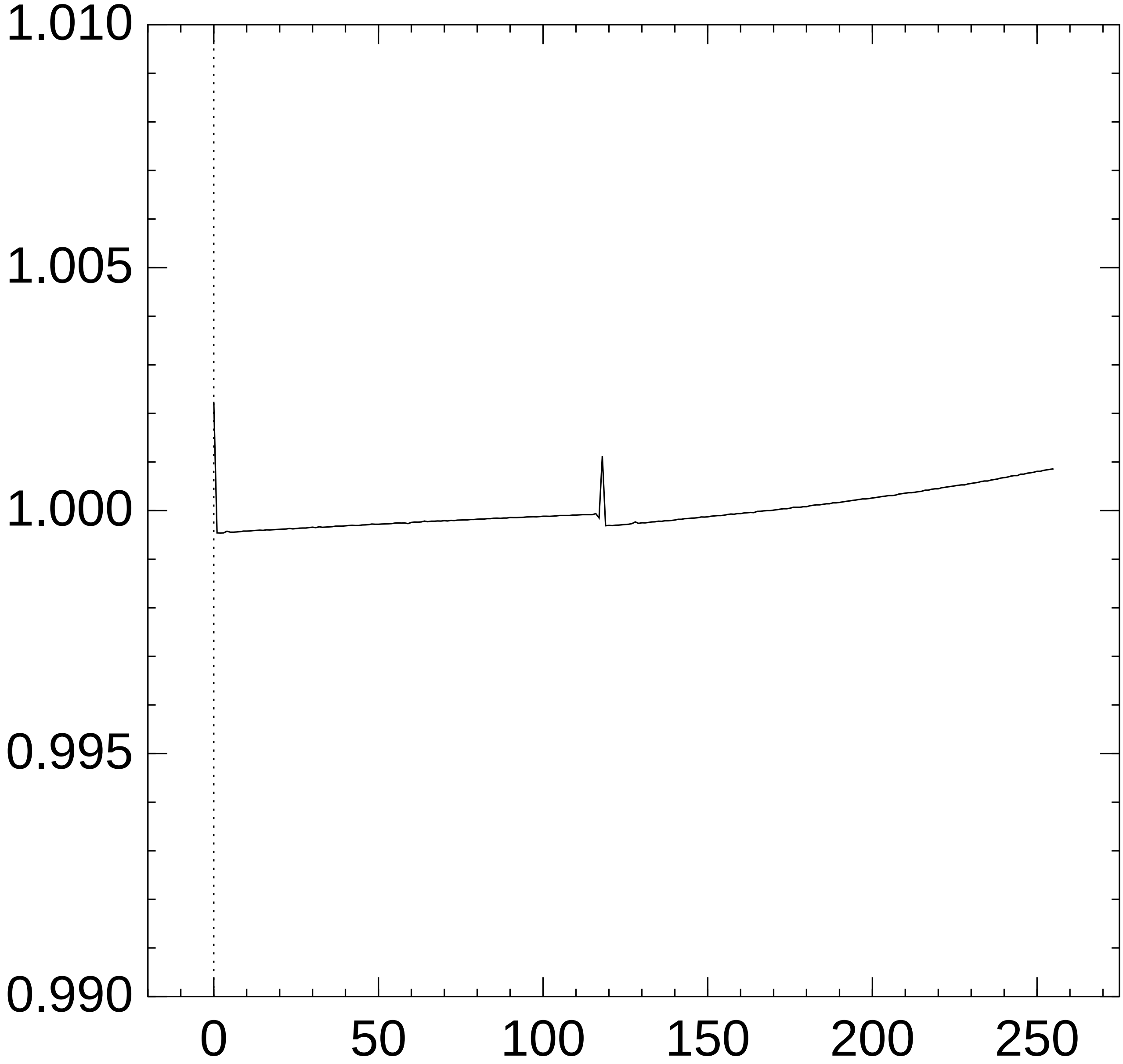
Graph of $256\,\mathrm{Pr}[z_{116} = x]$:



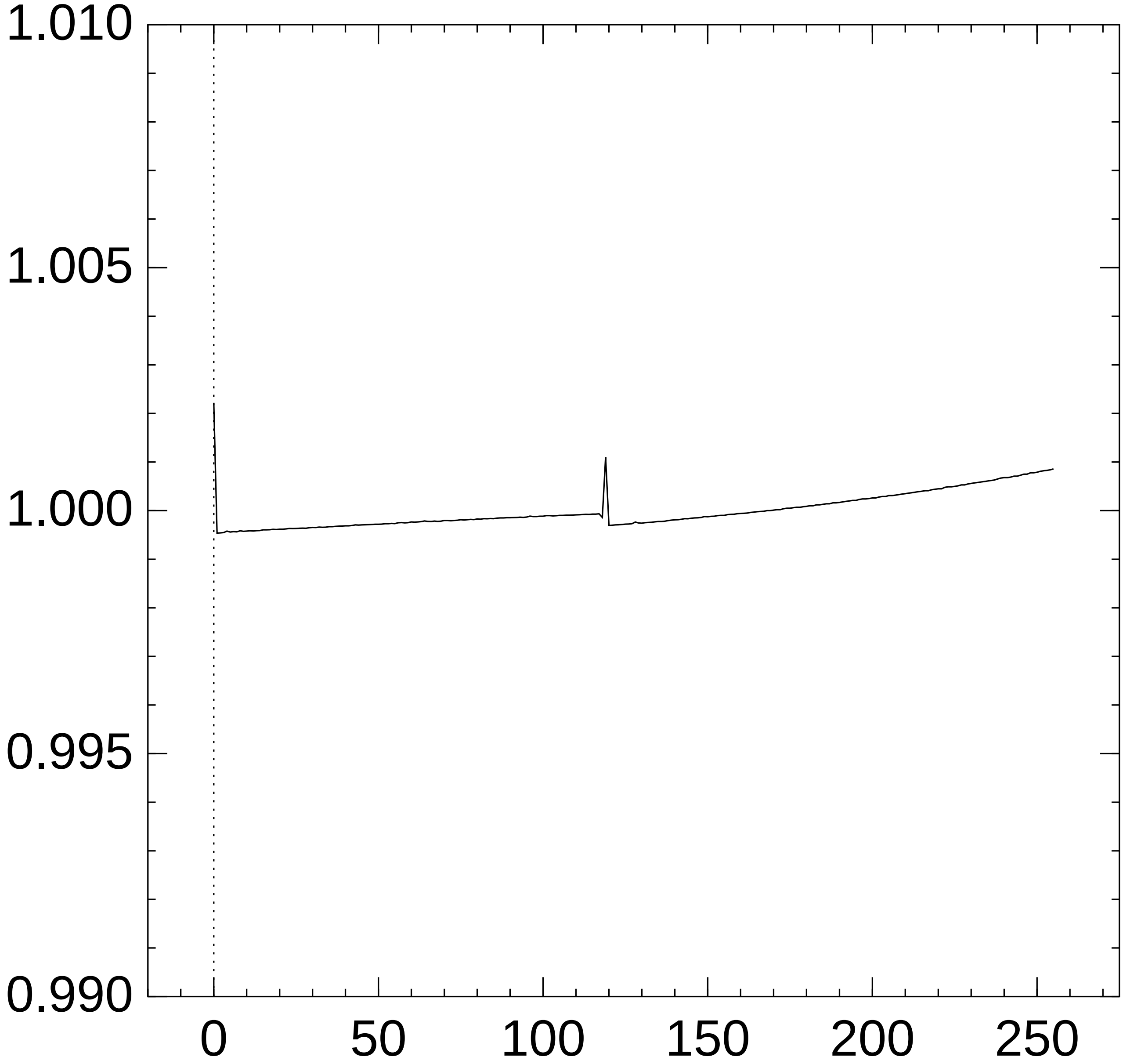
Graph of $256\,\mathrm{Pr}[z_{117} = x]$:



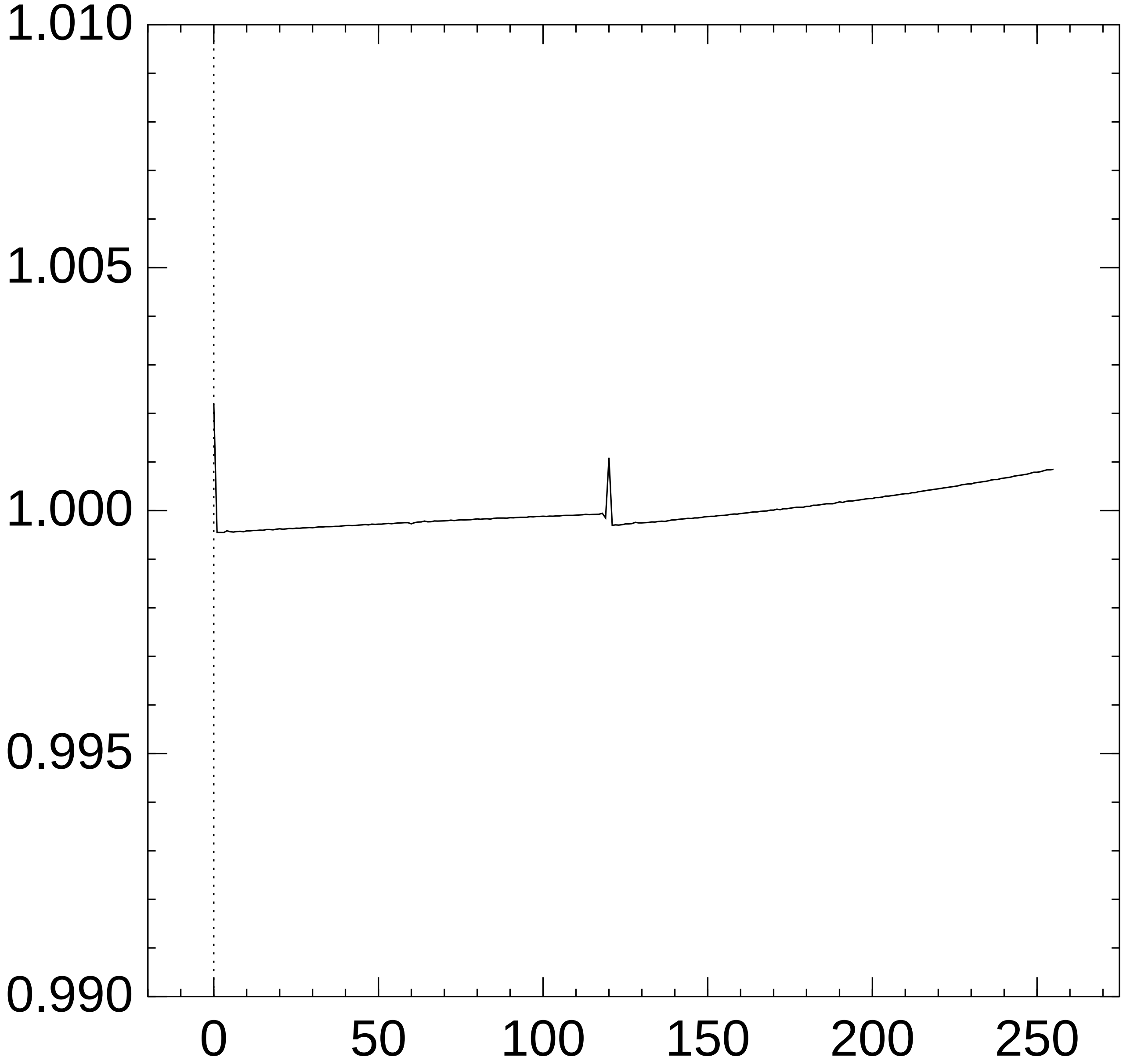
Graph of $256\,\mathrm{Pr}[z_{118} = x]$:



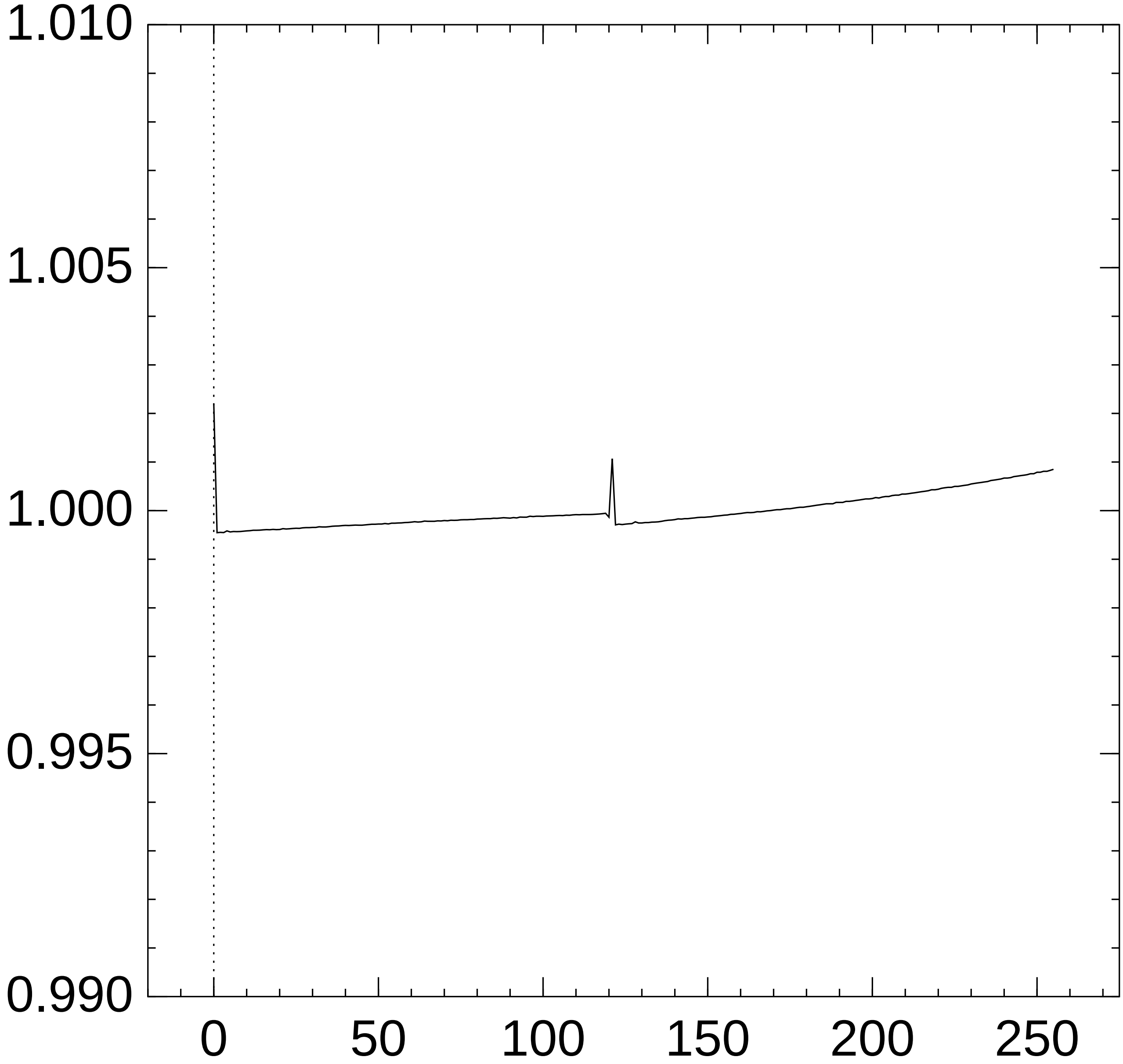
Graph of $256\,\Pr[z_{119} = x]$:



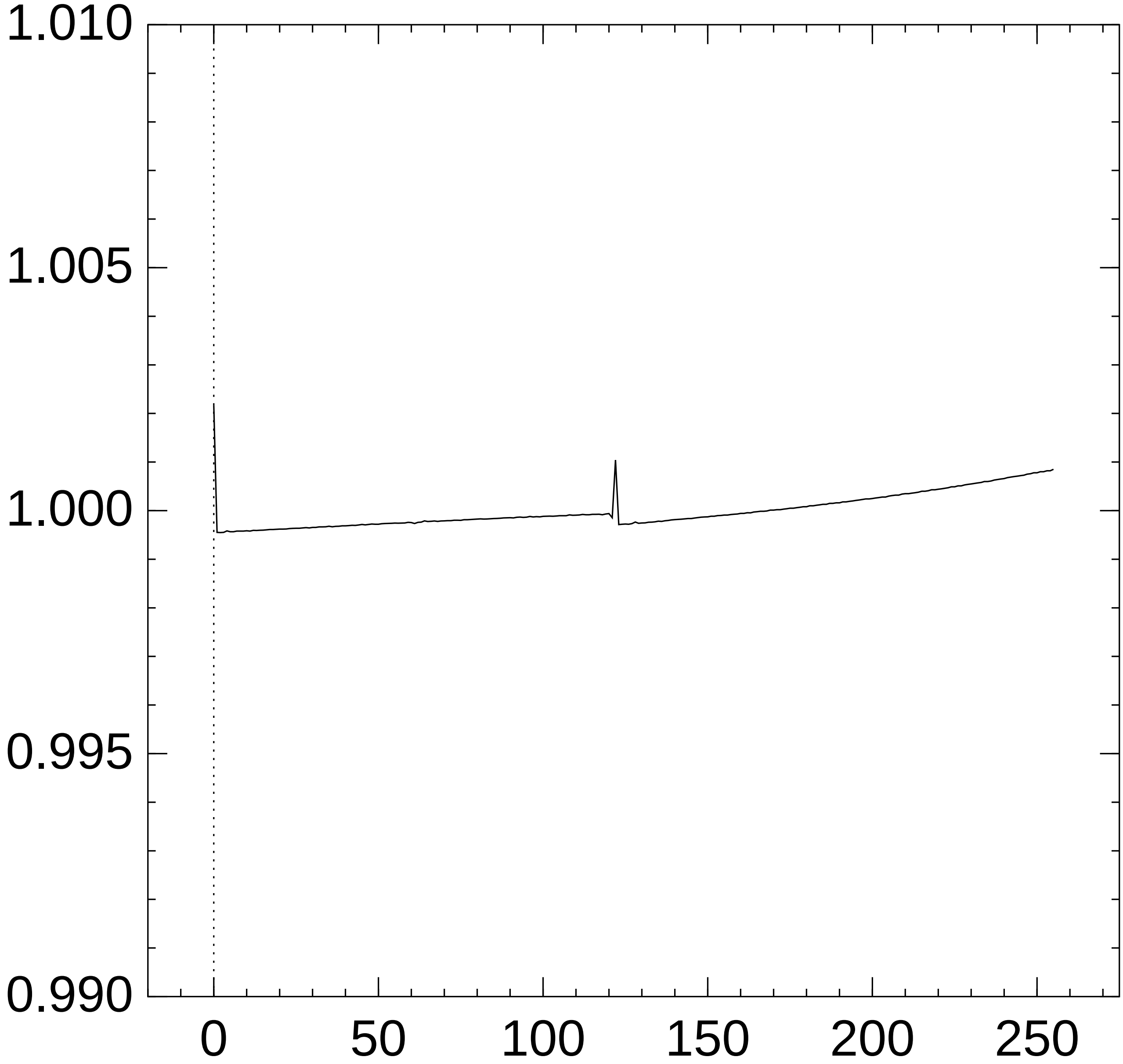
Graph of $256\,\Pr[z_{120} = x]$:



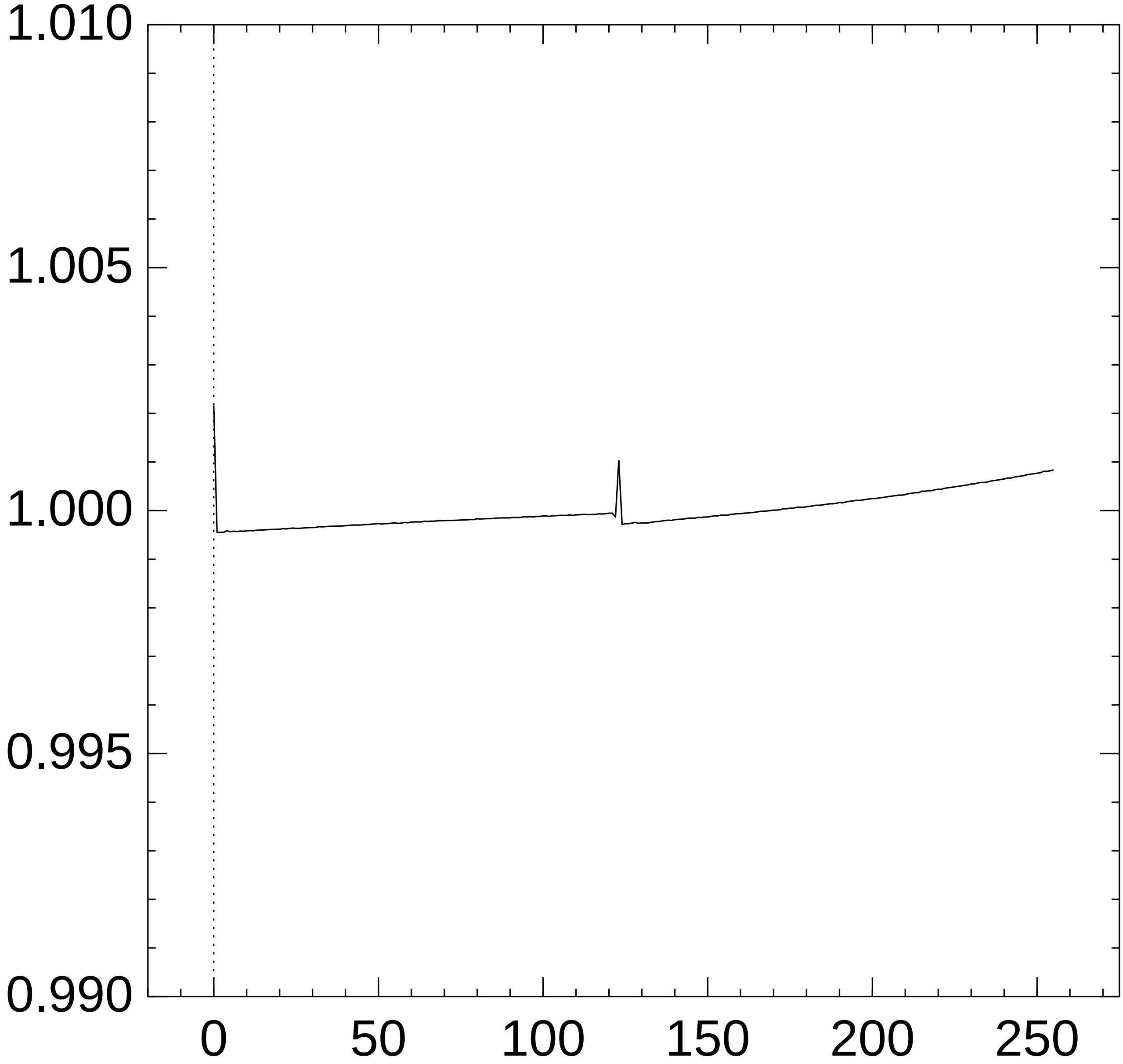
Graph of $256 \Pr[z_{121} = x]$:



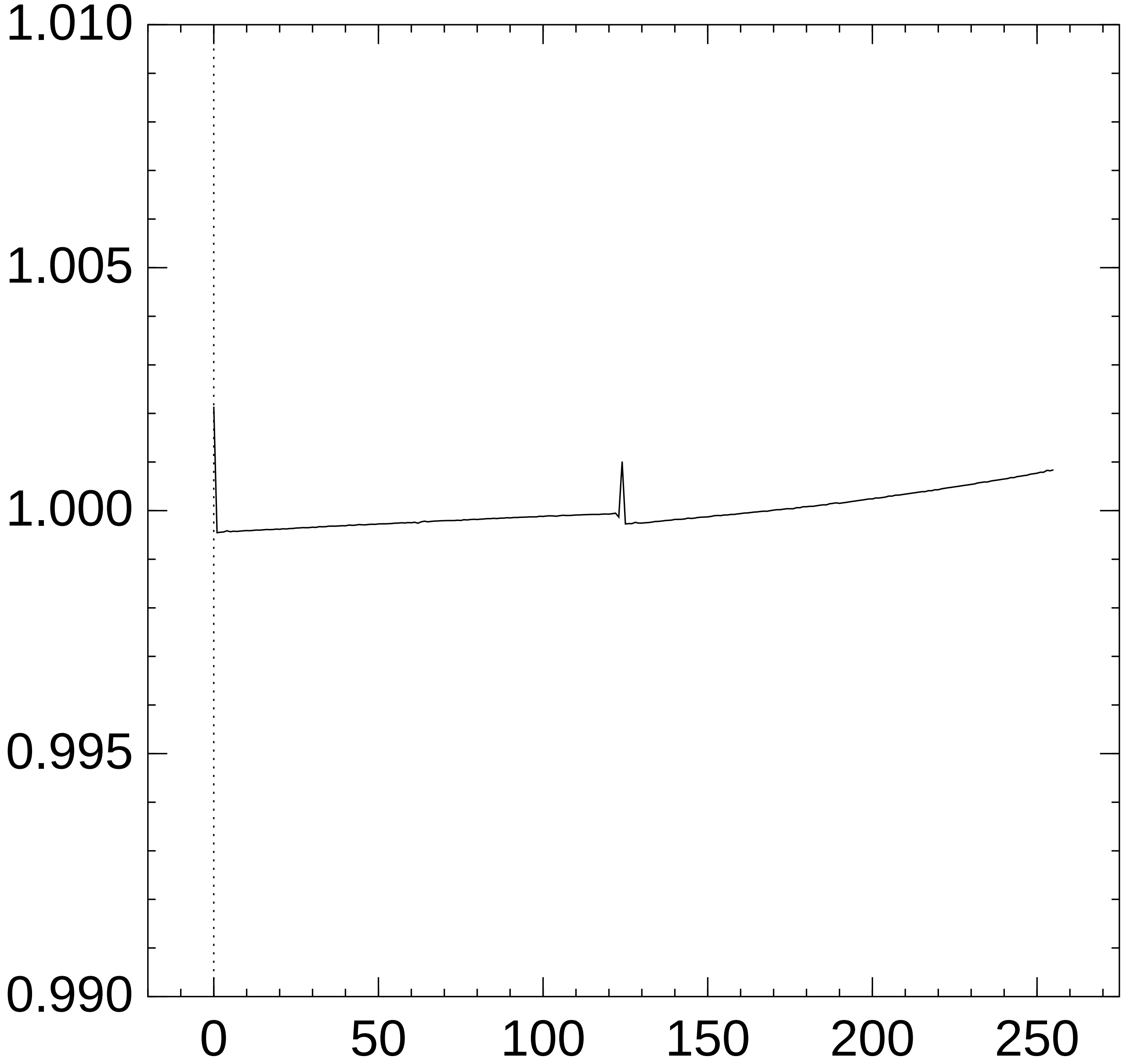
Graph of $256\,\Pr[z_{122} = x]$:



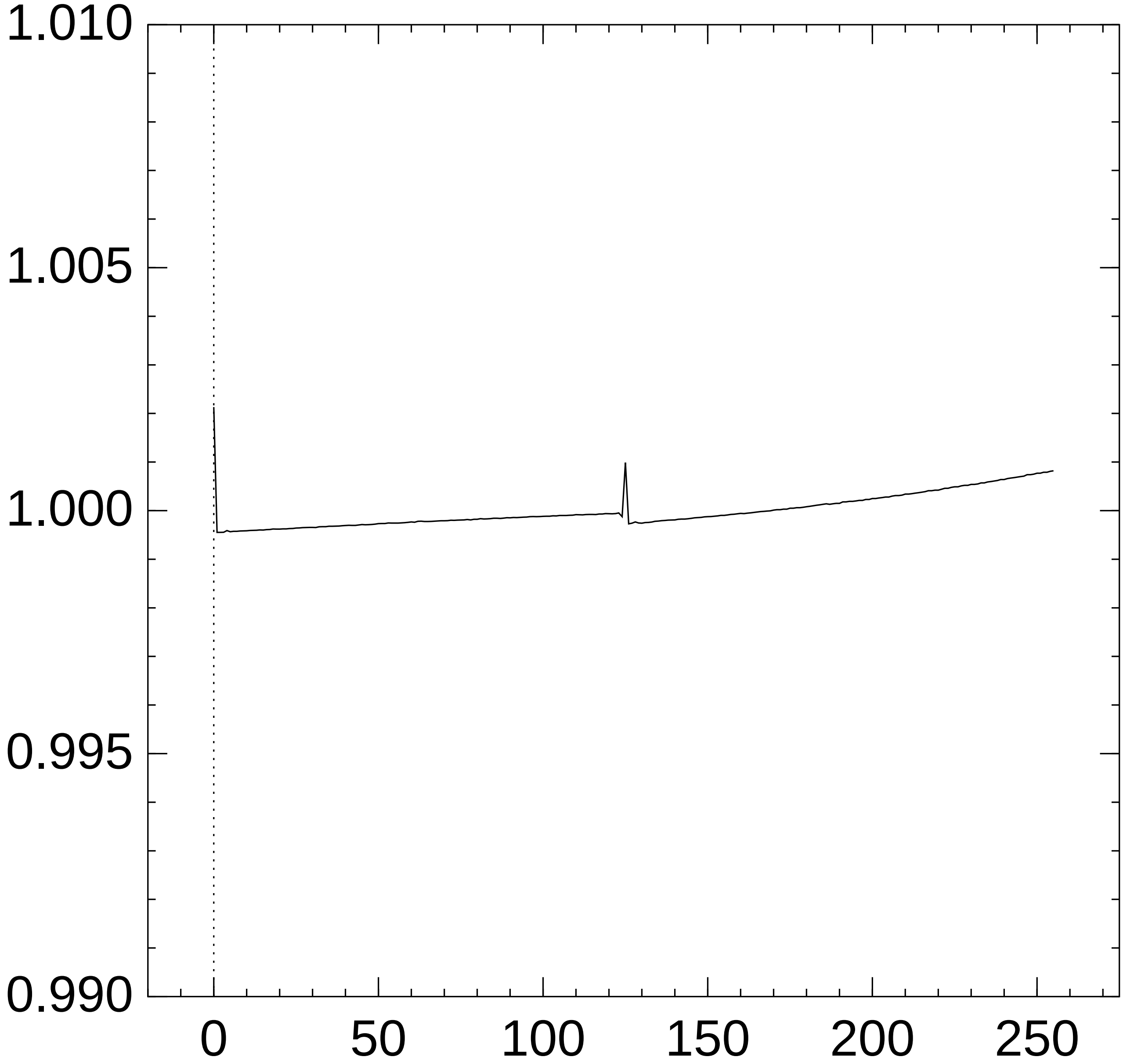
Graph of $256\,\Pr[z_{123} = x]$:



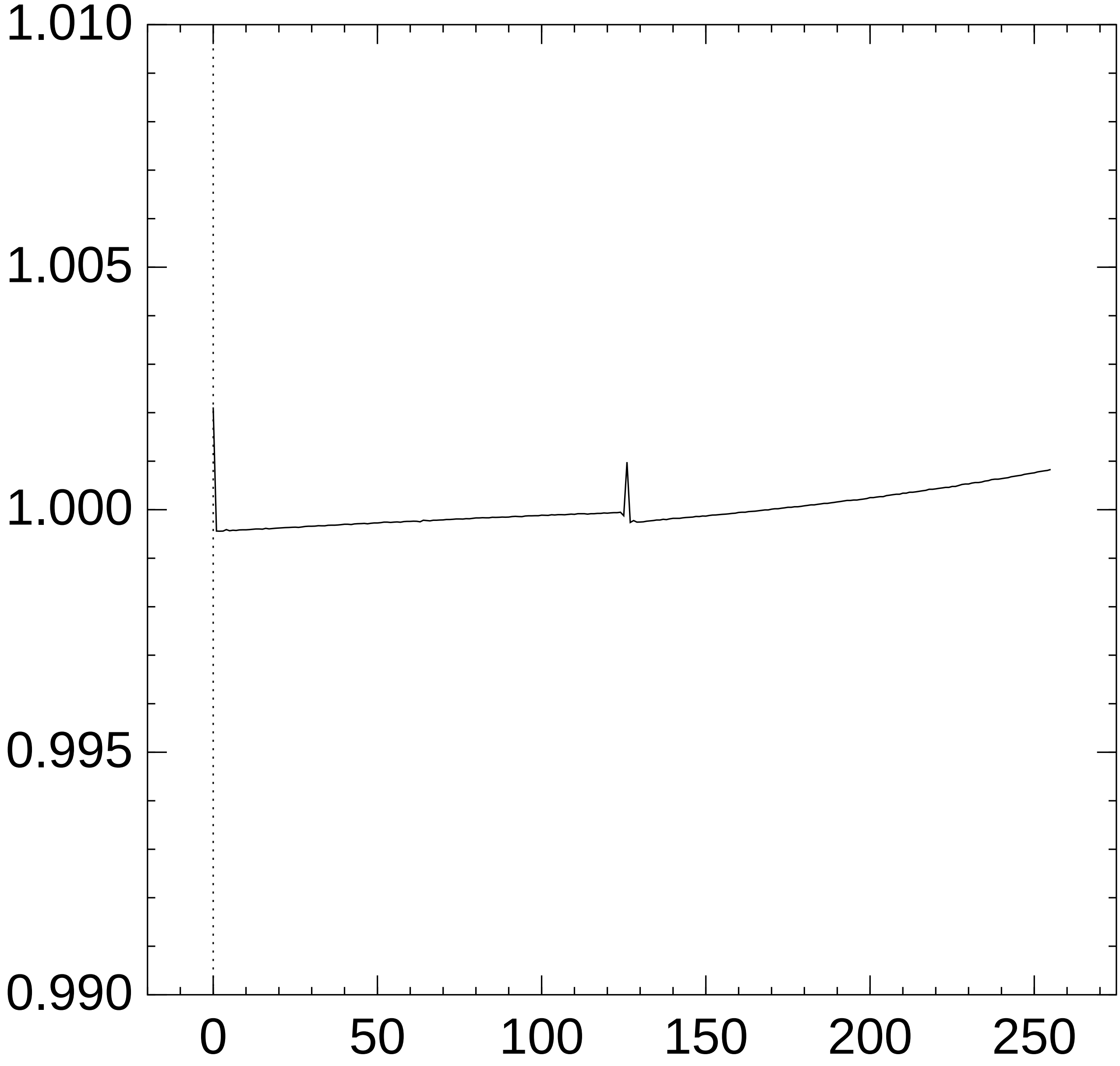
Graph of $256\,\Pr[z_{124} = x]$:



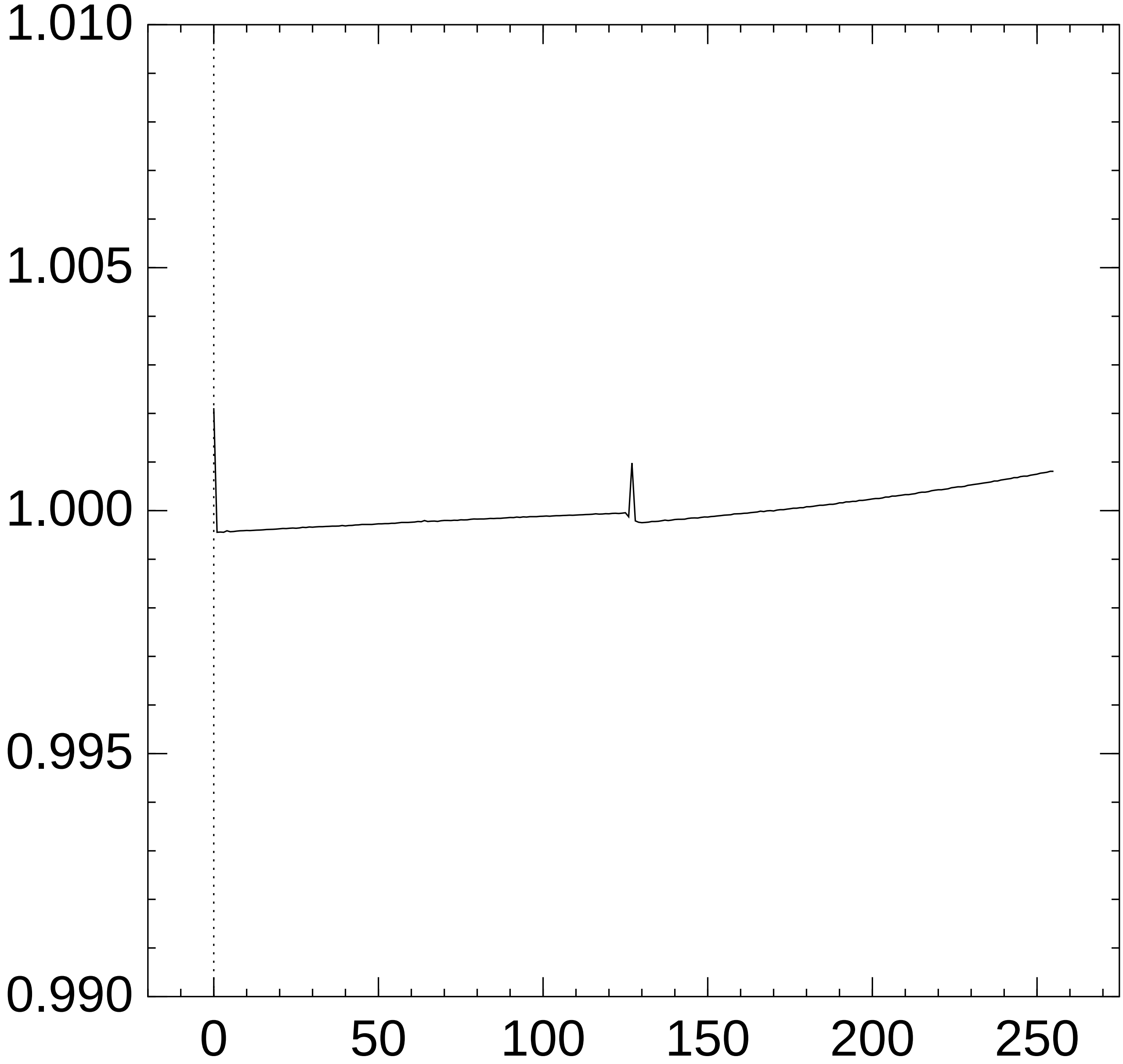
Graph of $256\,\Pr[z_{125} = x]$:



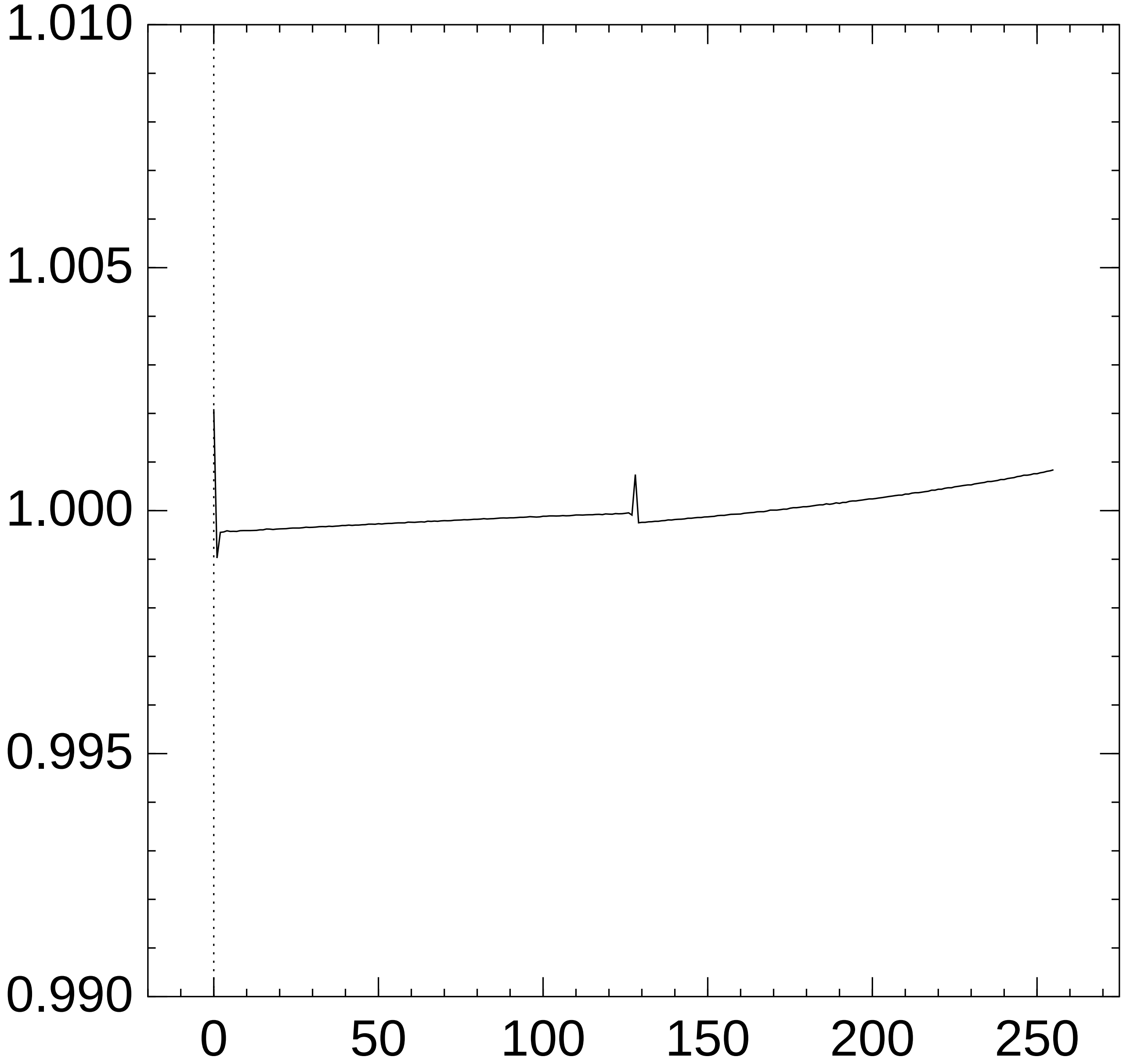
Graph of $256\,\Pr[z_{126} = x]$:



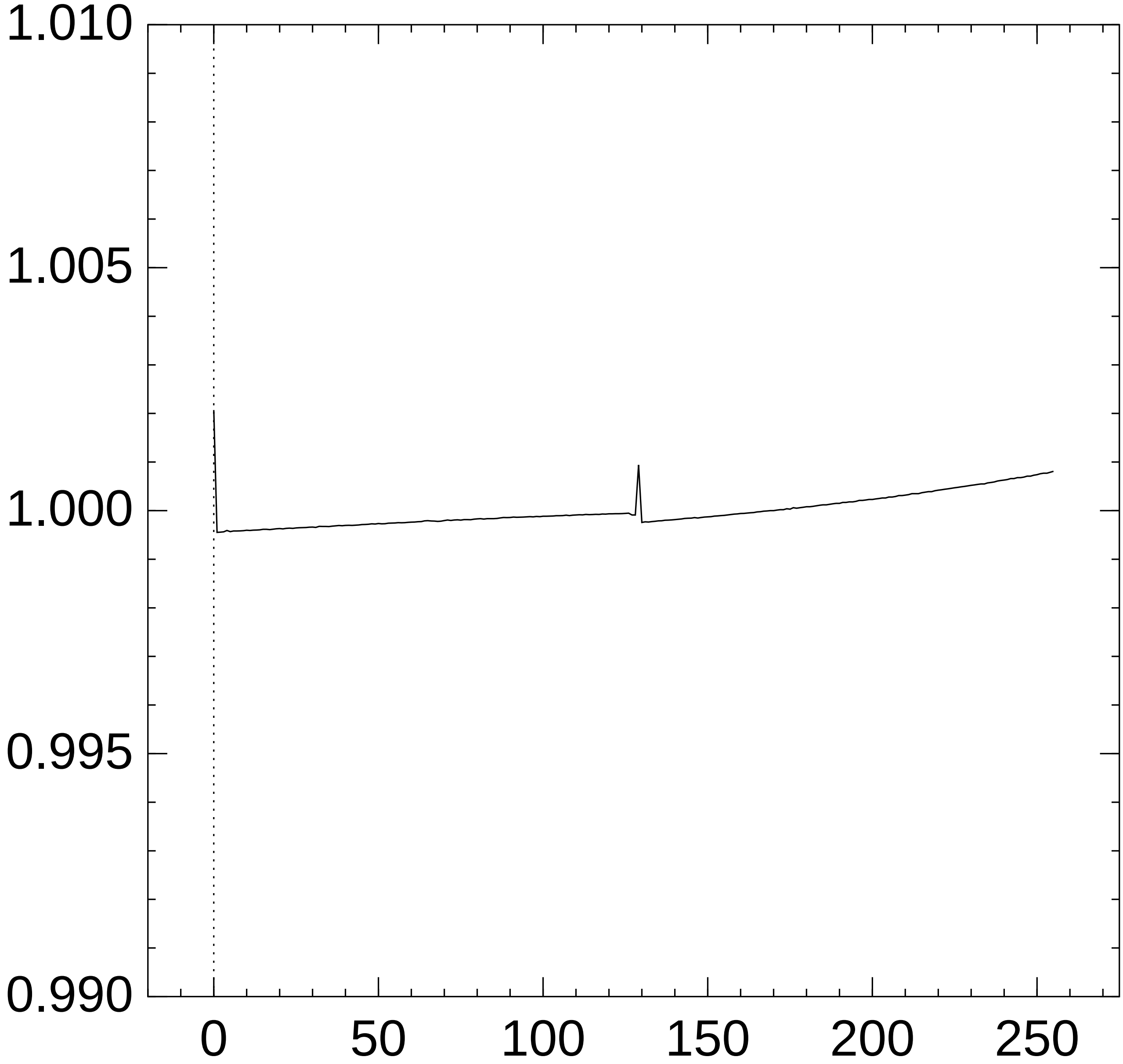
Graph of $256\,\Pr[z_{127} = x]$:



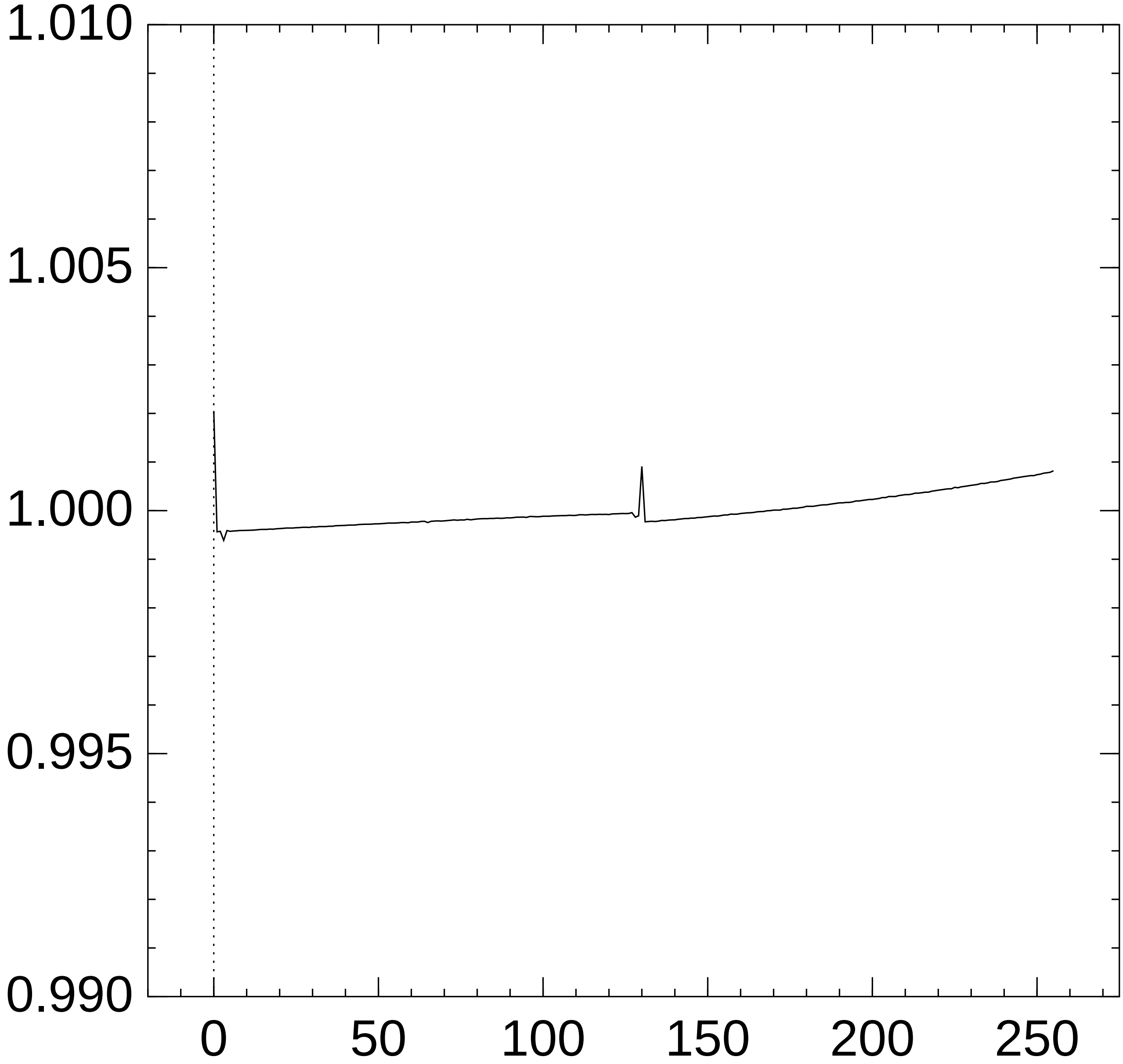
Graph of $256\,\mathrm{Pr}[z_{128} = x]$:



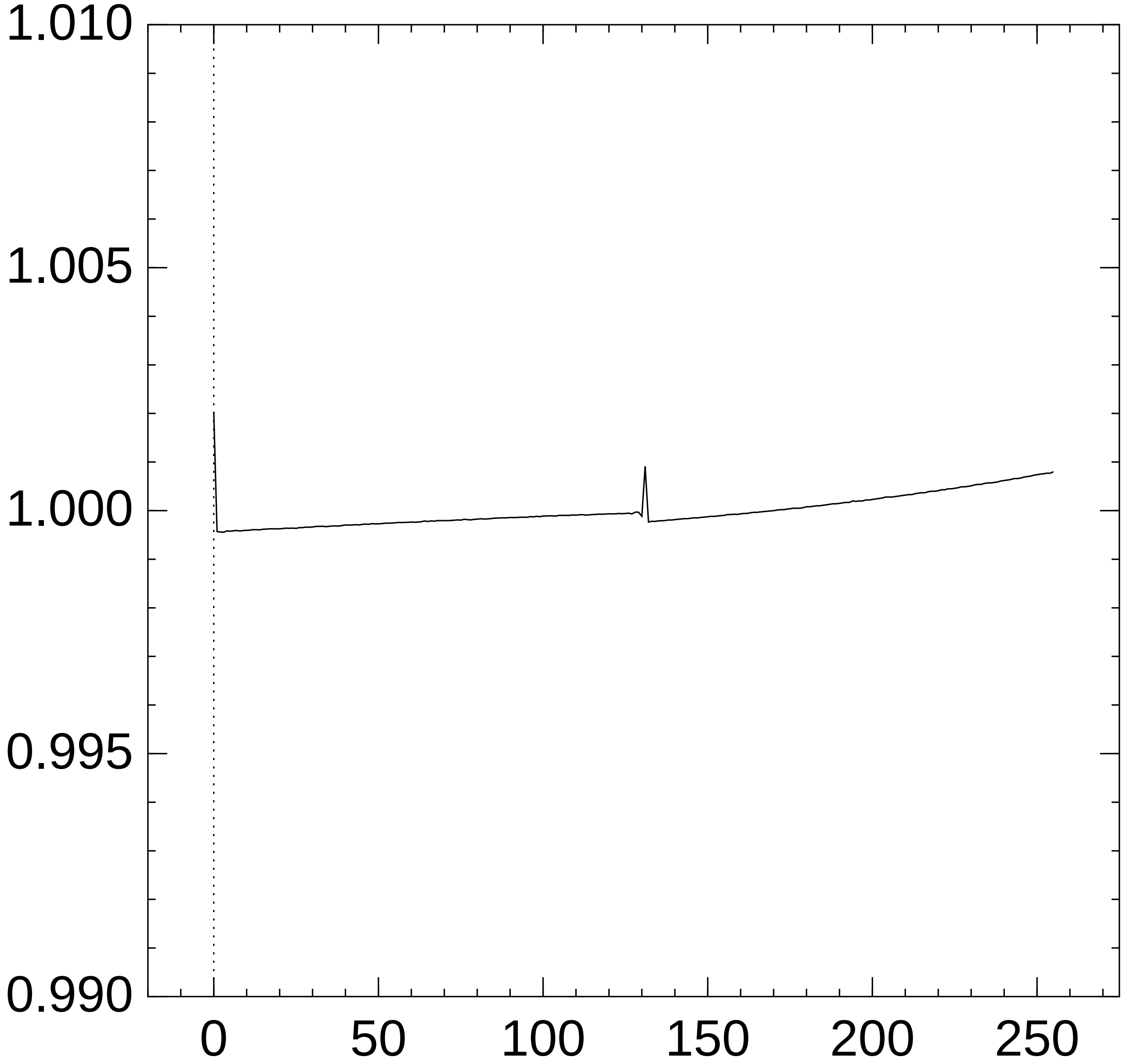
Graph of $256\,\Pr[z_{129} = x]$:



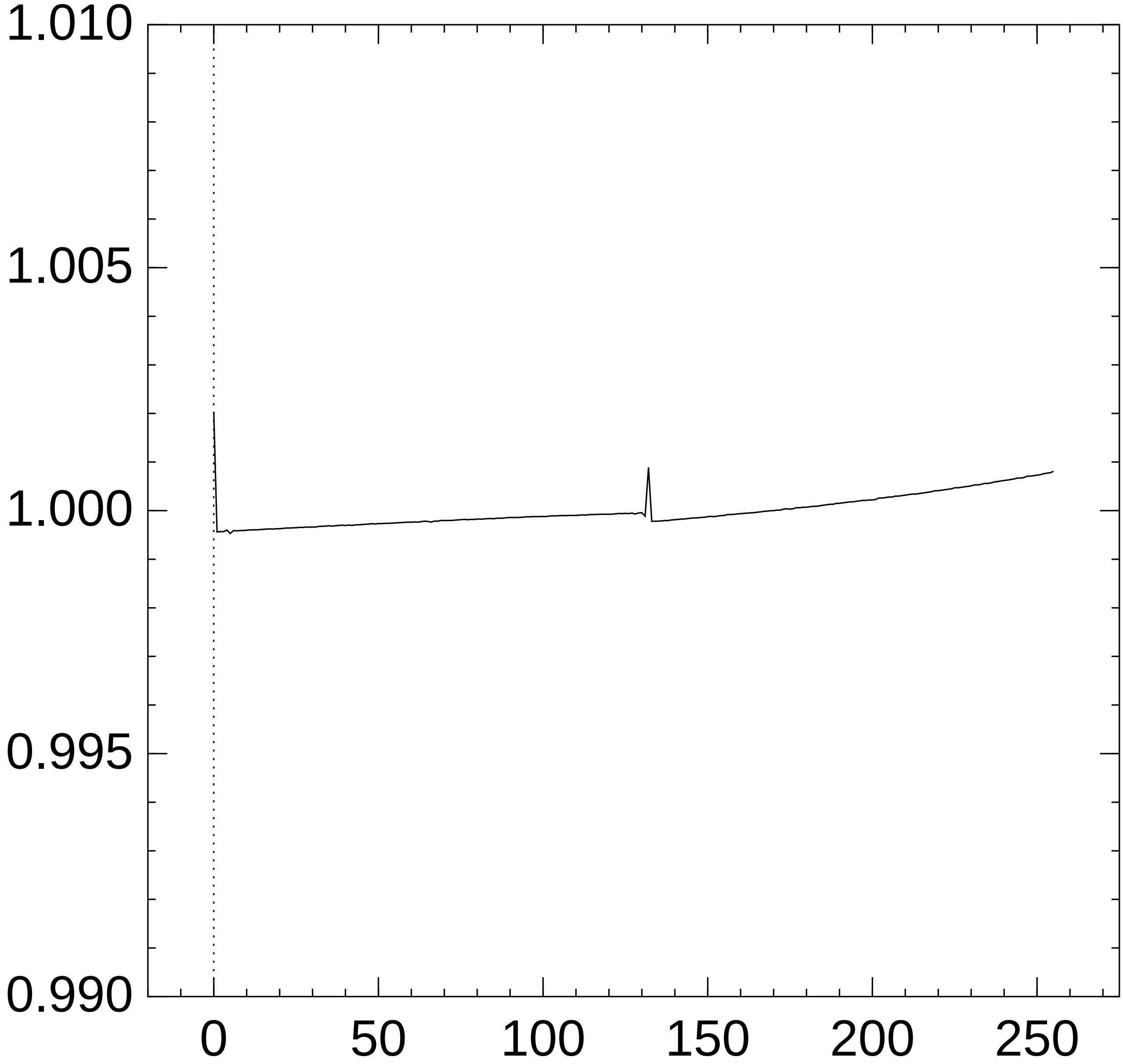
Graph of $256\,\Pr[z_{130} = x]$:



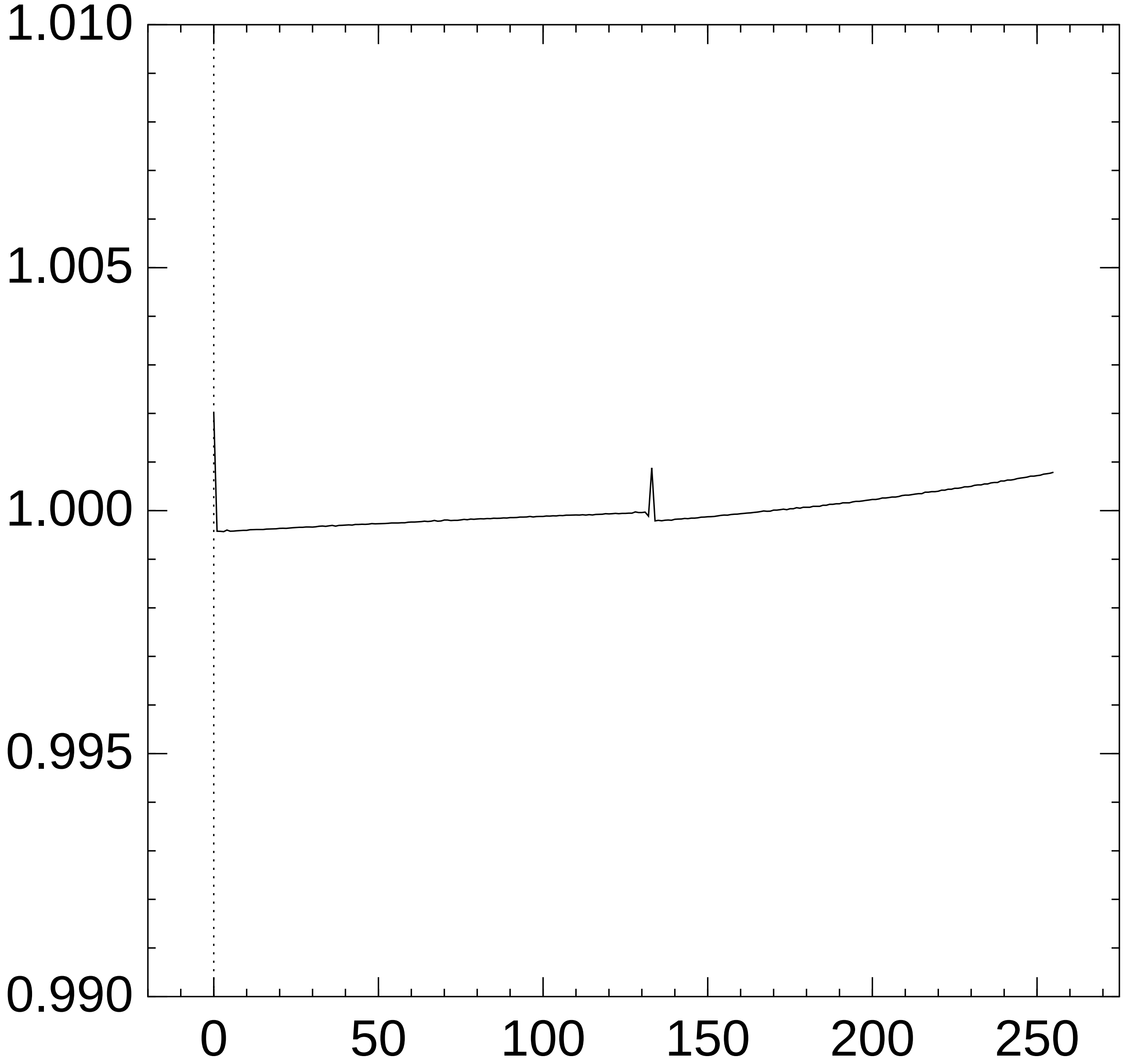
Graph of $256\,\Pr[z_{131} = x]$:



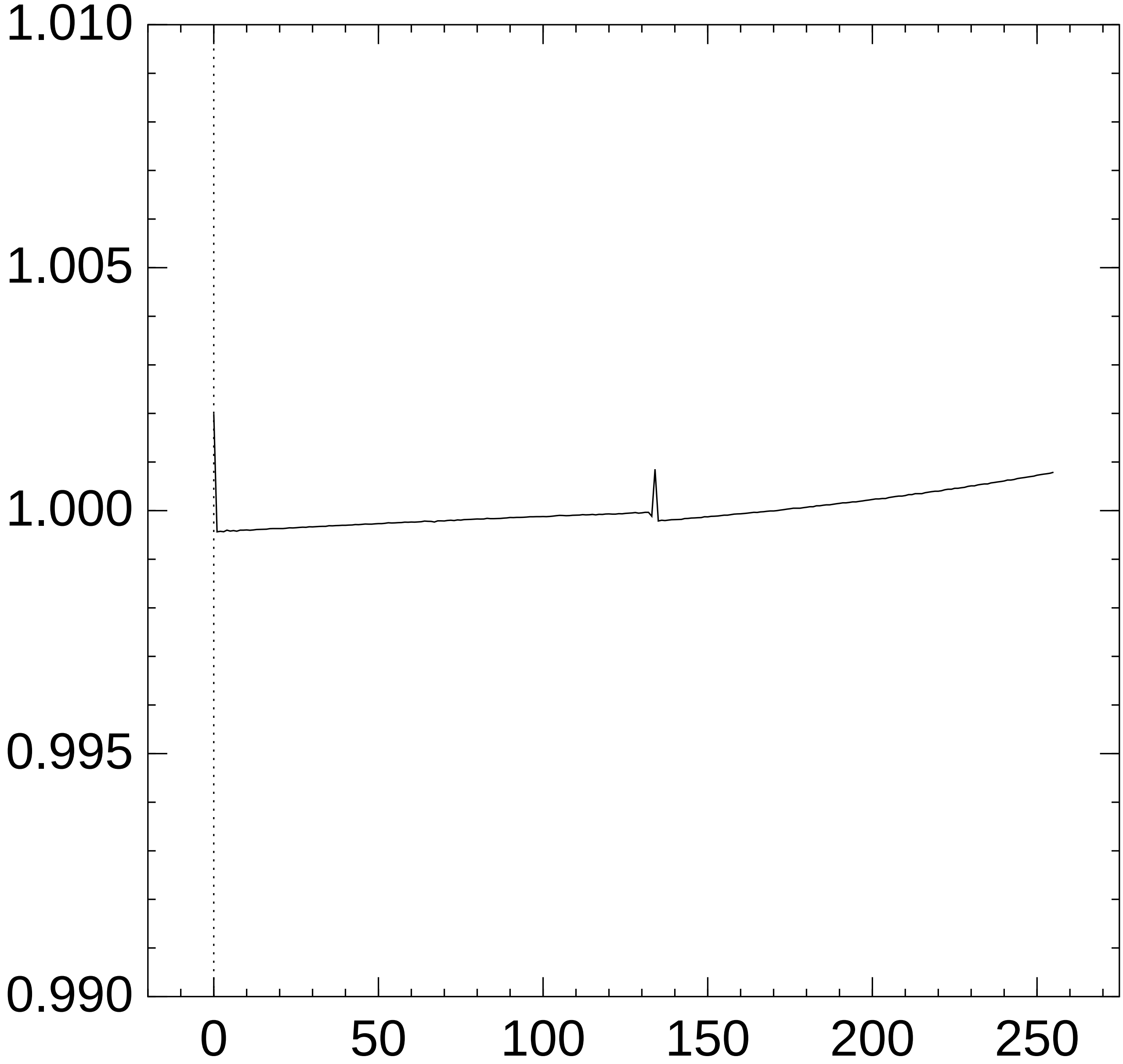
Graph of $256 \Pr[z_{132} = x]$:



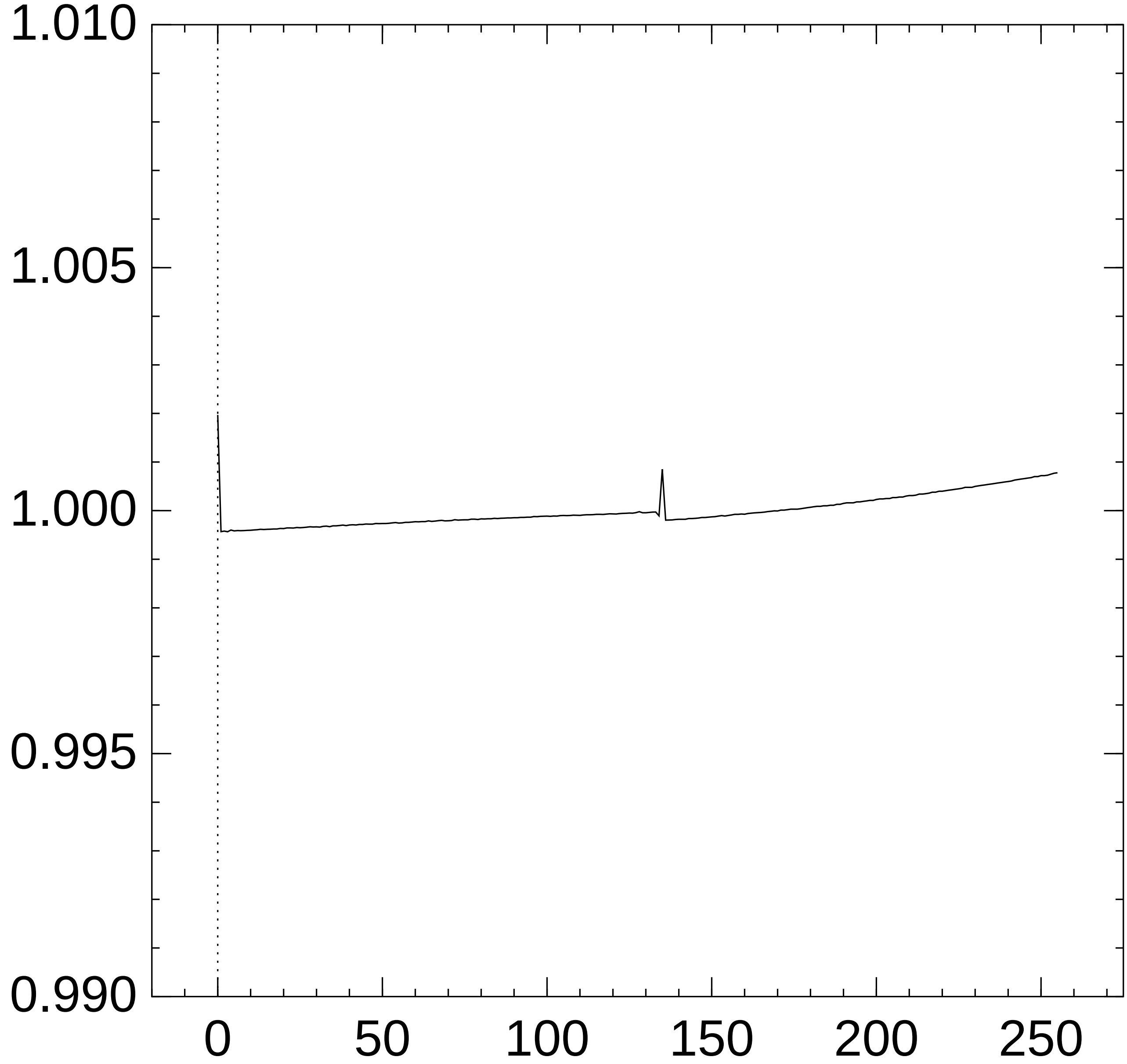
Graph of $256\,\Pr[z_{133} = x]$:



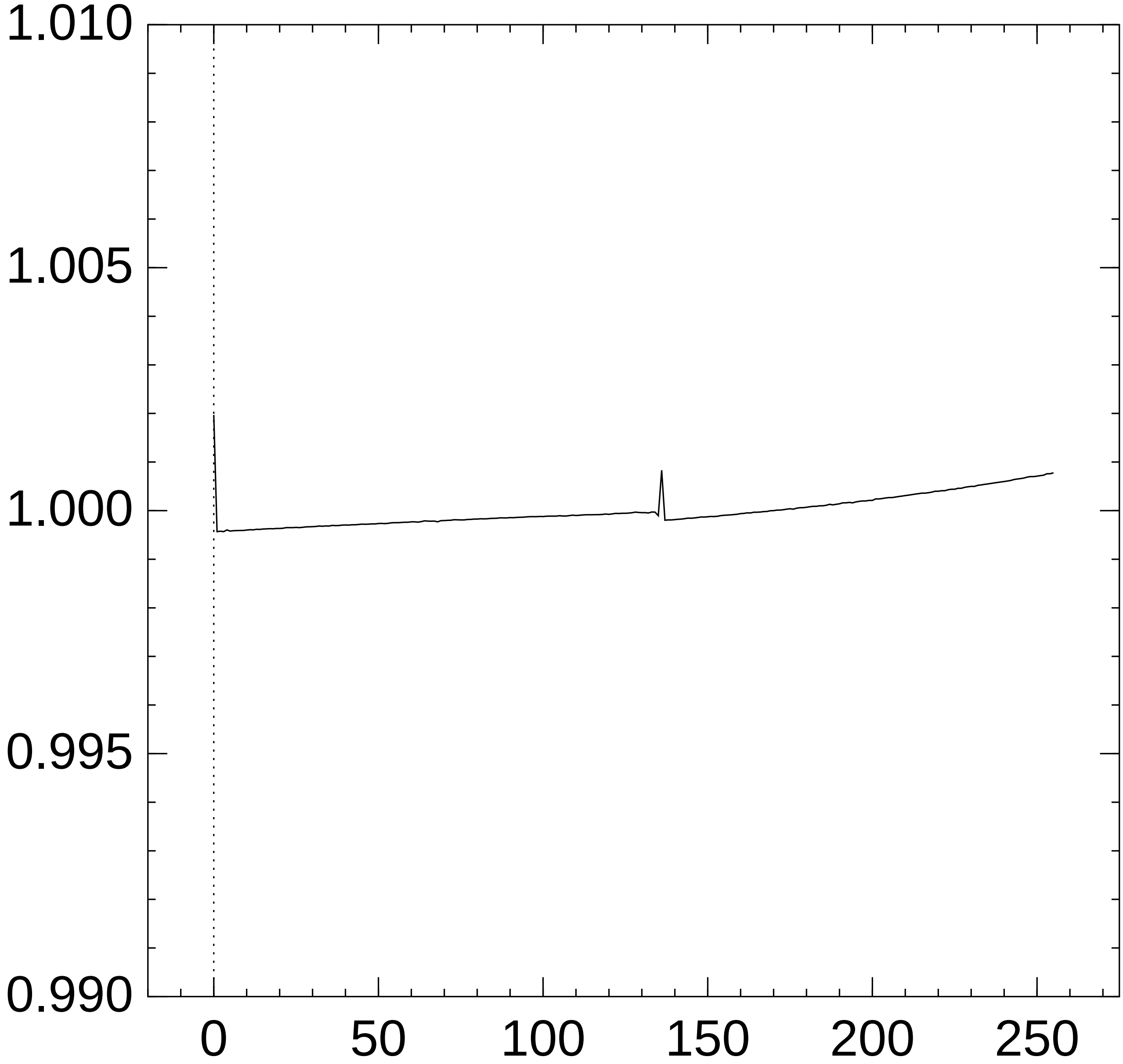
Graph of $256\,\Pr[z_{134} = x]$:



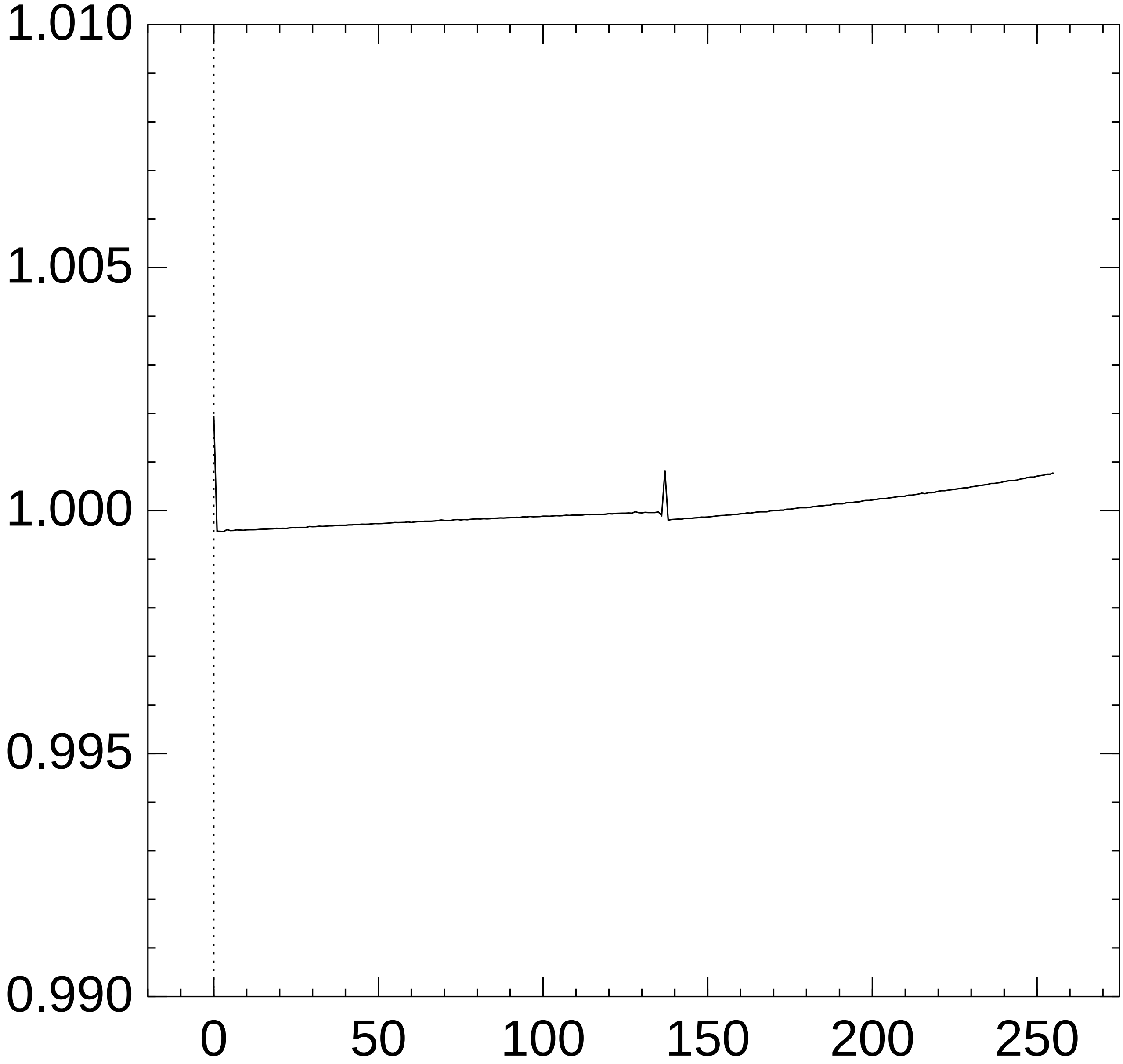
Graph of $256\,\Pr[z_{135} = x]$:



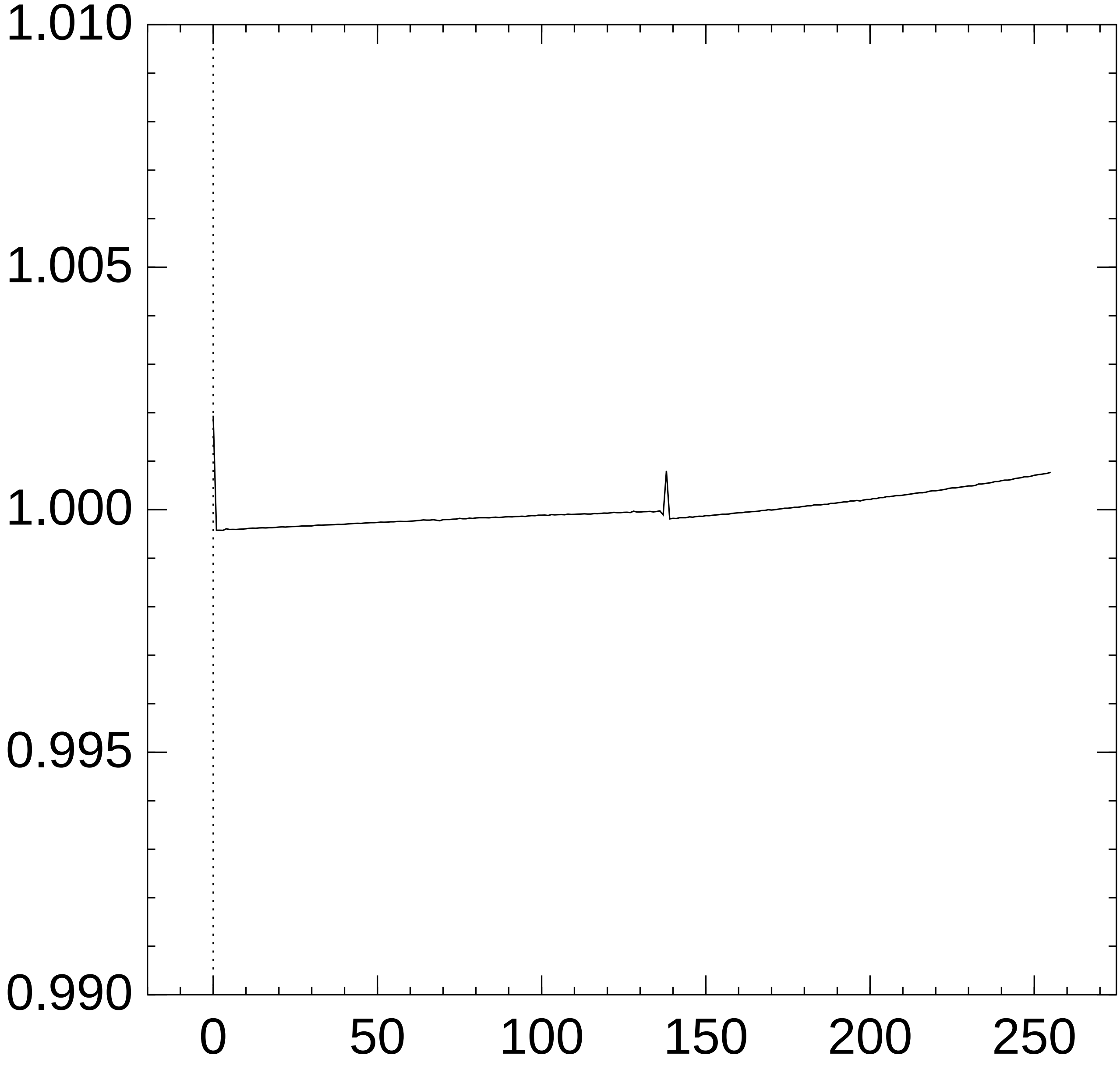
Graph of $256\,\mathrm{Pr}[z_{136} = x]$:



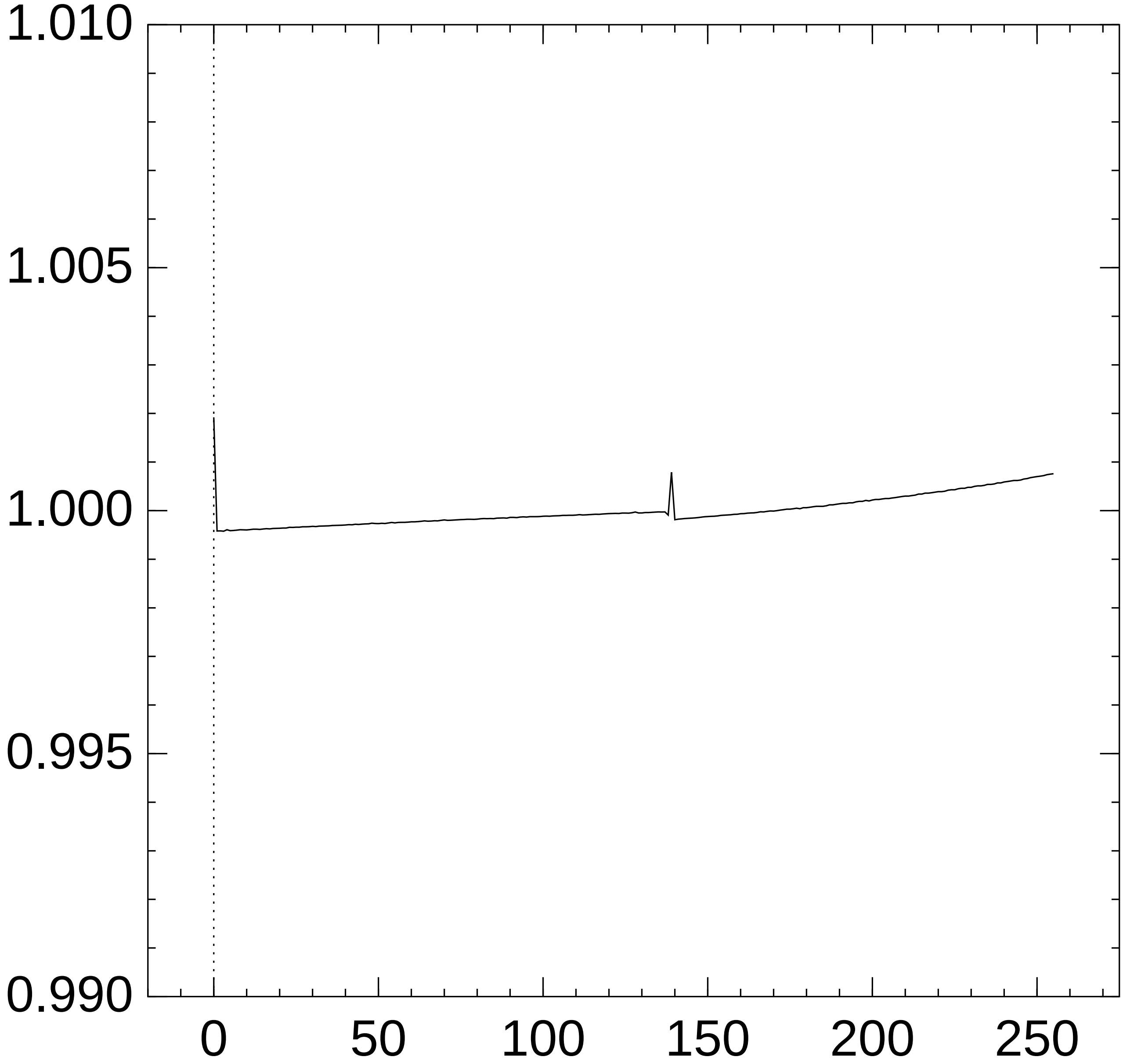
Graph of $256\,\Pr[z_{137} = x]$:



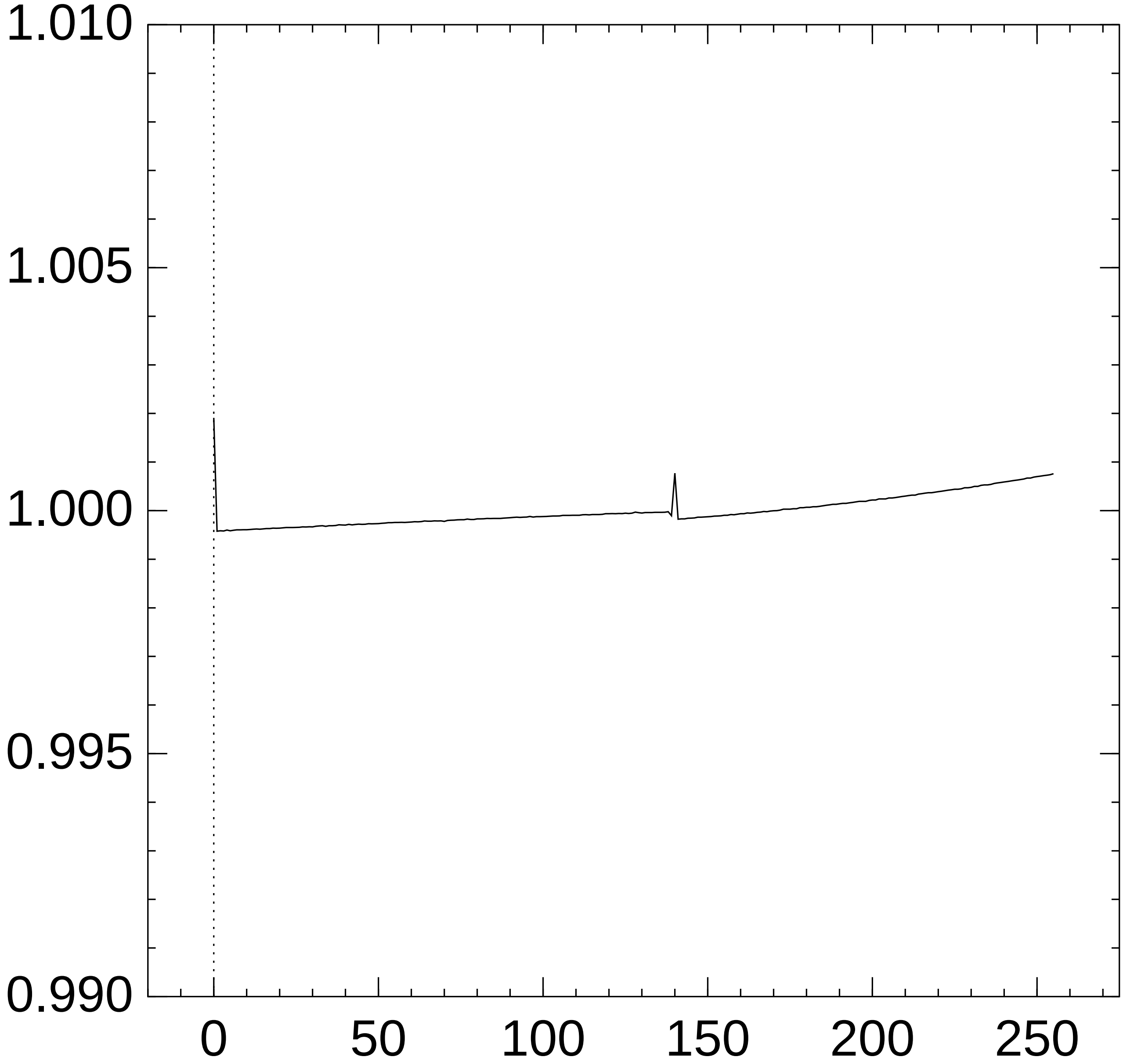
Graph of $256\,\Pr[z_{138} = x]$:



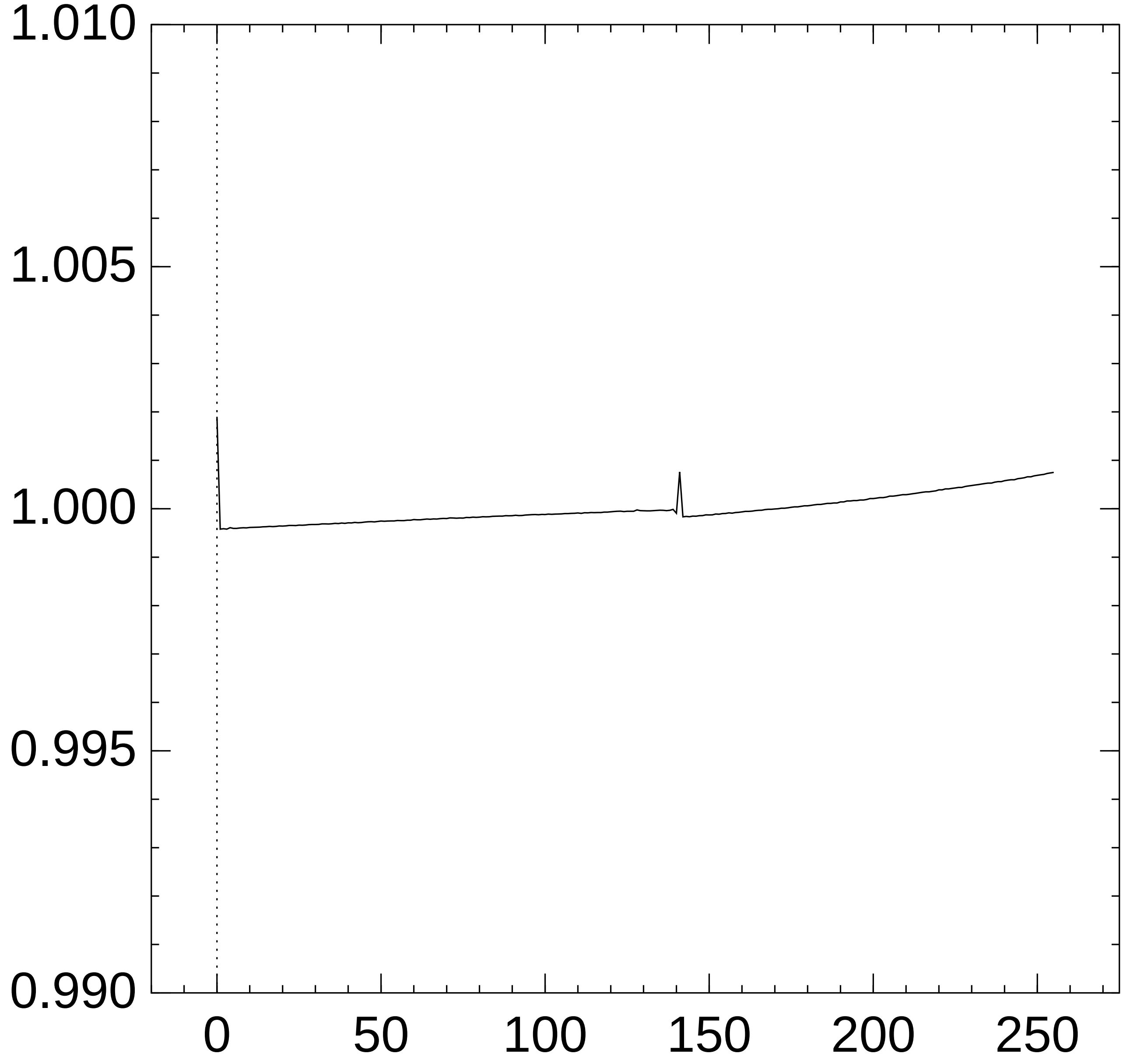
Graph of $256 \Pr[z_{139} = x]$:



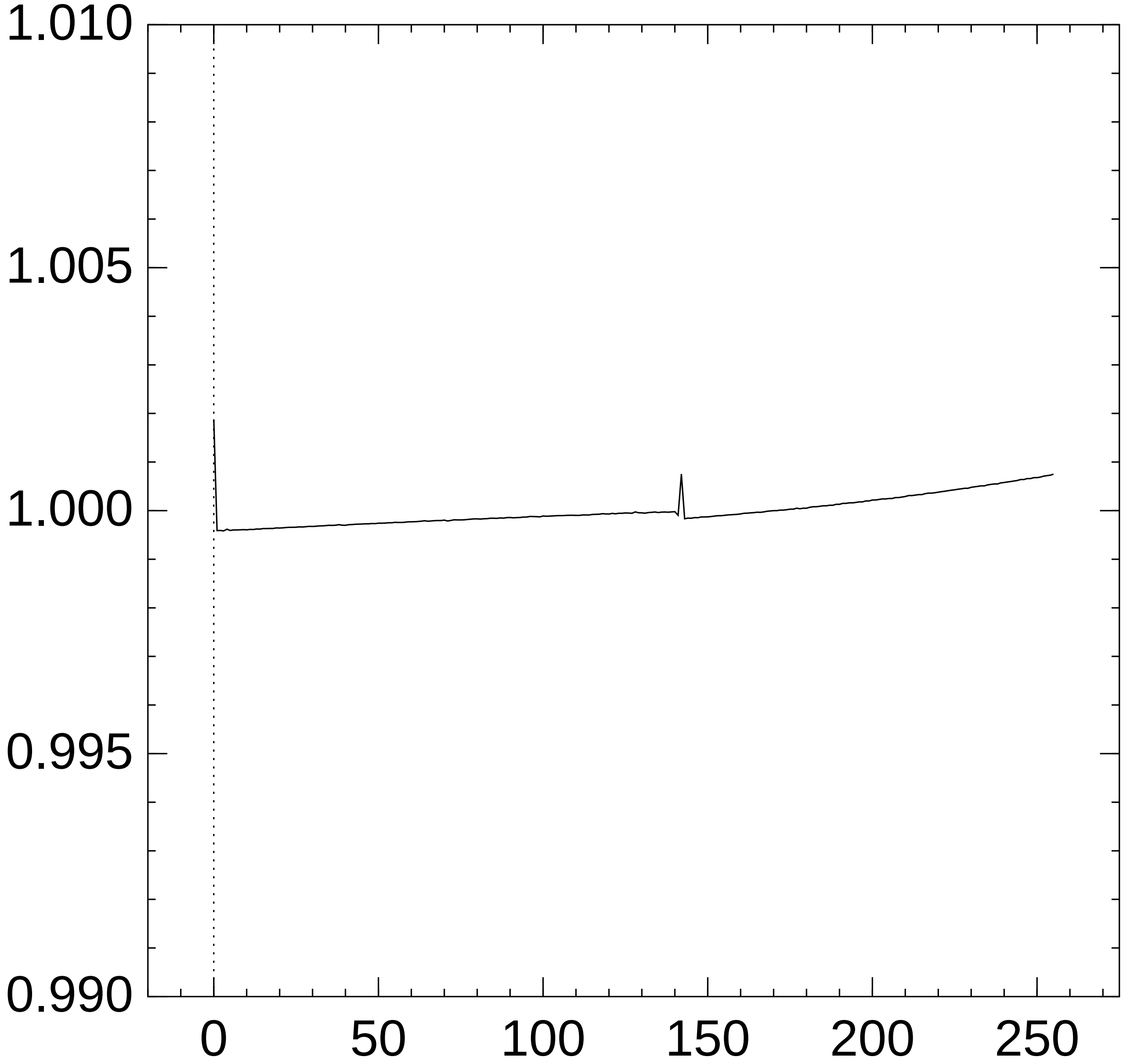
Graph of $256\,\Pr[z_{140} = x]$:



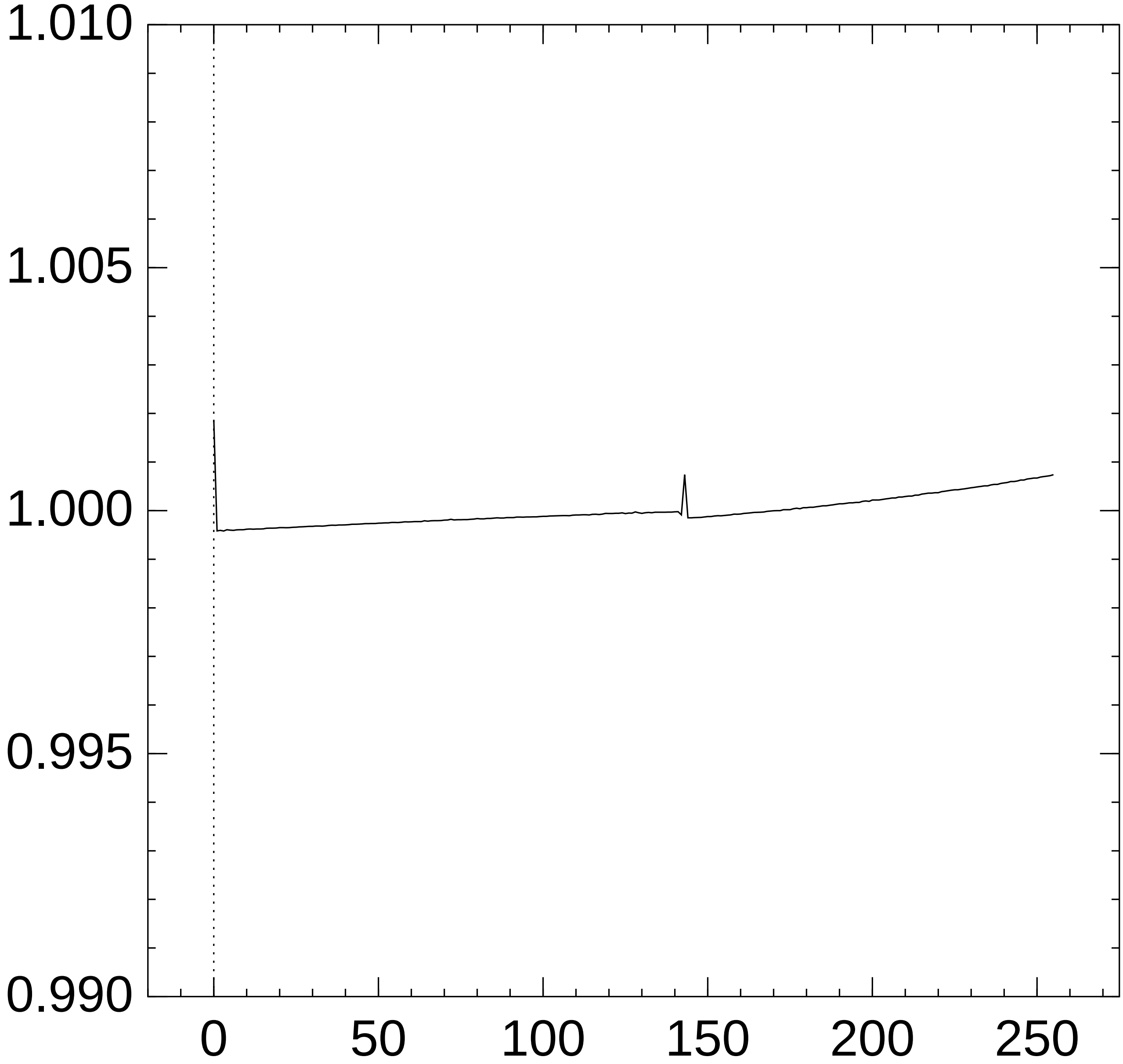
Graph of $256\,\Pr[z_{141} = x]$:



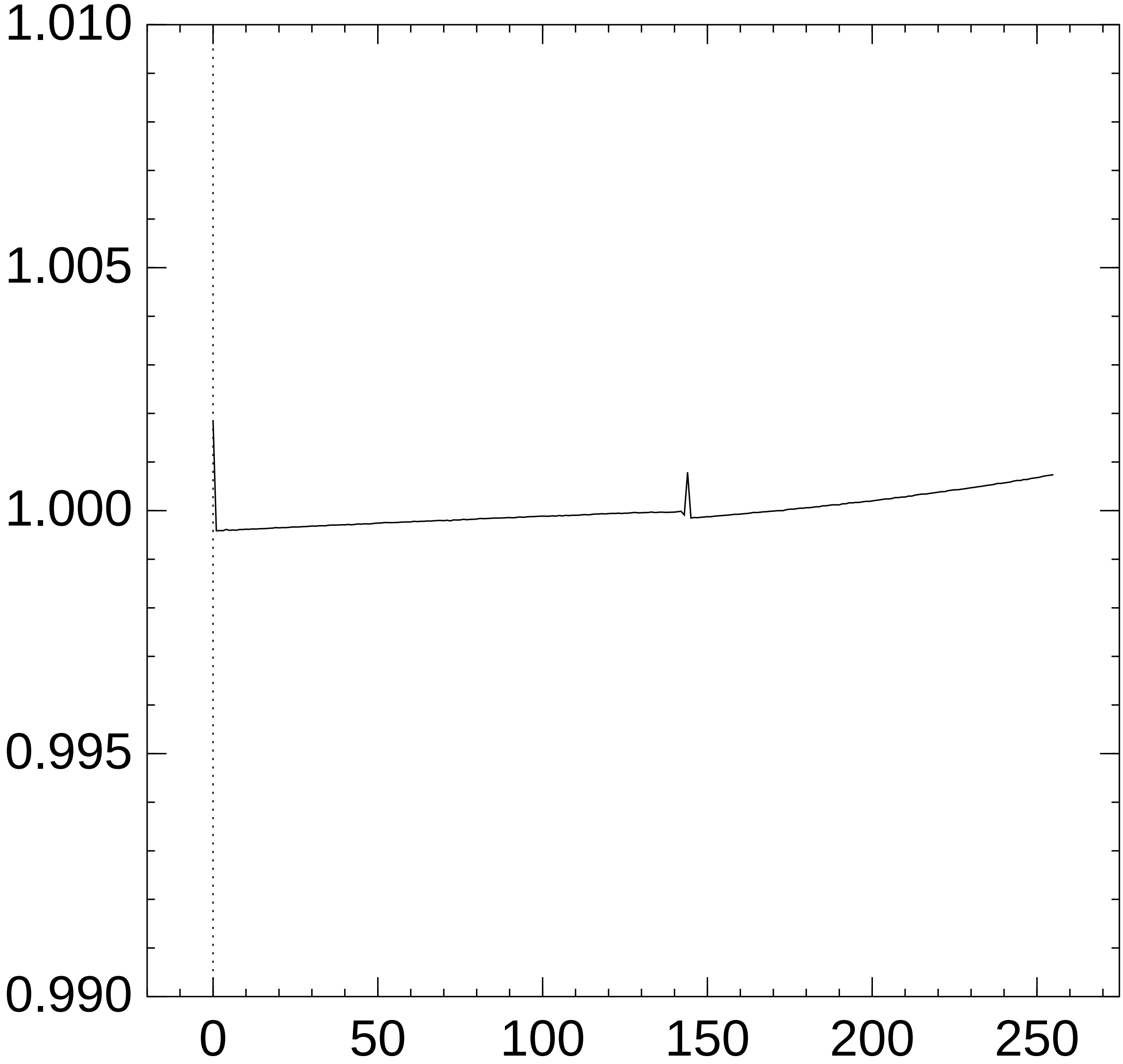
Graph of $256\,\Pr[z_{142} = x]$:



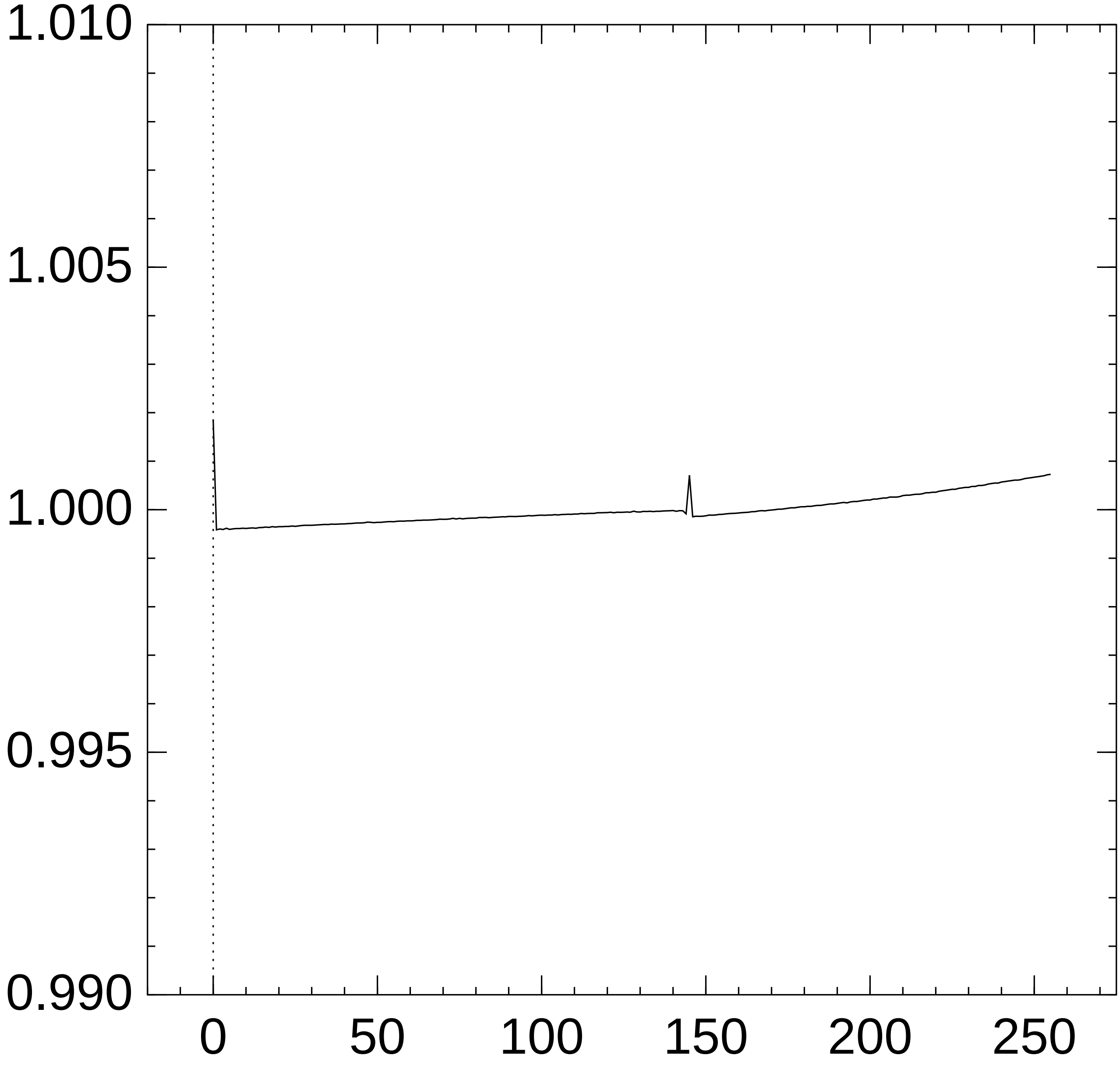
Graph of $256\,\mathrm{Pr}[z_{143} = x]$:



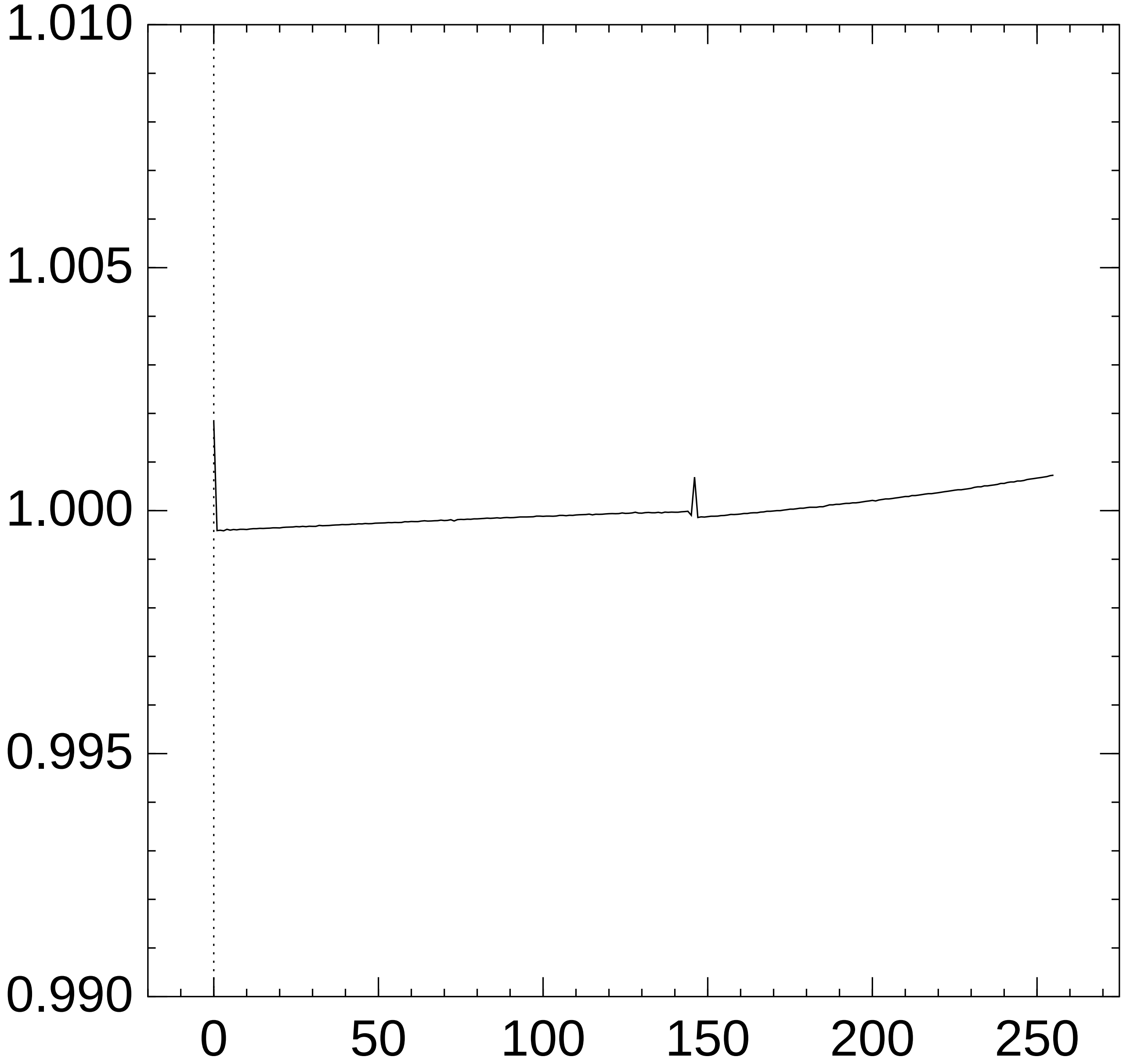
Graph of $256\,\mathrm{Pr}[z_{144} = x]$:



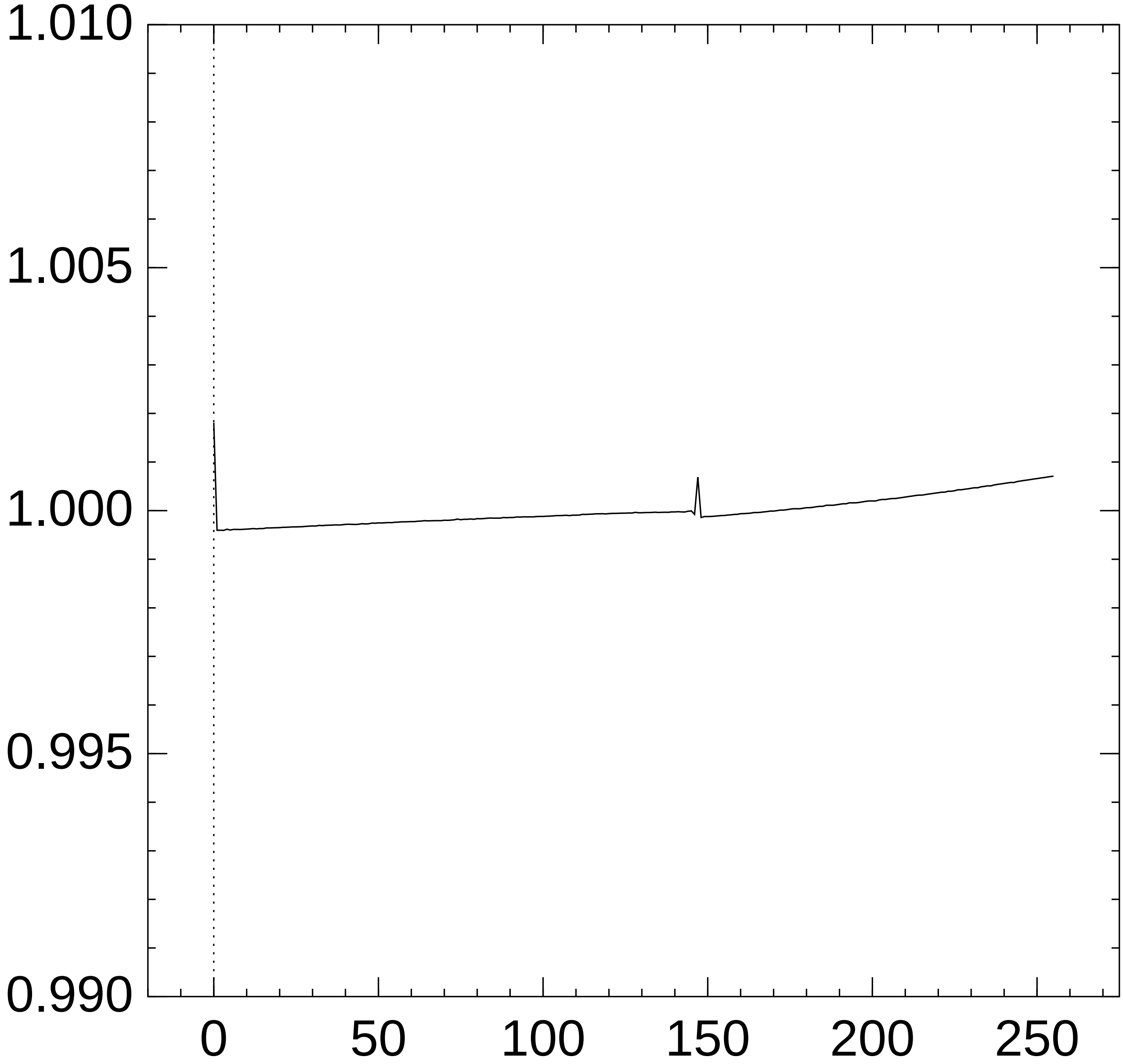
Graph of $256\,\mathrm{Pr}[z_{145} = x]$:



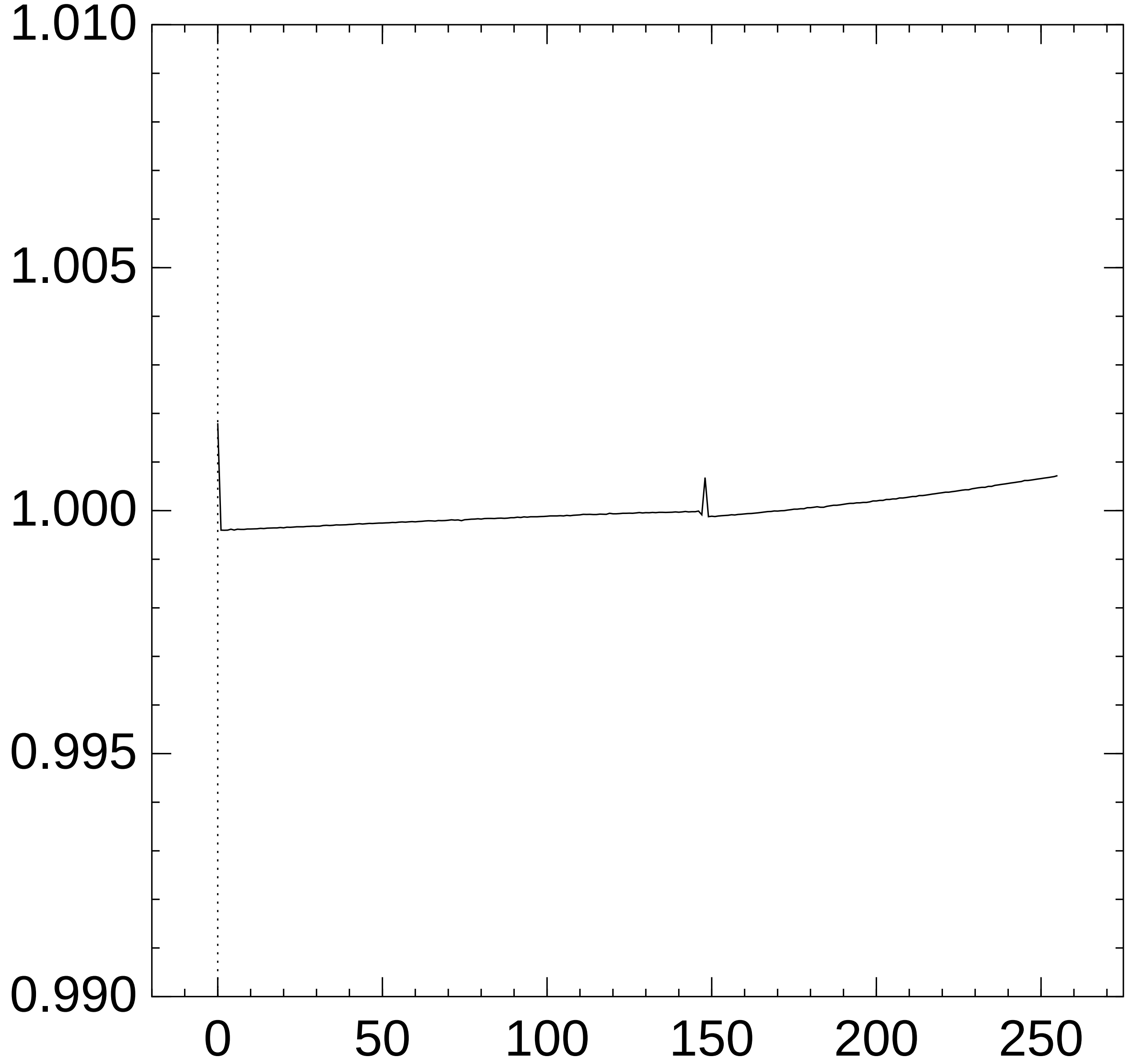
Graph of $256\,\Pr[z_{146} = x]$:



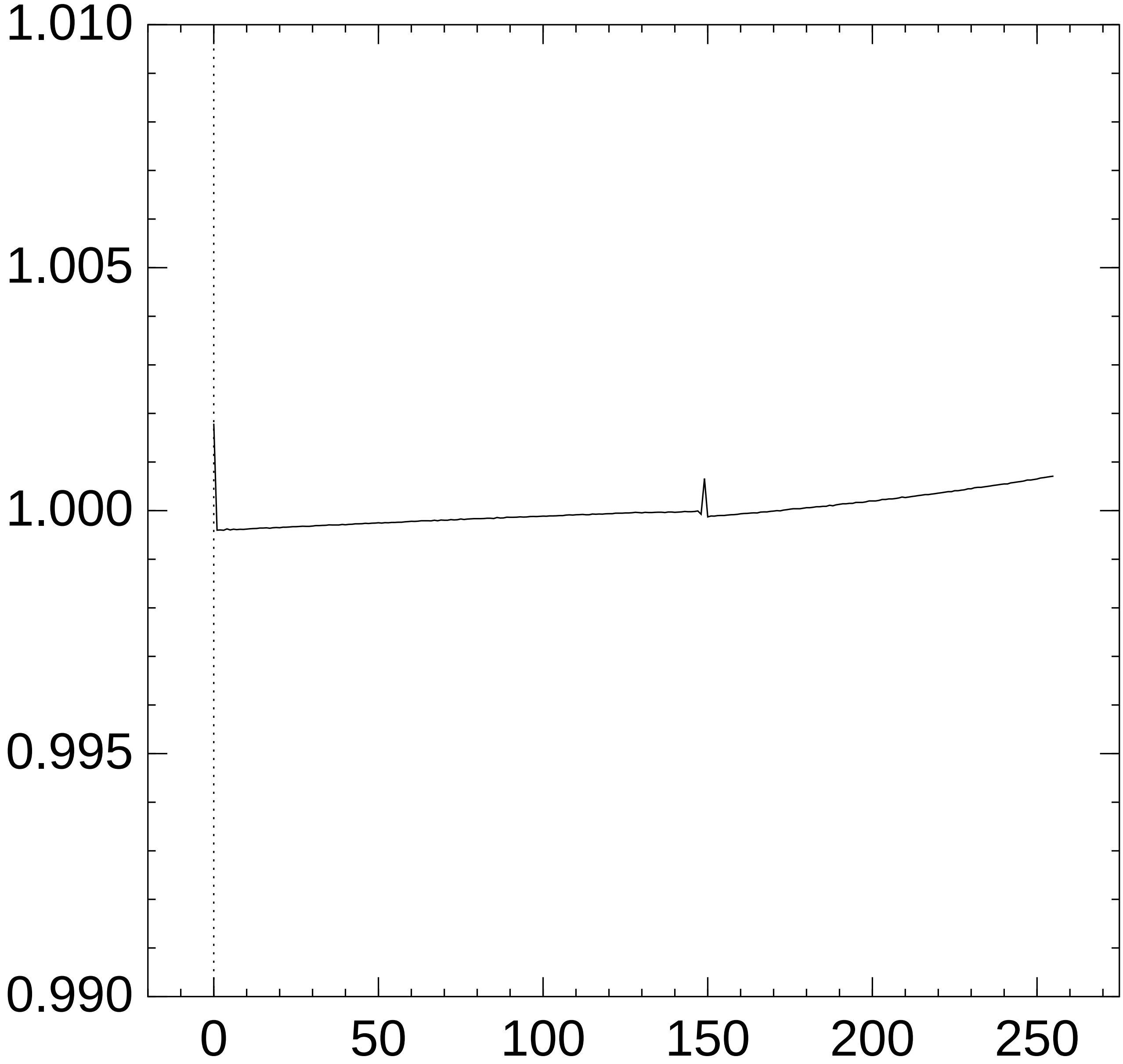
Graph of $256\,\Pr[z_{147} = x]$:



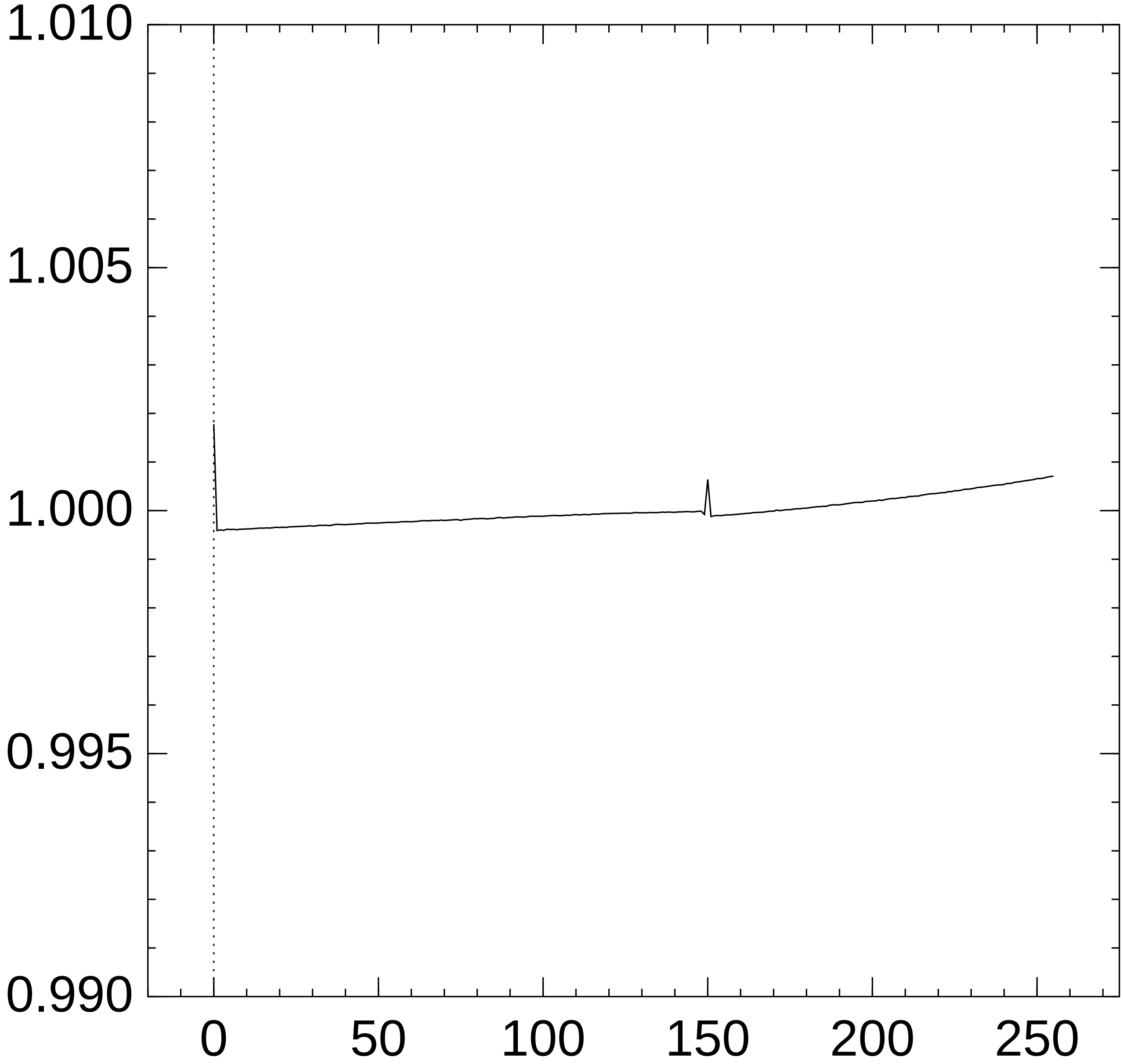
Graph of $256\,\Pr[z_{148} = x]$:



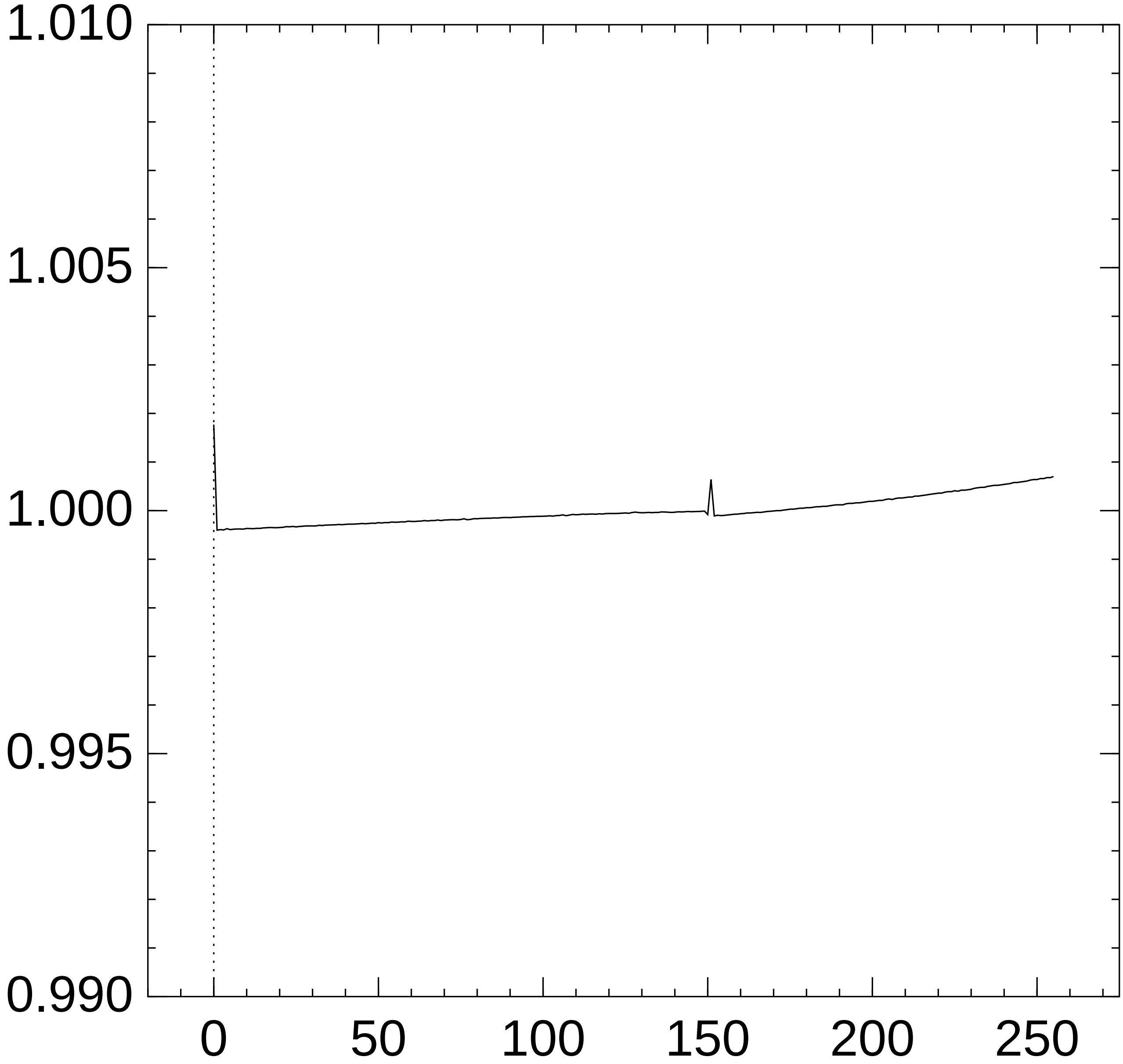
Graph of $256\,\Pr[z_{149} = x]$:



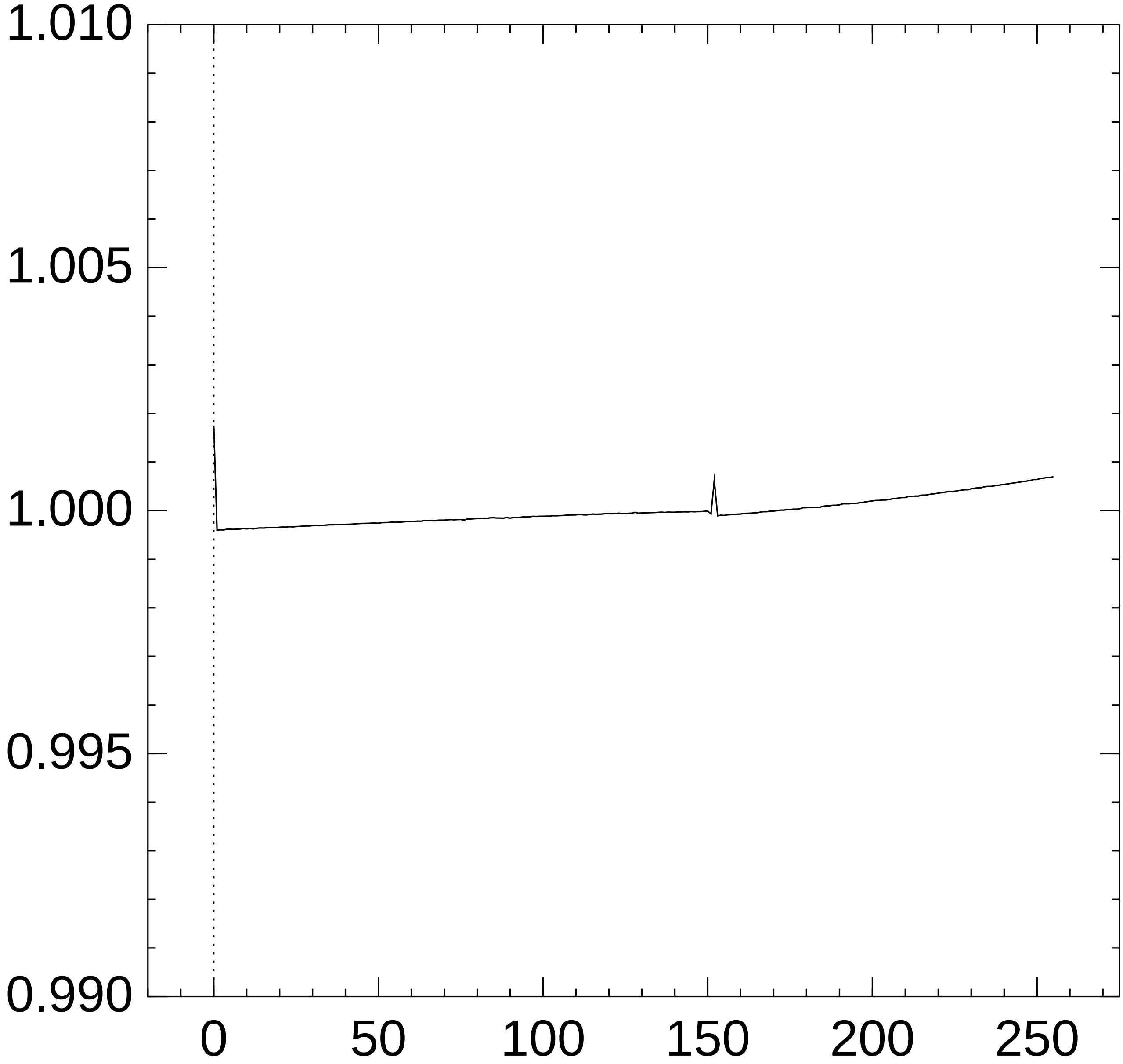
Graph of $256\,\Pr[z_{150} = x]$:



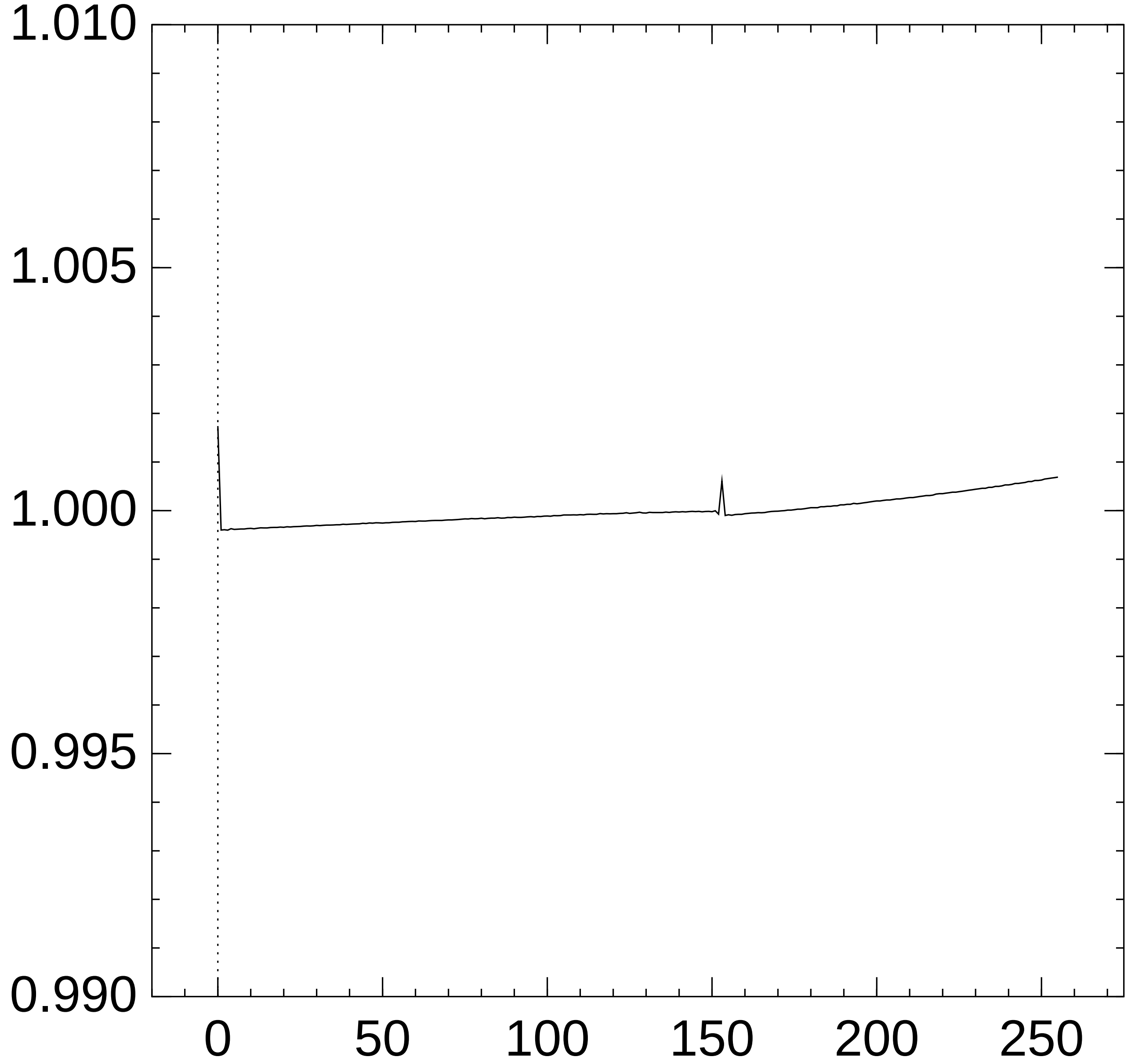
Graph of $256 \Pr[z_{151} = x]$:



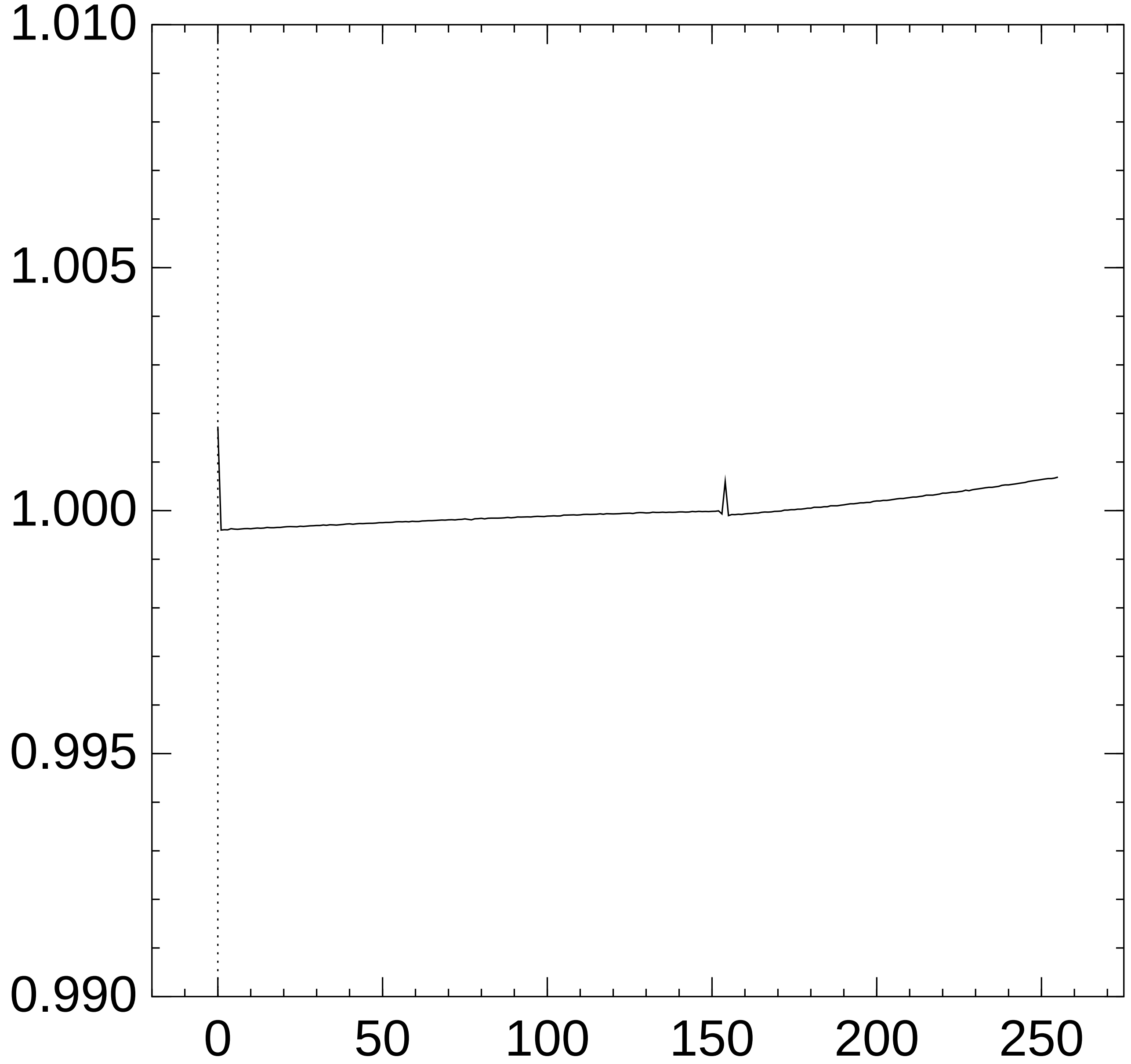
Graph of $256\,\Pr[z_{152} = x]$:



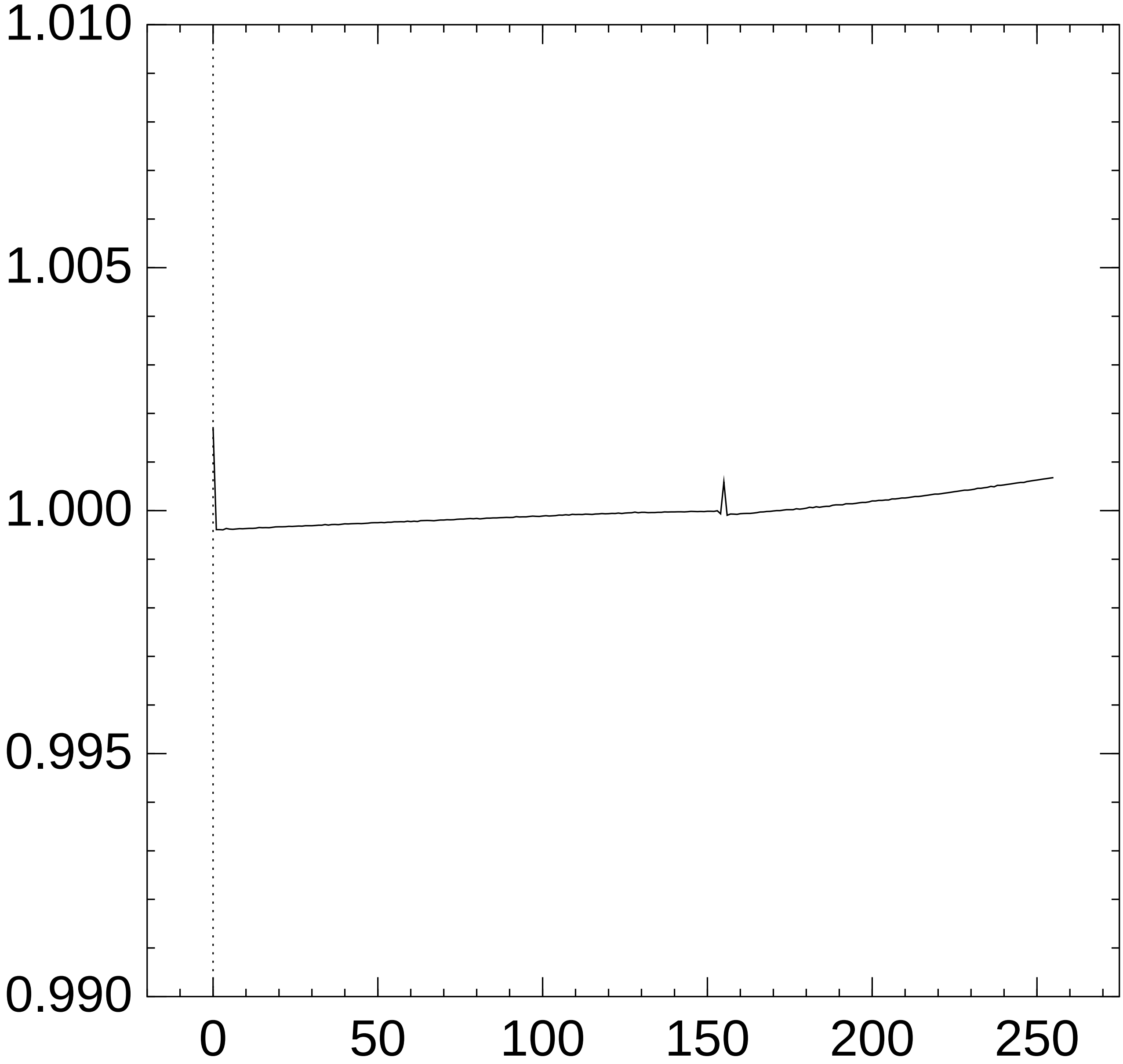
Graph of $256\,\mathrm{Pr}[z_{153} = x]$:



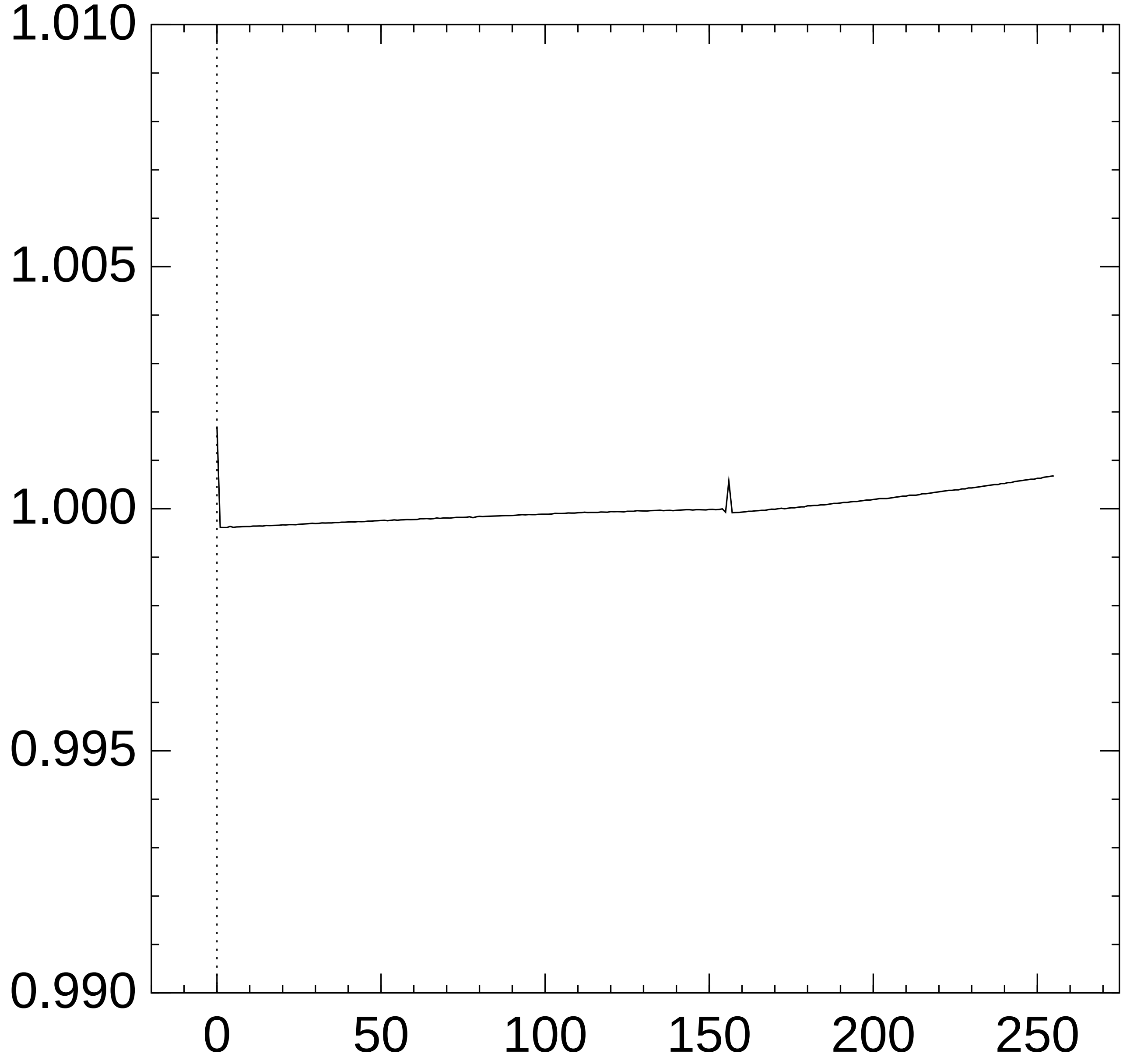
Graph of $256\,\Pr[z_{154} = x]$:



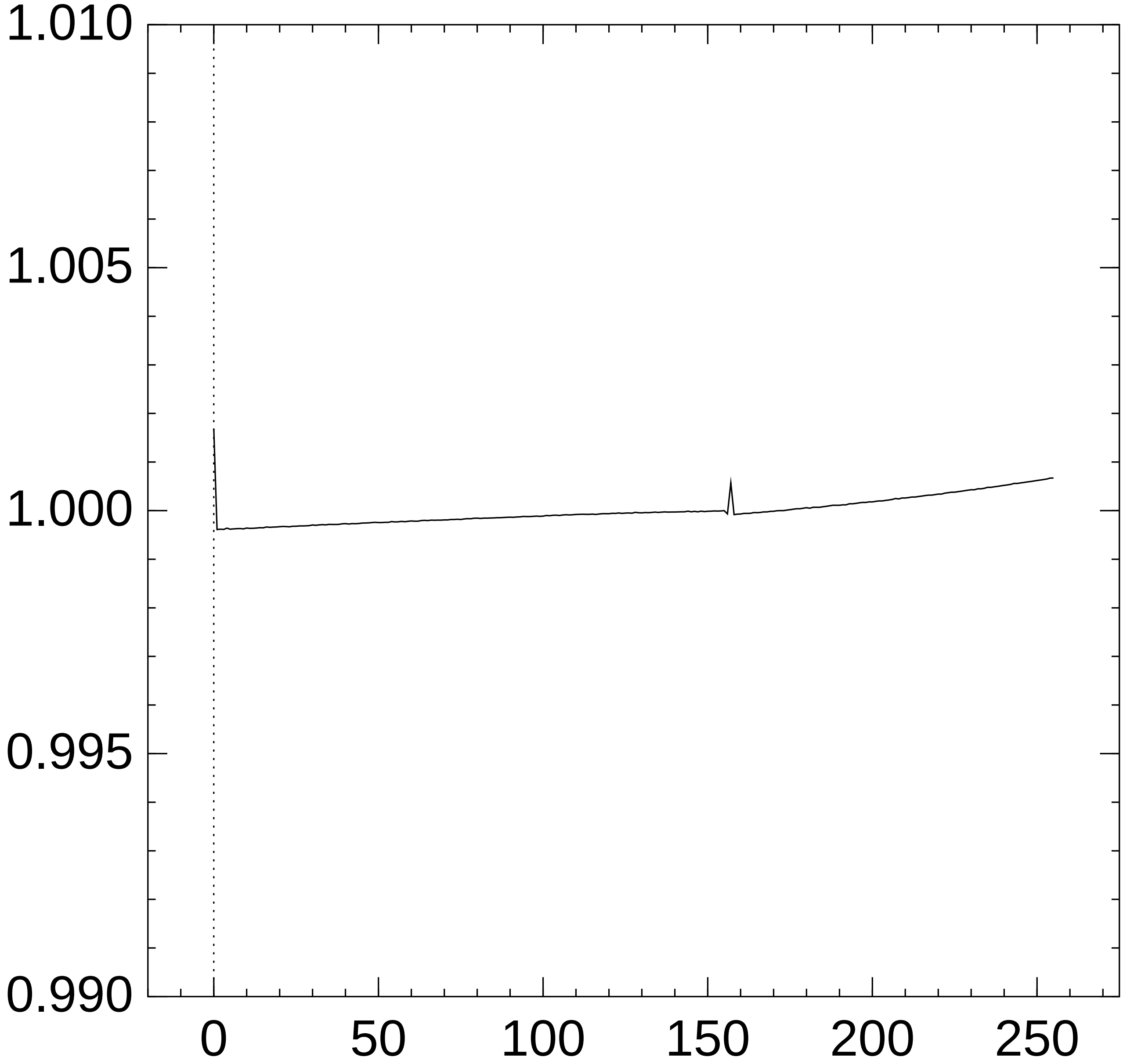
Graph of $256\,\Pr[z_{155} = x]$:



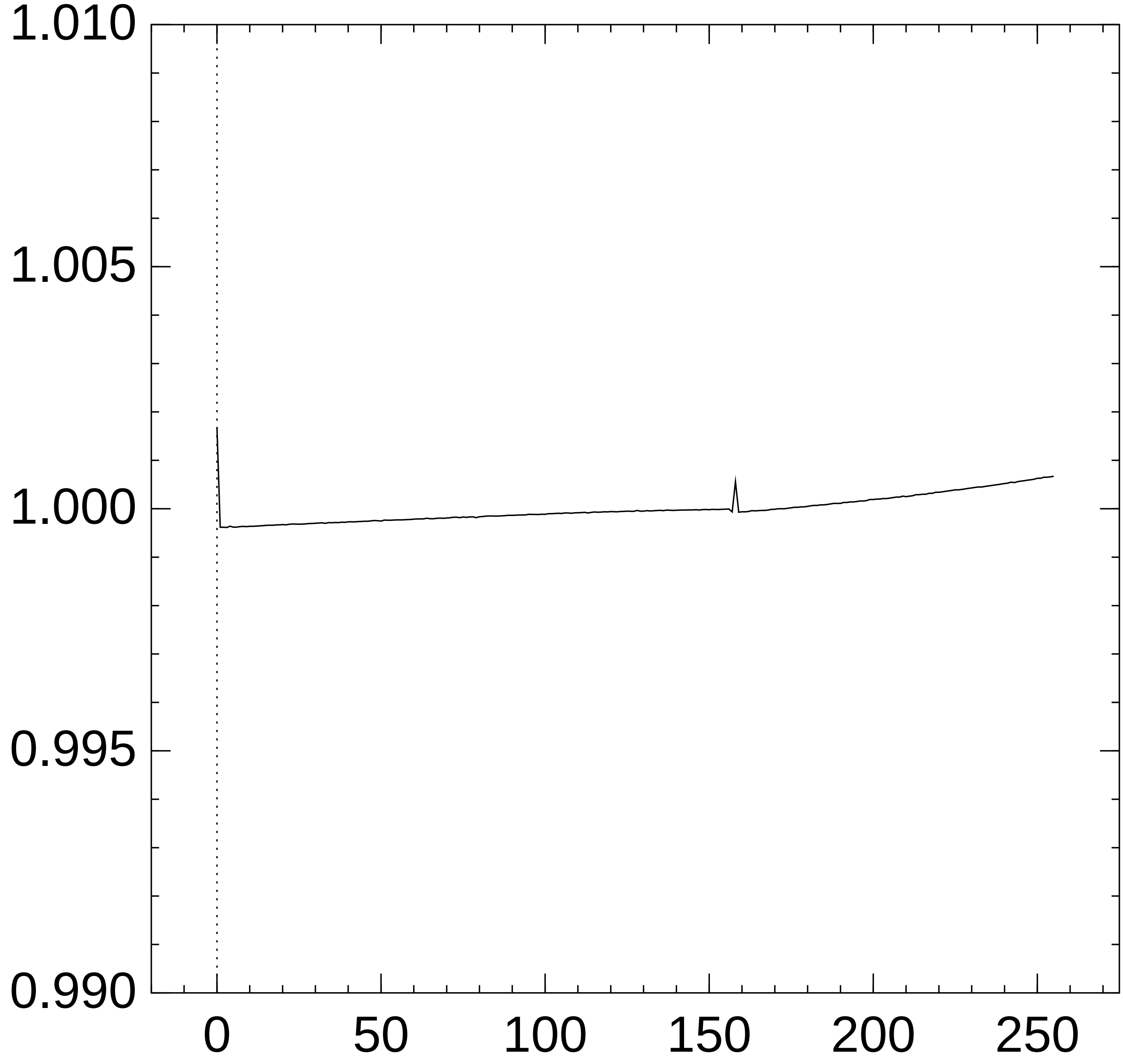
Graph of $256\,\Pr[z_{156} = x]$:



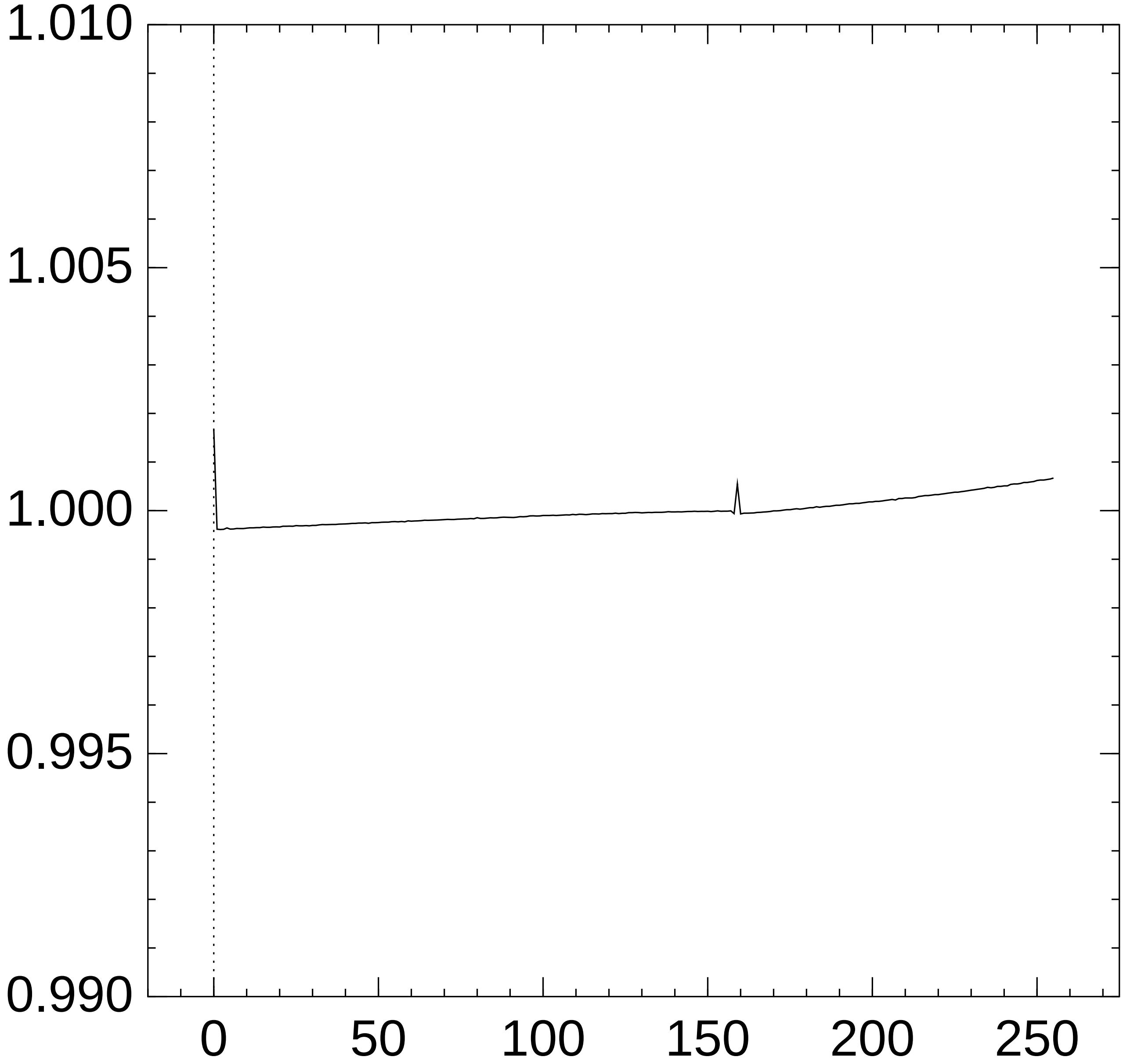
Graph of $256\,\Pr[z_{157} = x]$:



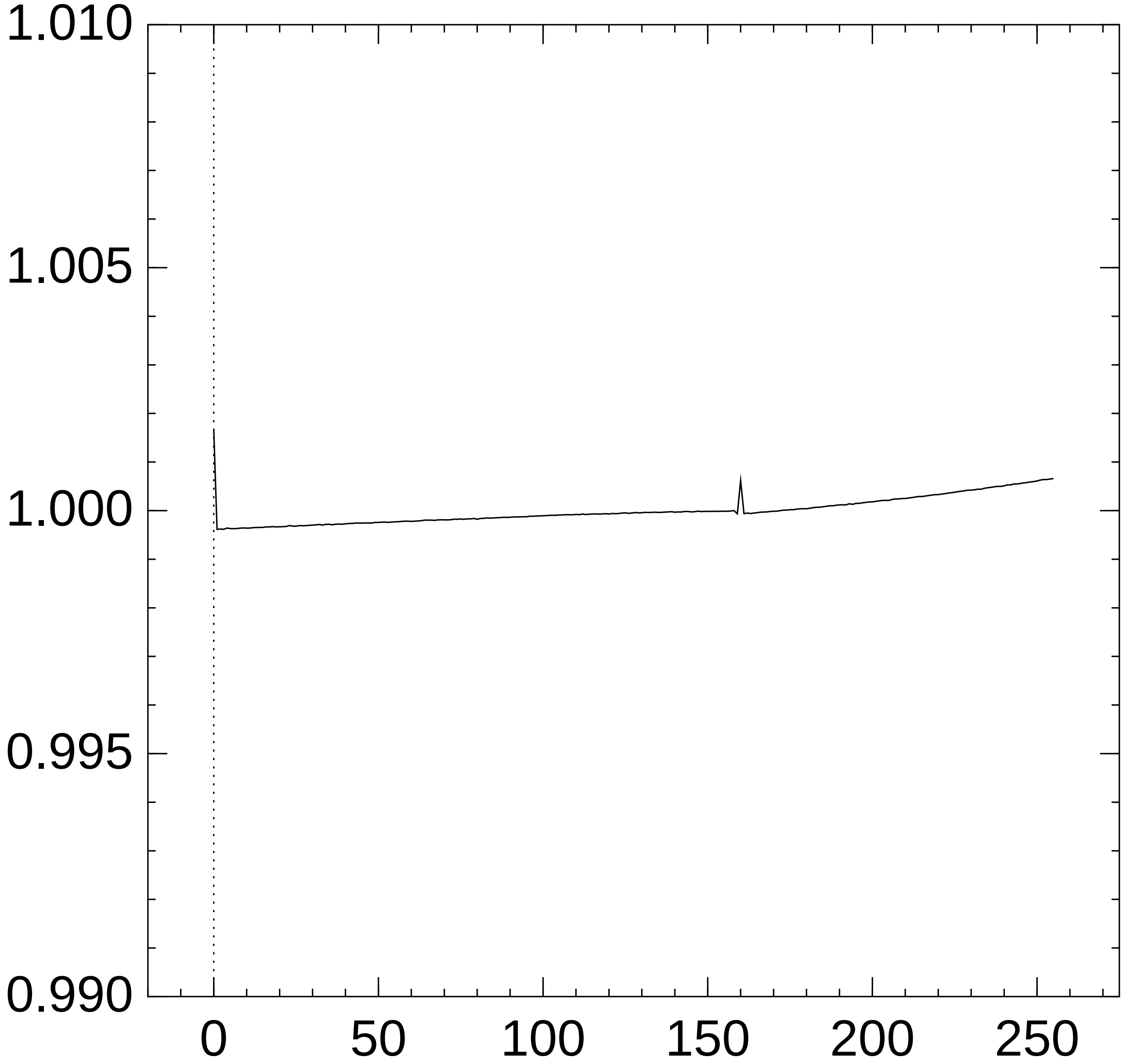
Graph of $256 \Pr[z_{158} = x]$:



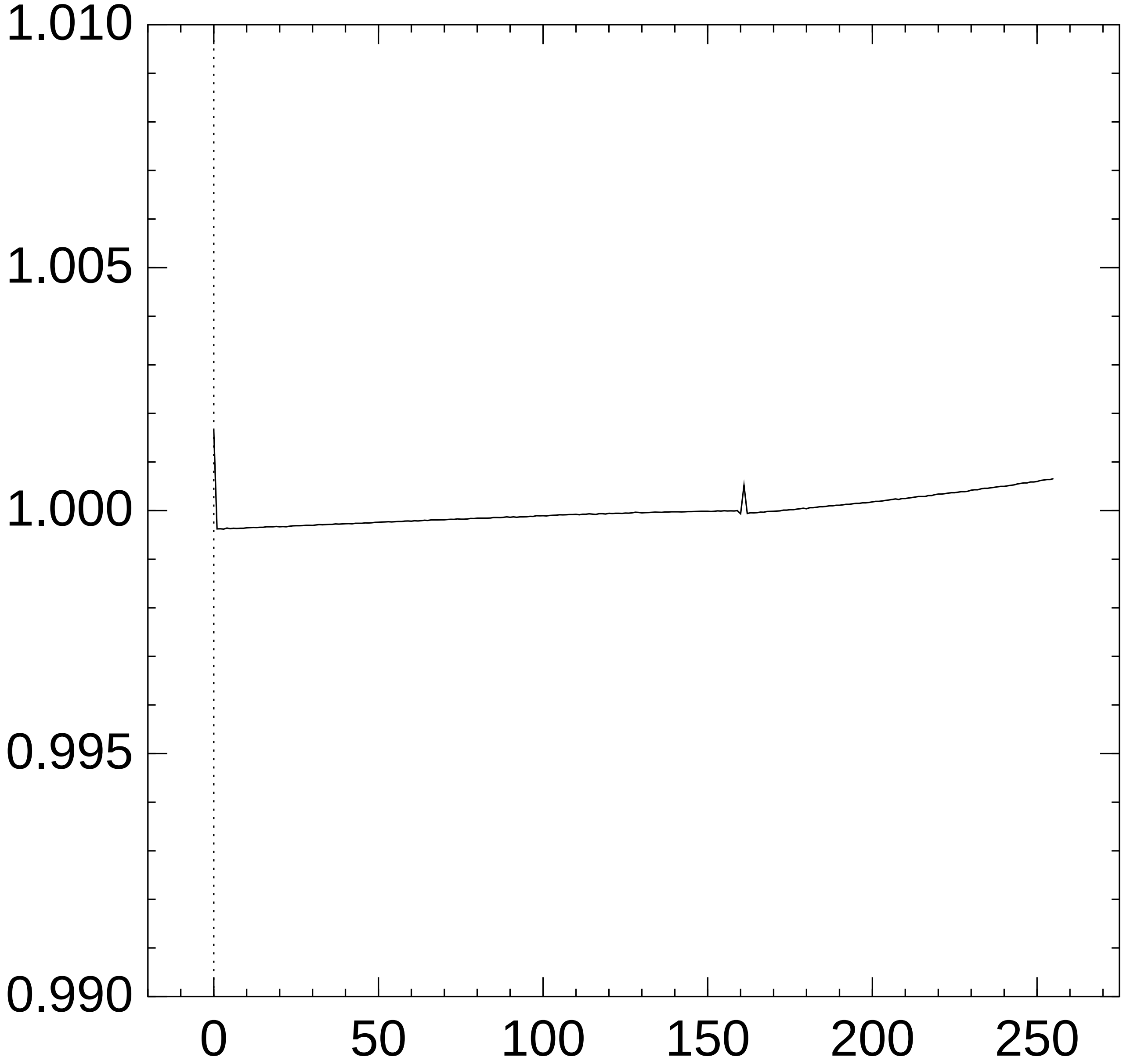
Graph of $256\,\Pr[z_{159} = x]$:



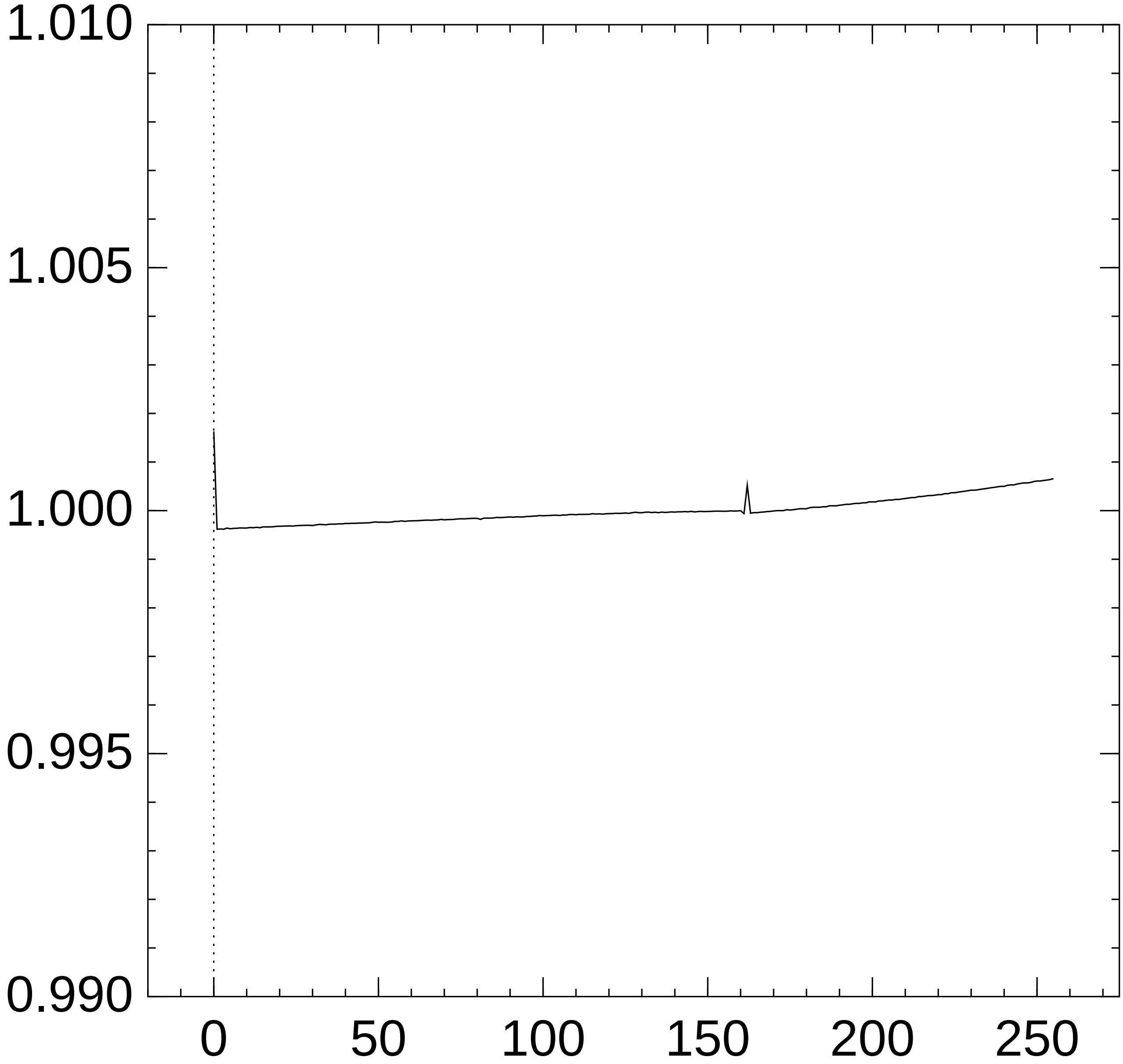
Graph of $256\,\Pr[z_{160} = x]$:



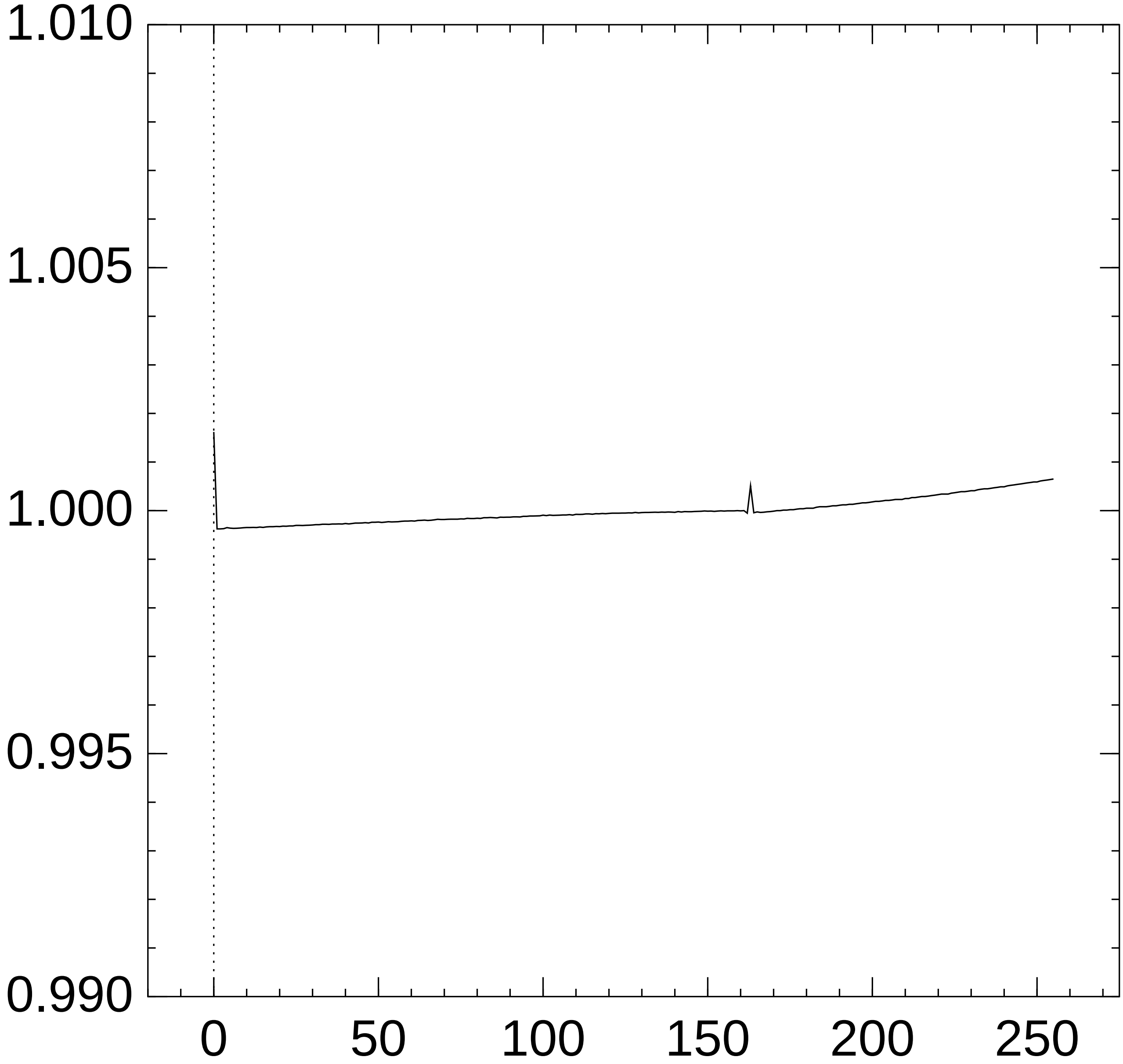
Graph of $256\,\mathrm{Pr}[z_{161} = x]$:



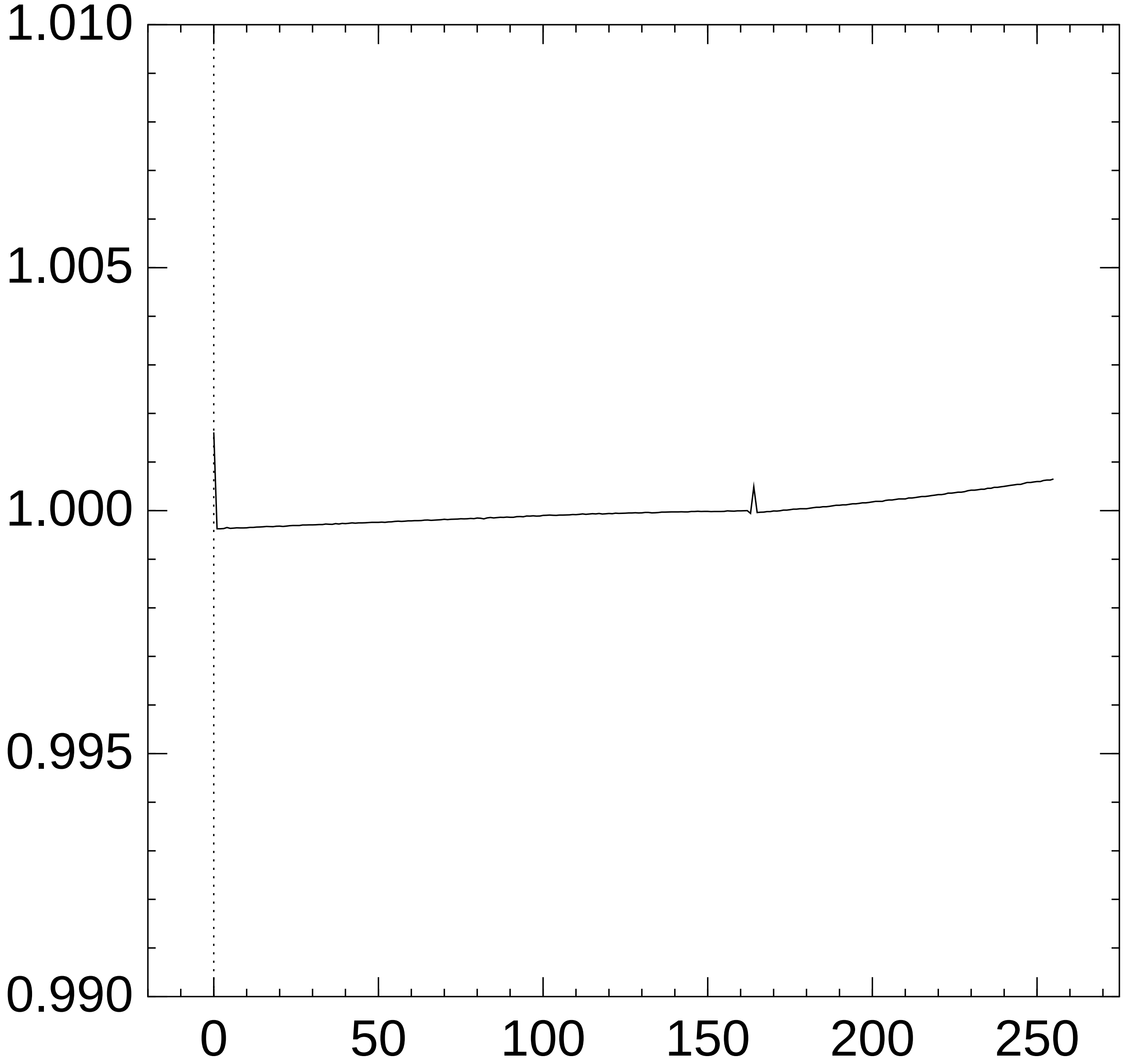
Graph of $256\,\mathrm{Pr}[z_{162} = x]$:



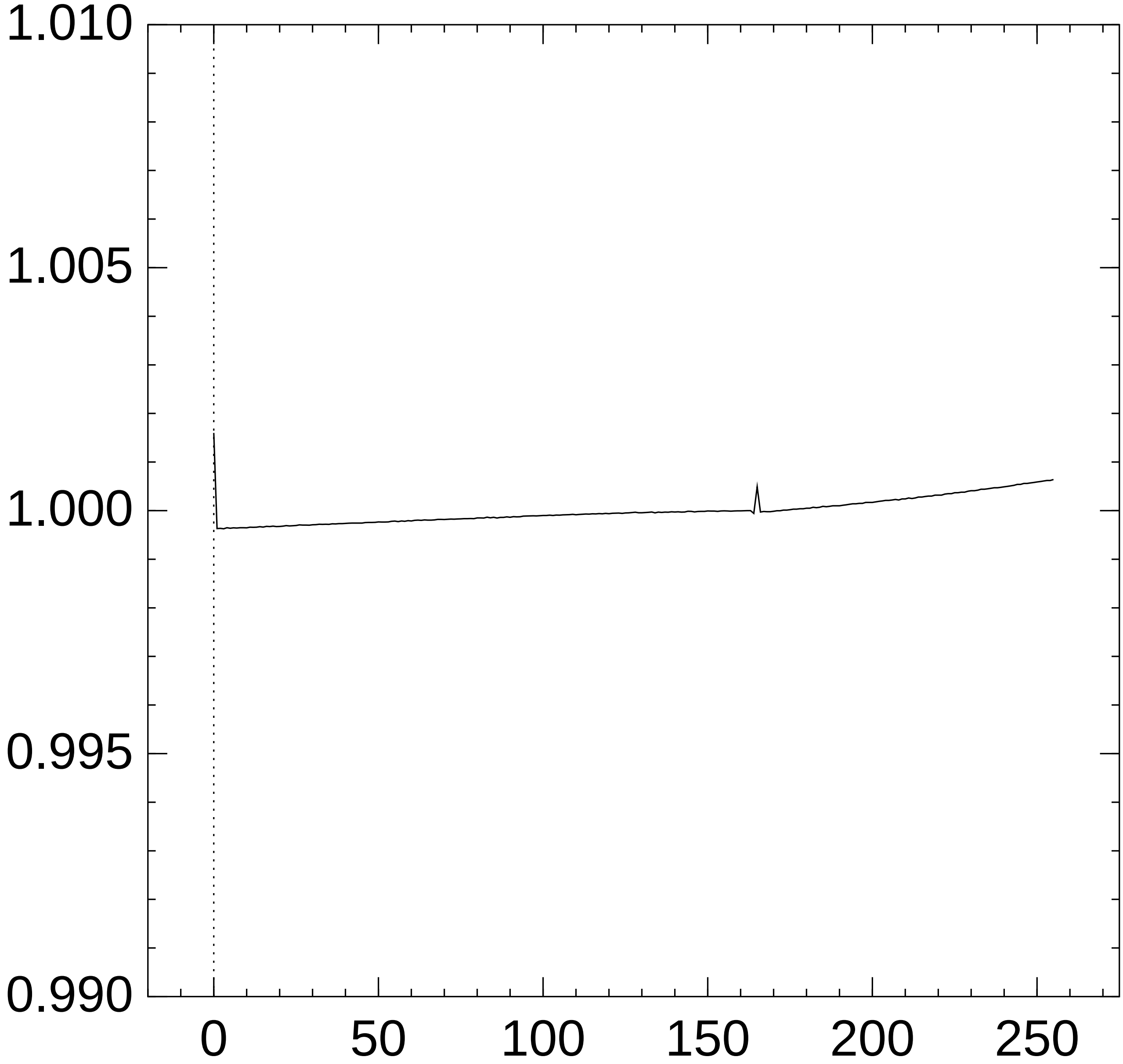
Graph of $256\,\Pr[z_{163} = x]$:



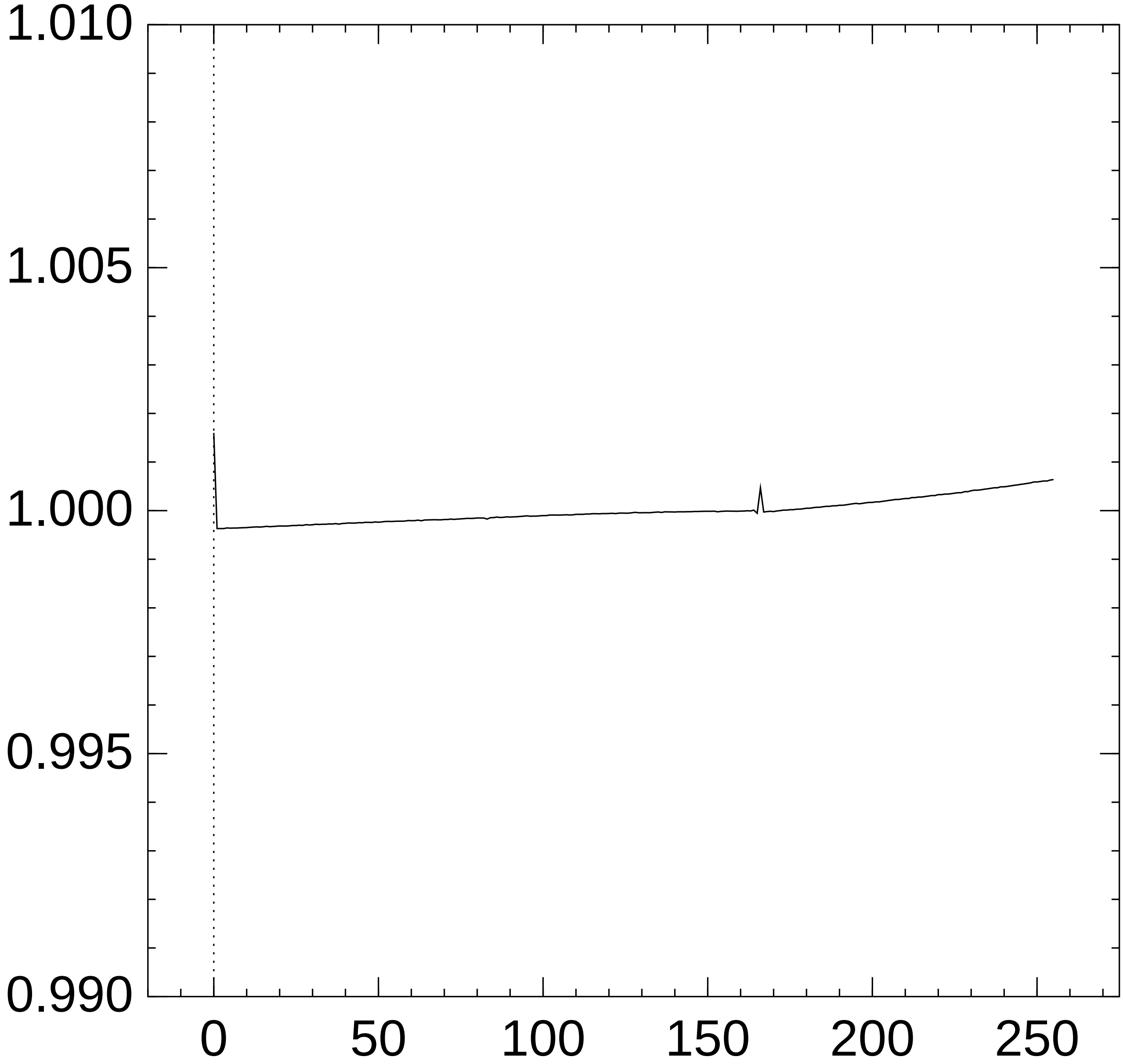
Graph of $256\,\Pr[z_{164} = x]$:



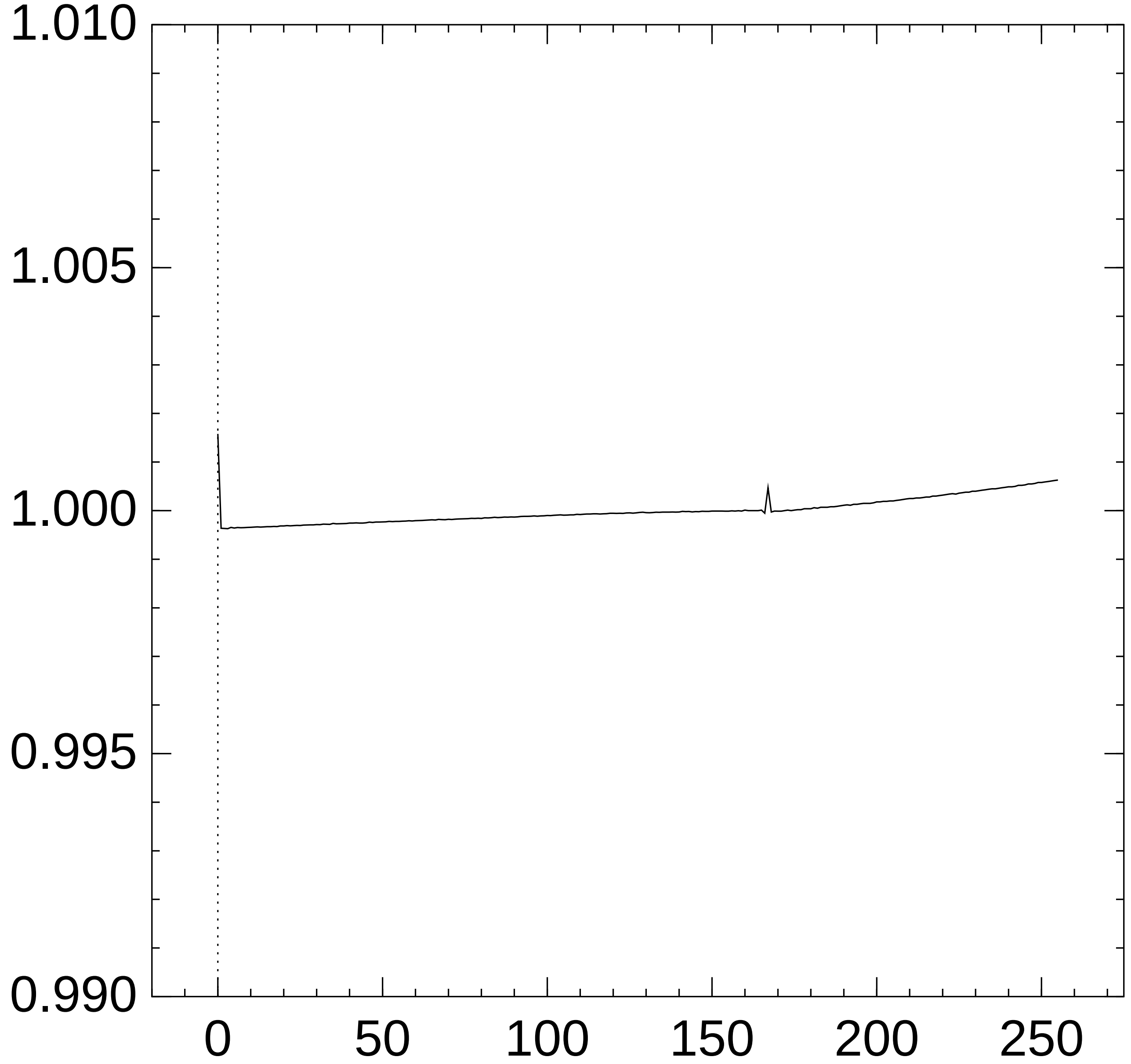
Graph of $256 \Pr[z_{165} = x]$:



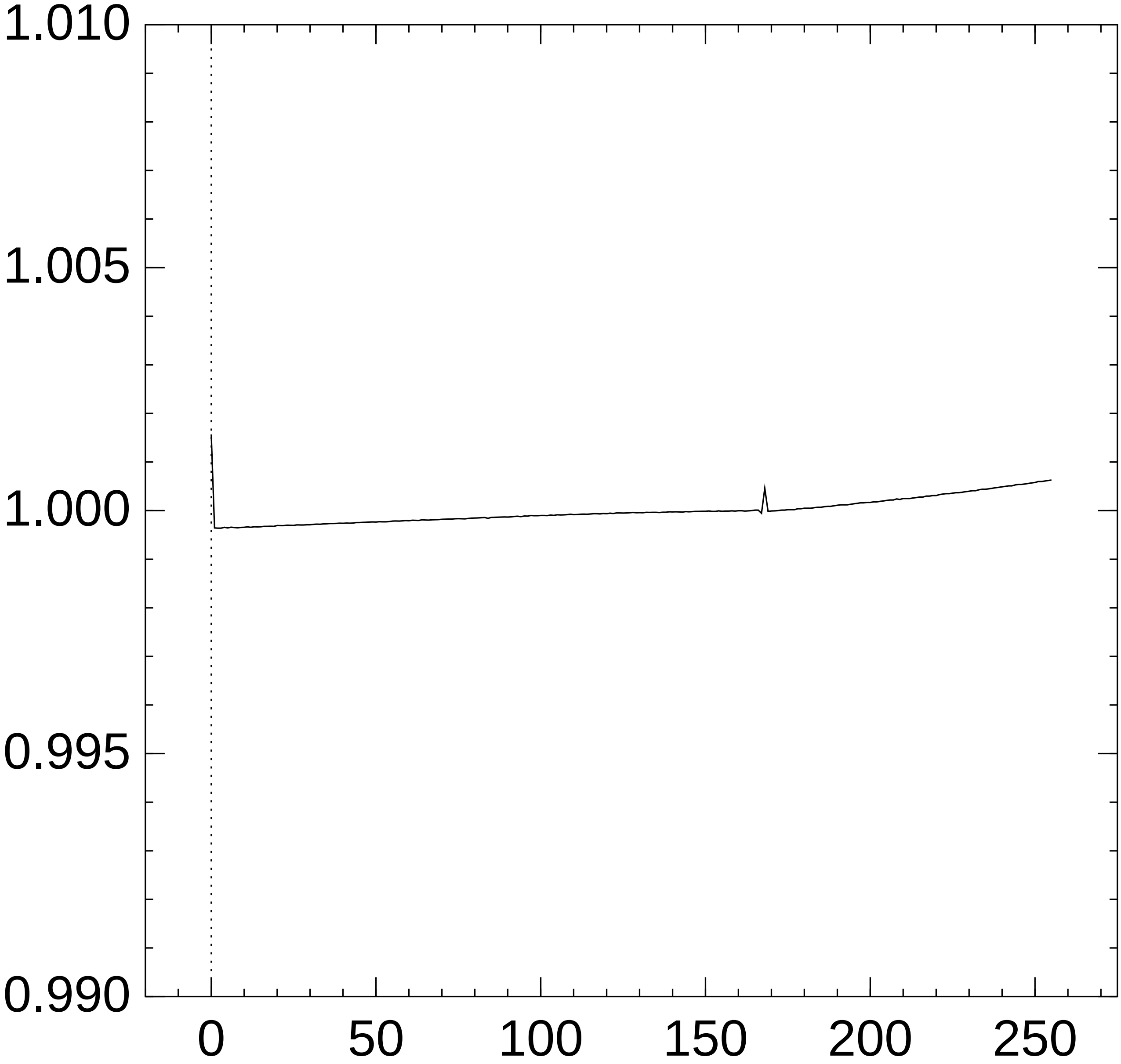
Graph of $256\,\mathrm{Pr}[z_{166} = x]$:



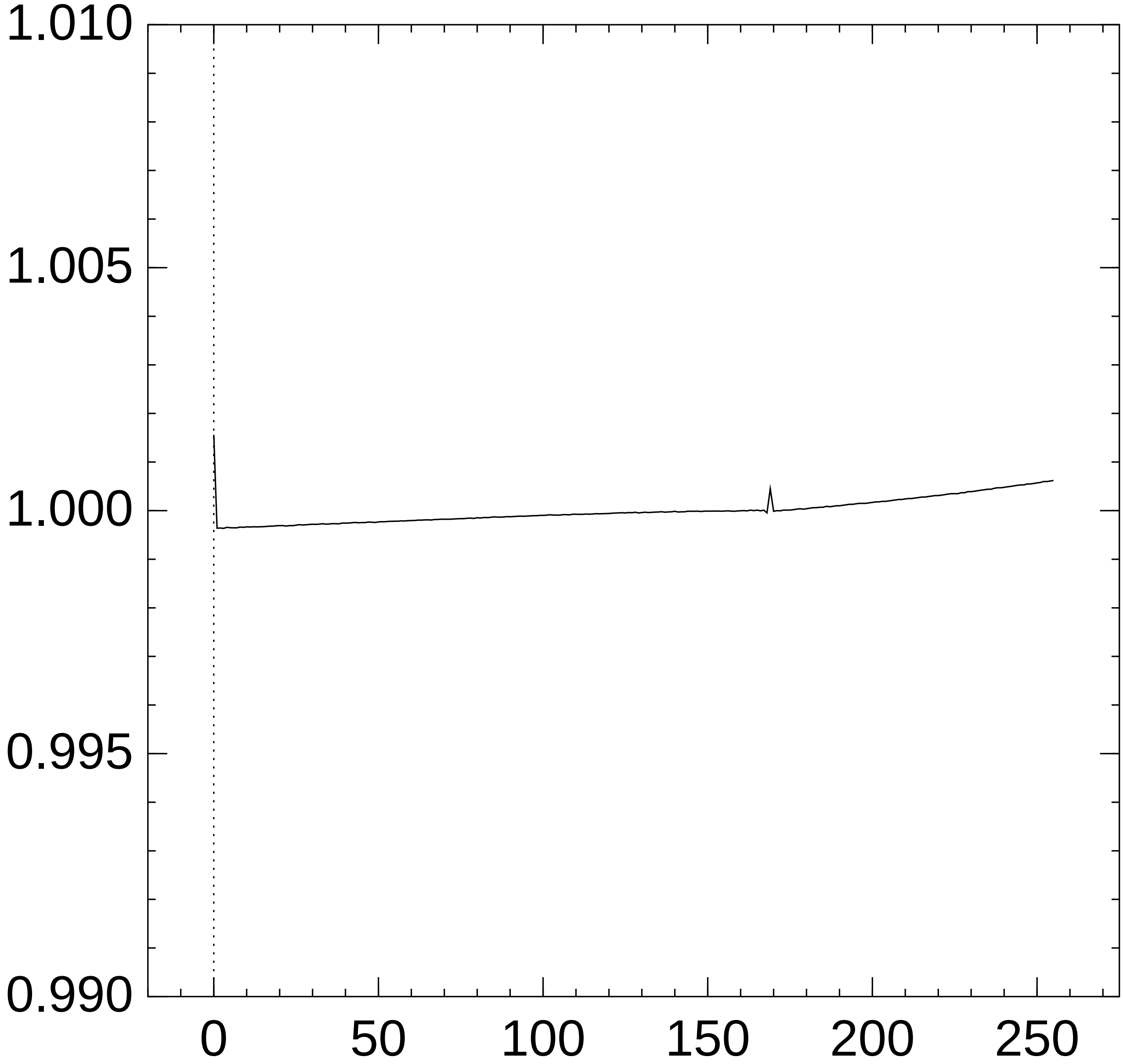
Graph of $256\,\Pr[z_{167} = x]$:



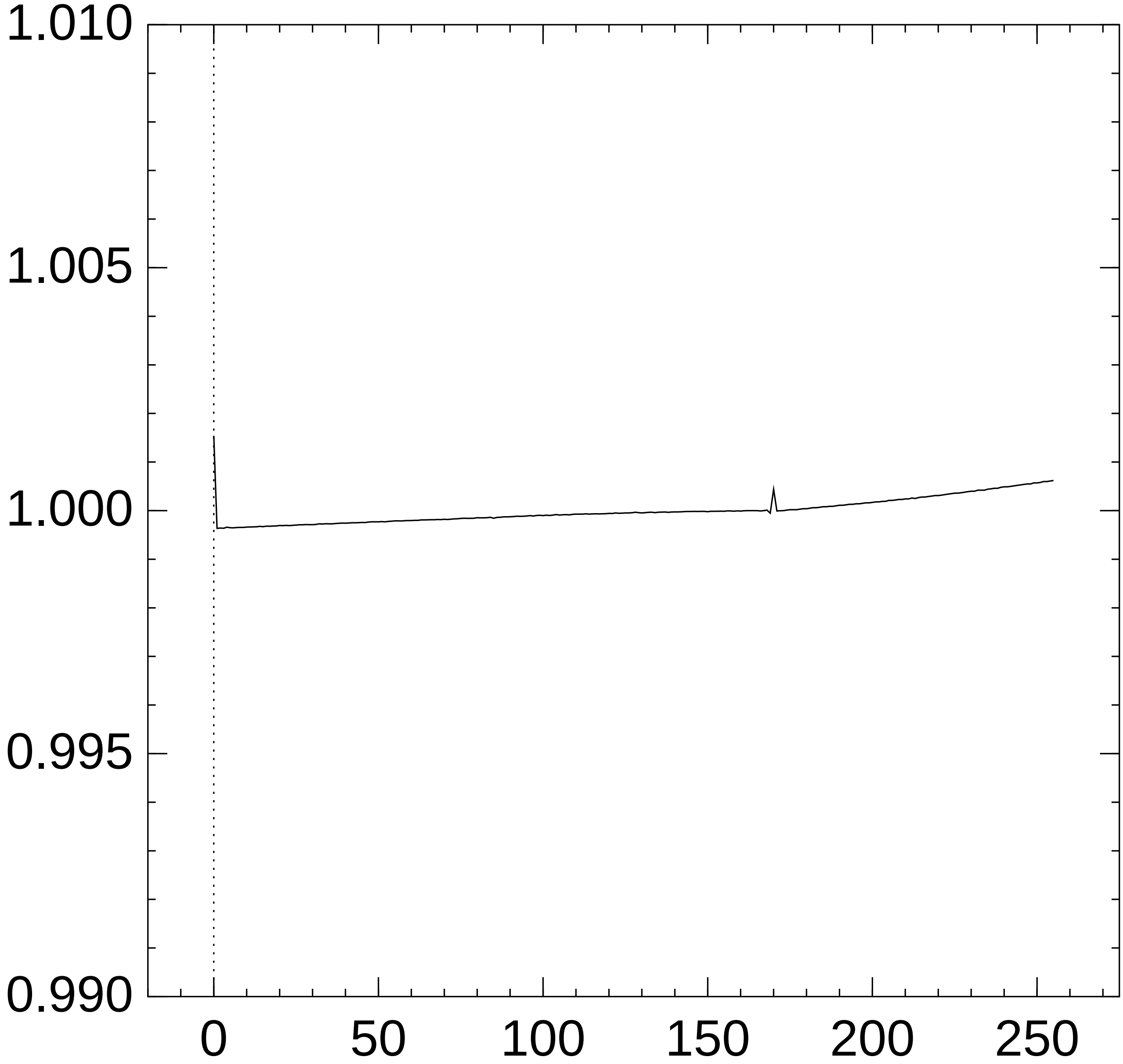
Graph of $256\,\Pr[z_{168} = x]$:



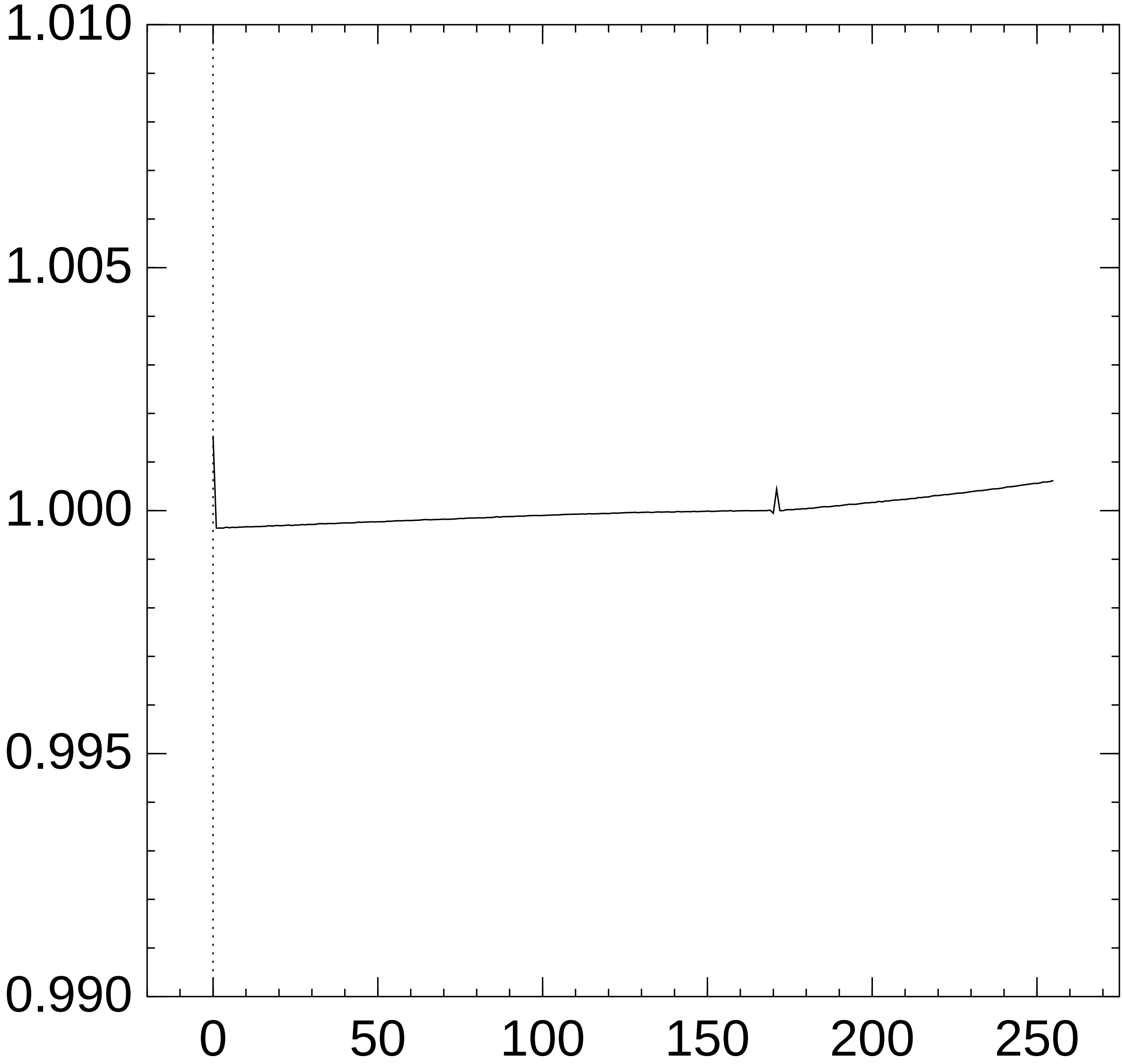
Graph of $256\,\mathrm{Pr}[z_{169} = x]$:



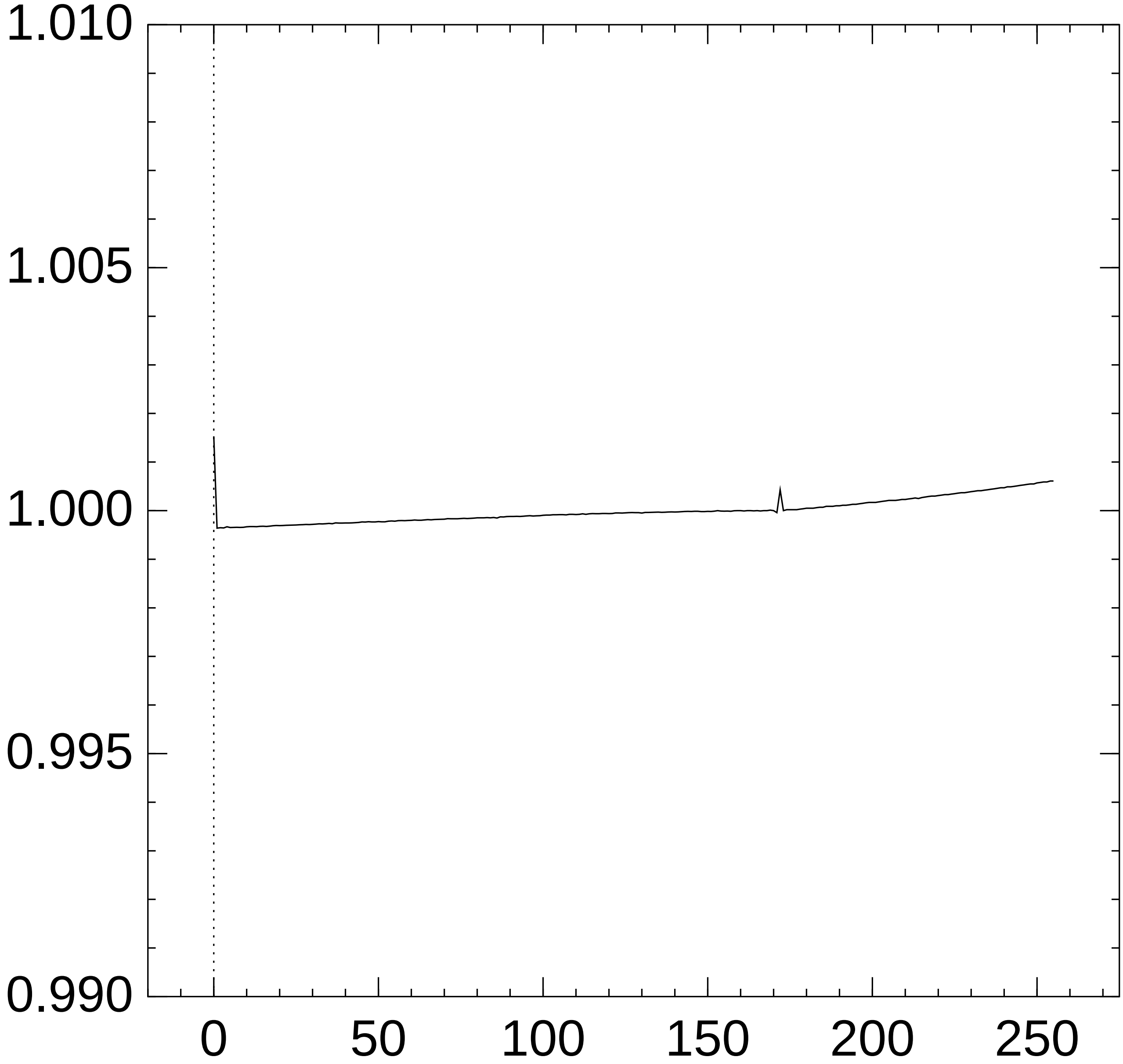
Graph of $256\,\Pr[z_{170} = x]$:



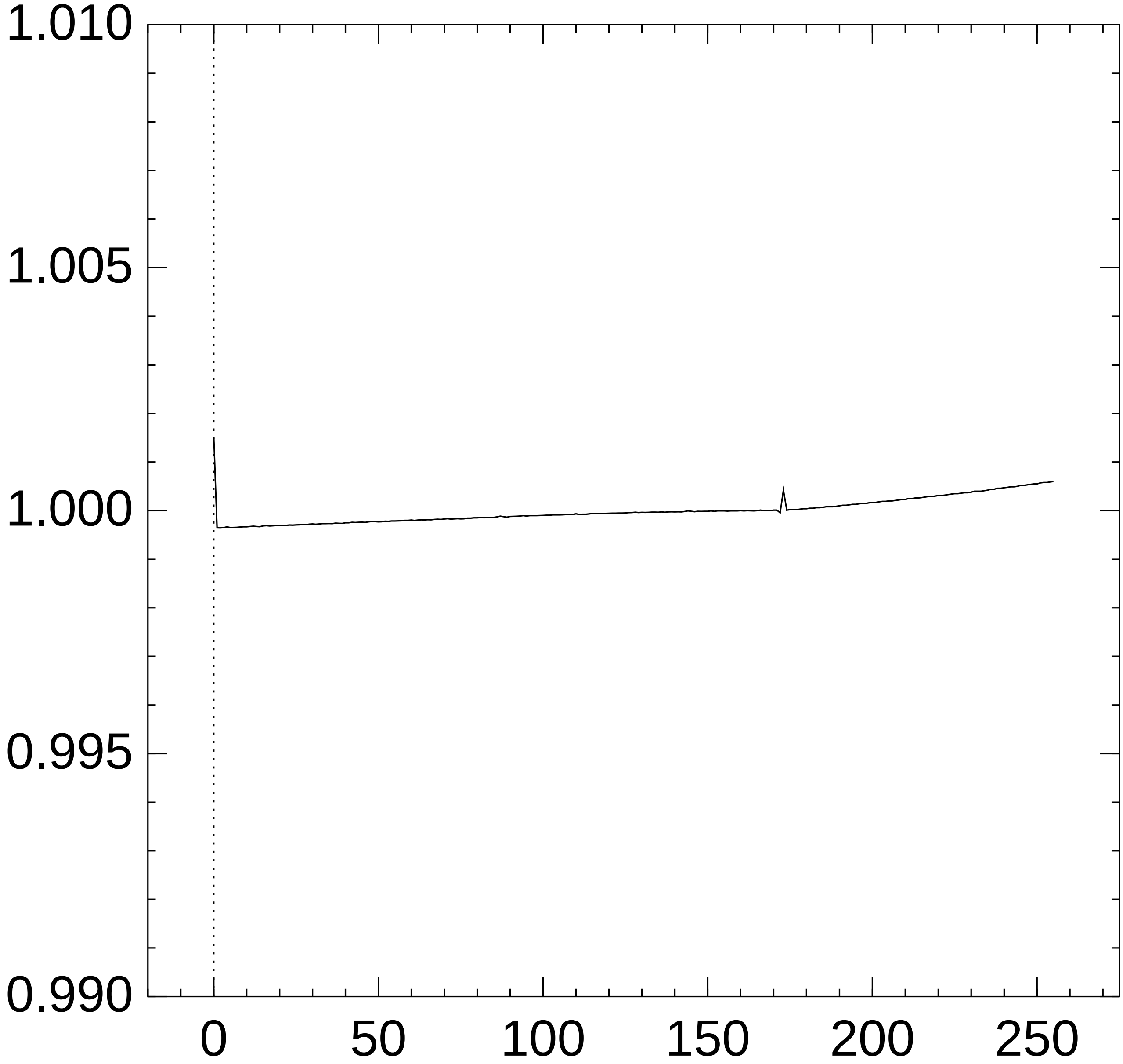
Graph of $256\,\Pr[z_{171} = x]$:



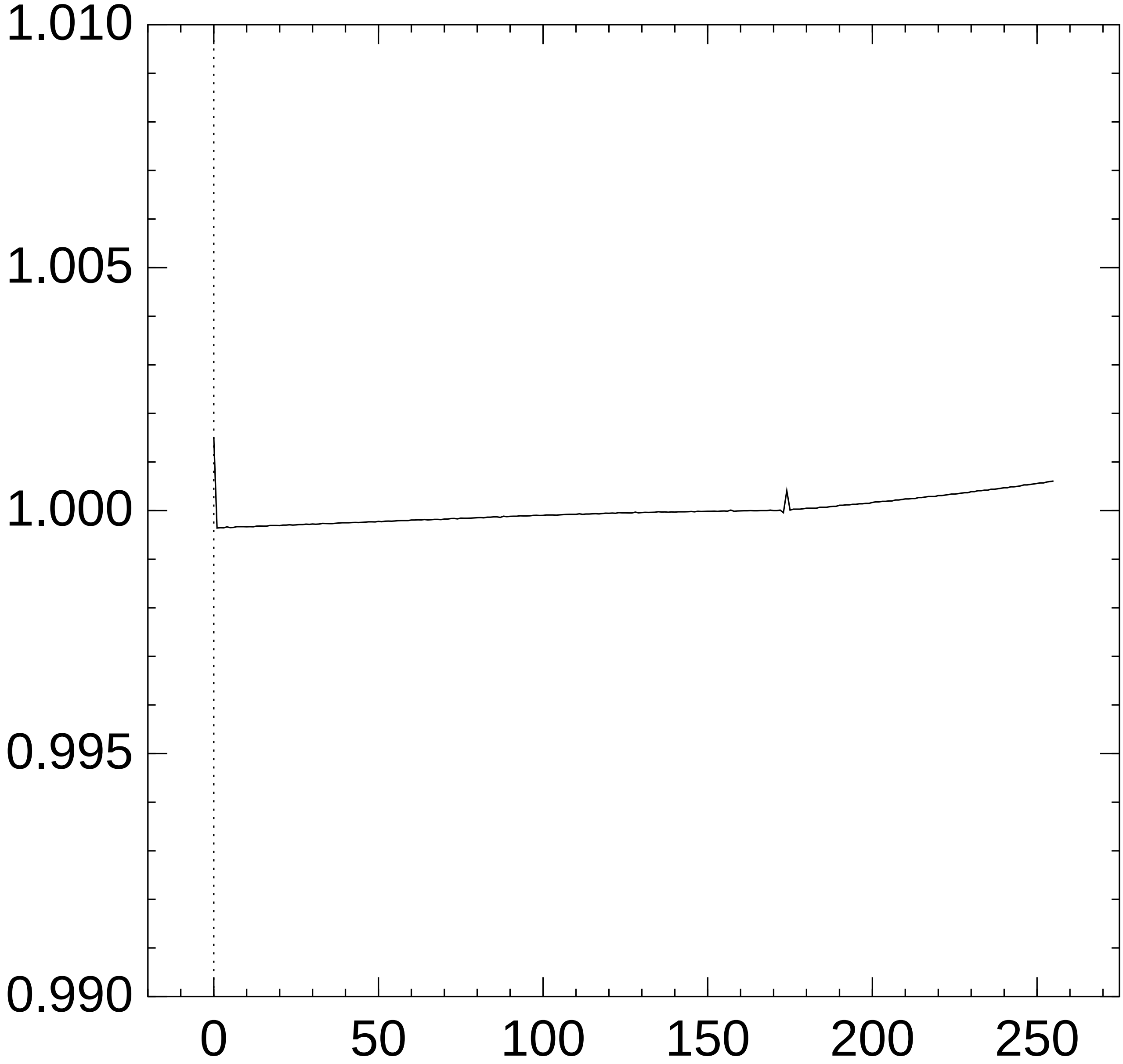
Graph of $256\,\mathrm{Pr}[z_{172} = x]$:



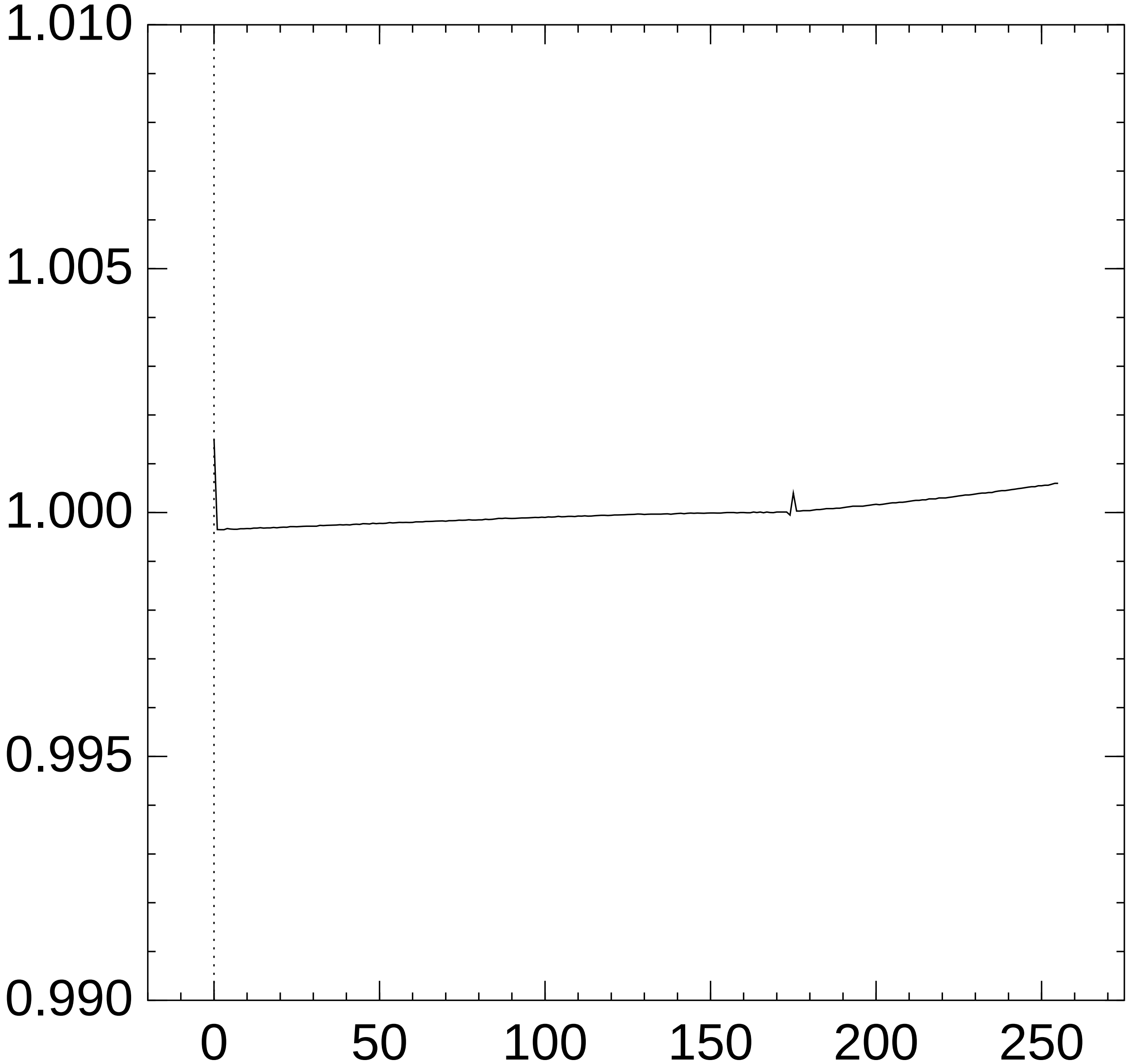
Graph of $256\,\Pr[z_{173} = x]$:



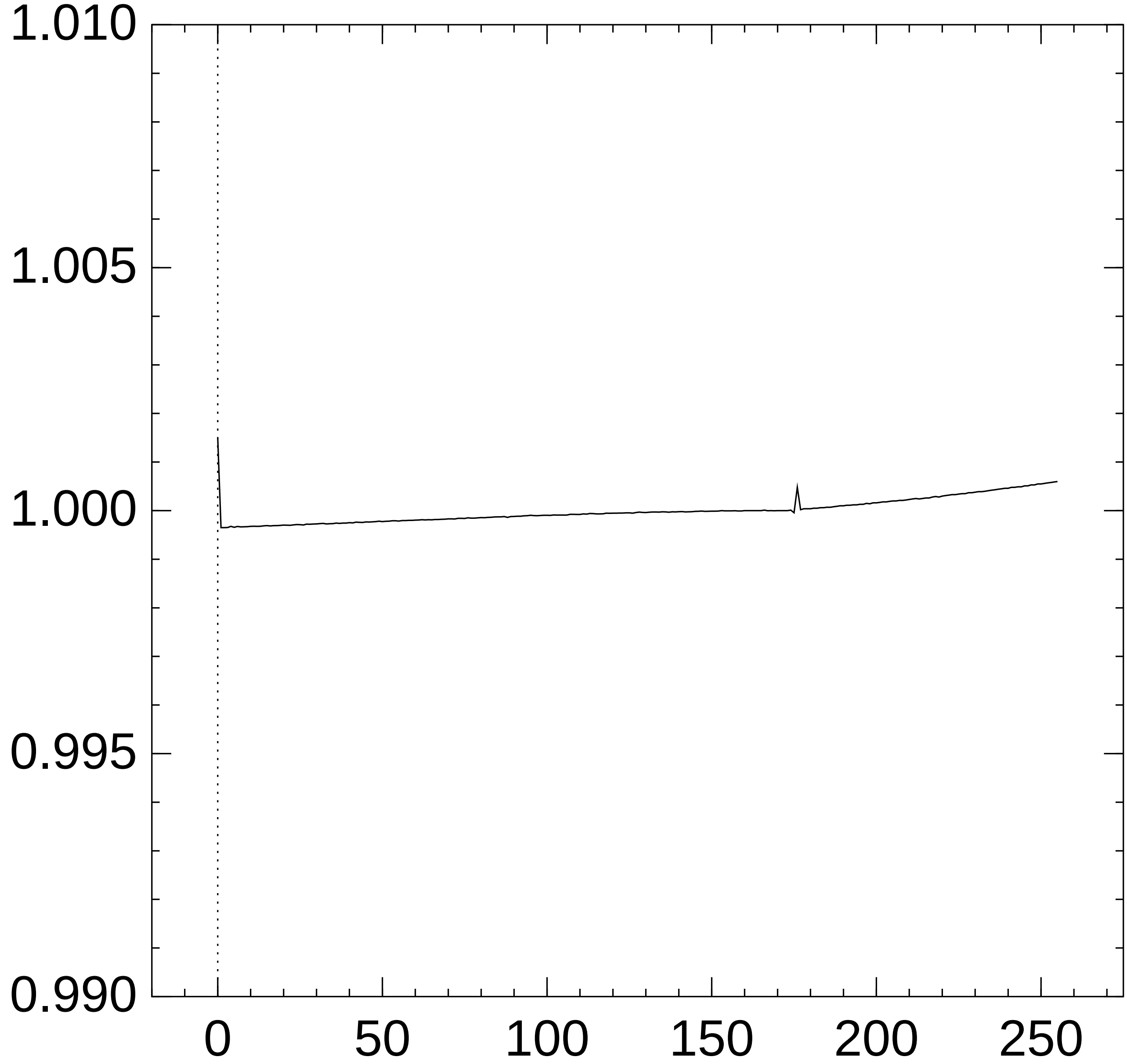
Graph of $256 \Pr[z_{174} = x]$:



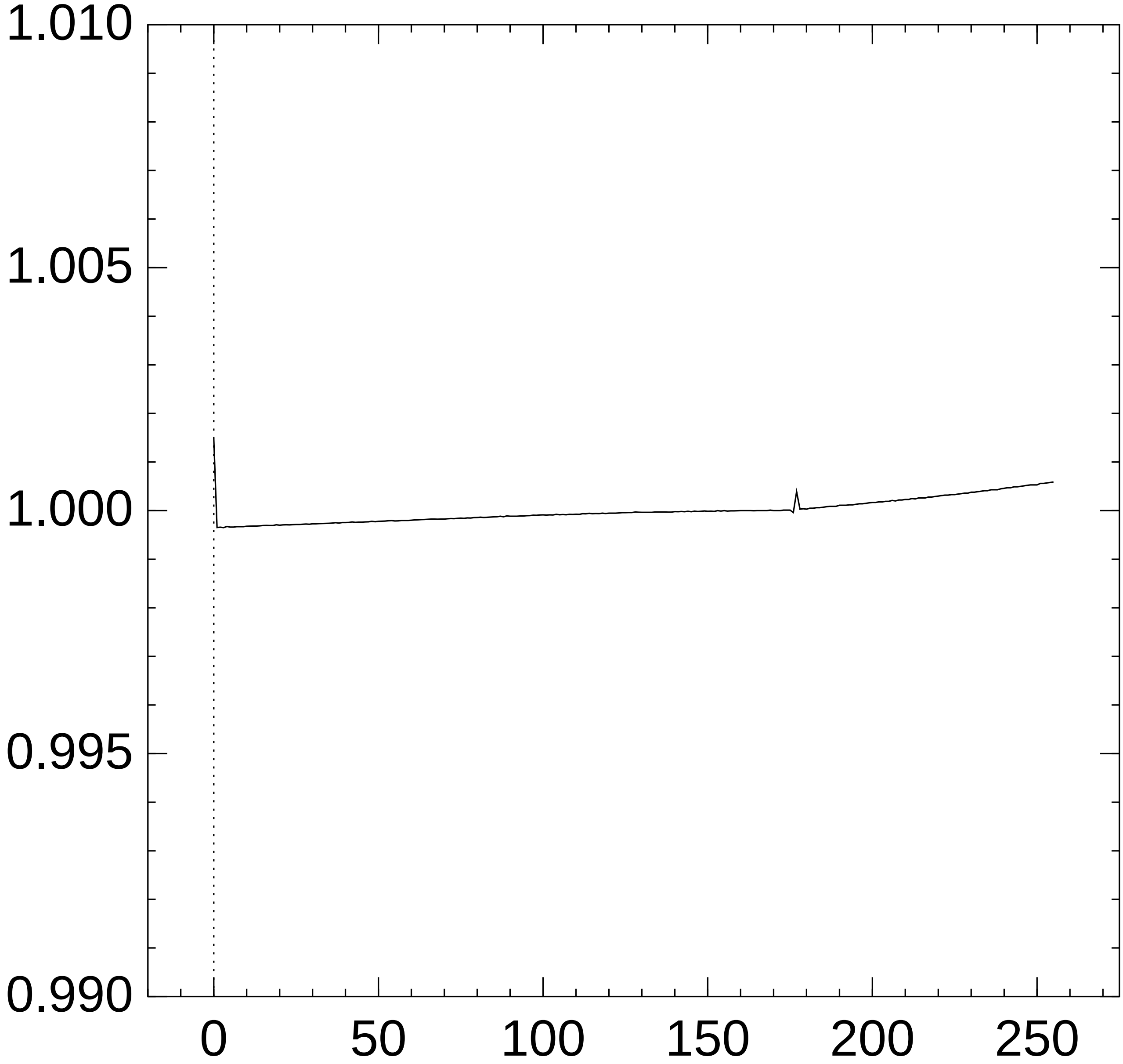
Graph of $256\,\Pr[z_{175} = x]$:



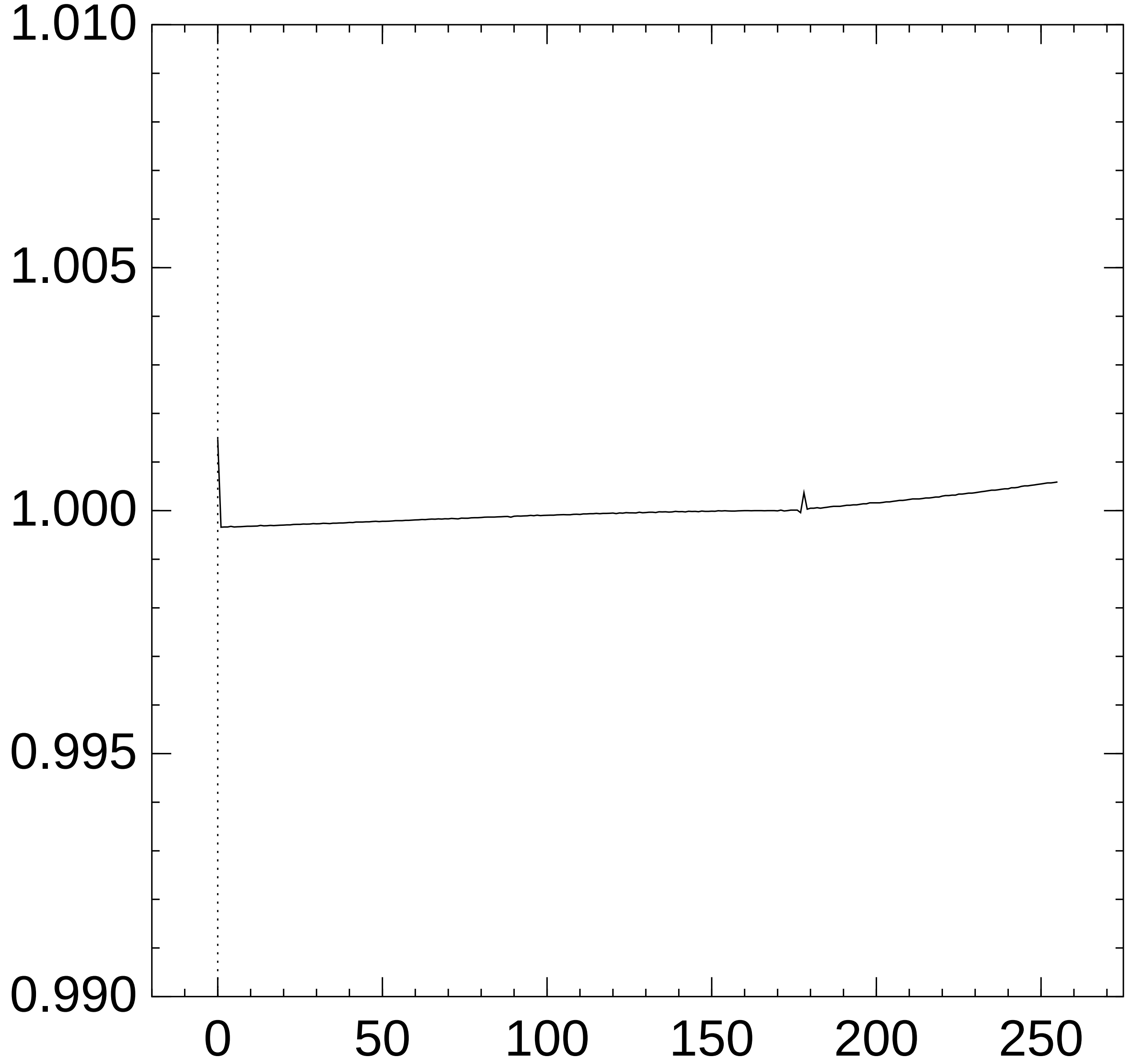
Graph of $256\,\Pr[z_{176} = x]$:



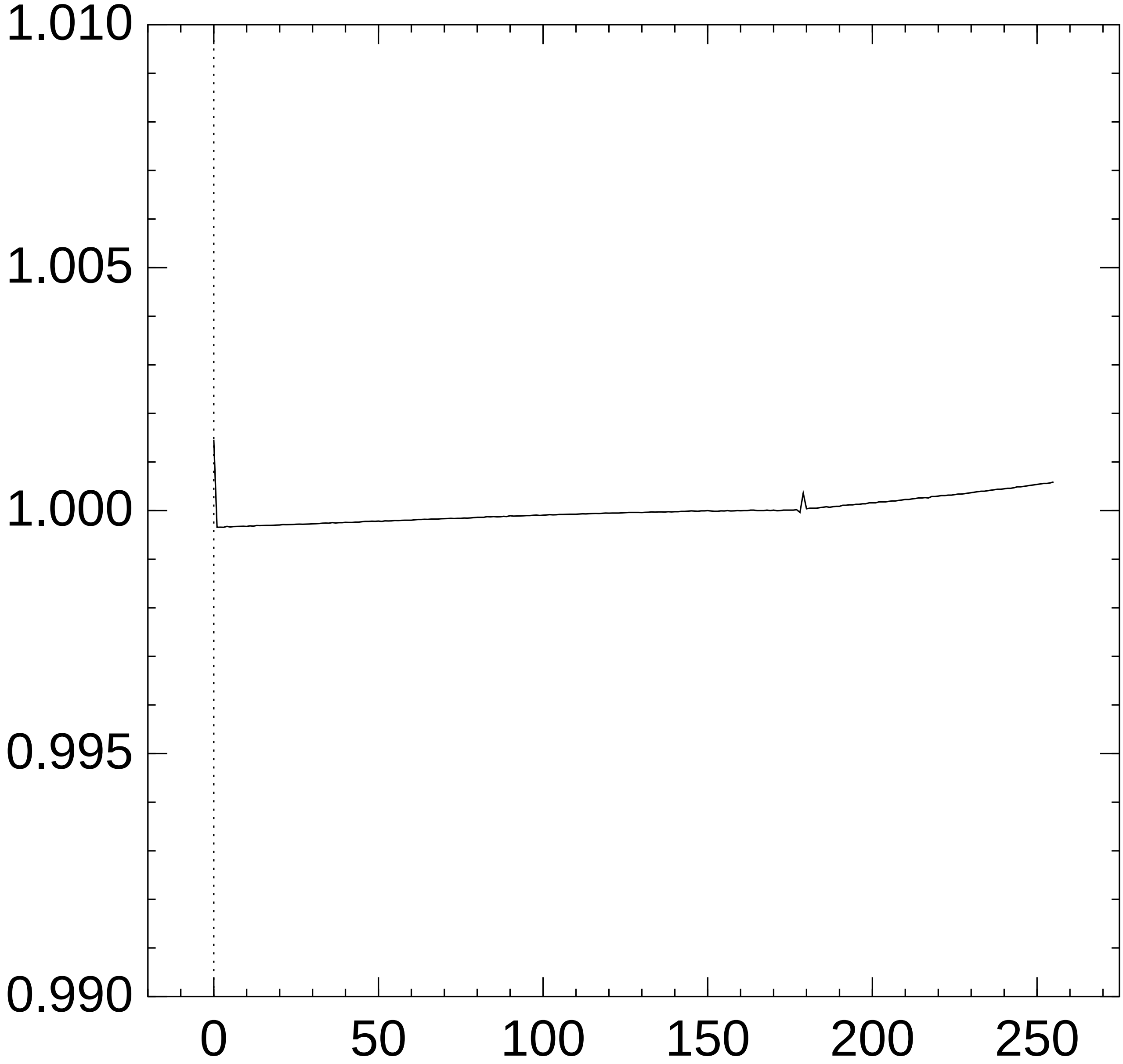
Graph of $256\,\Pr[z_{177} = x]$:



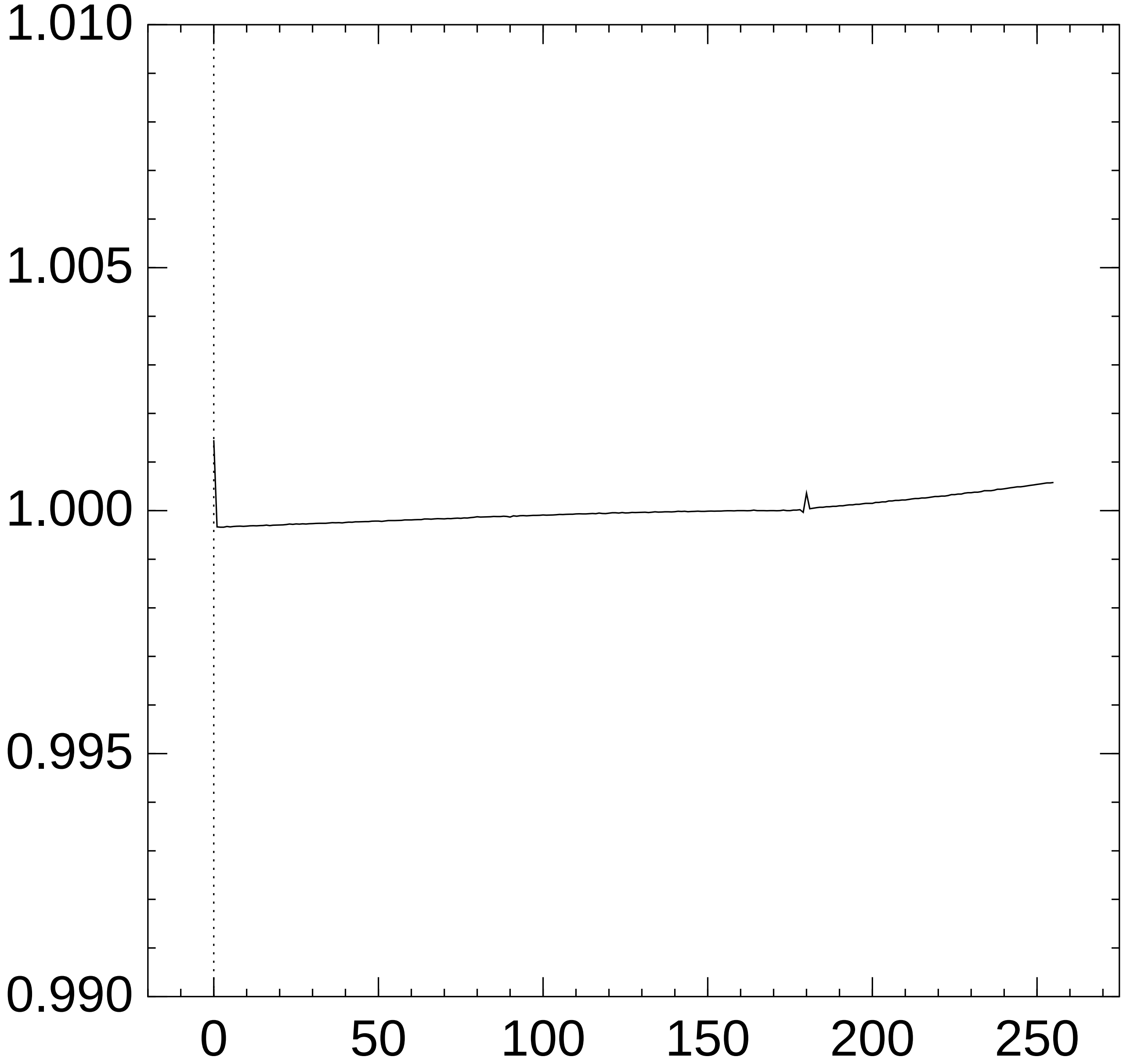
Graph of $256 \, \mathrm{Pr}[z_{178} = x]$:



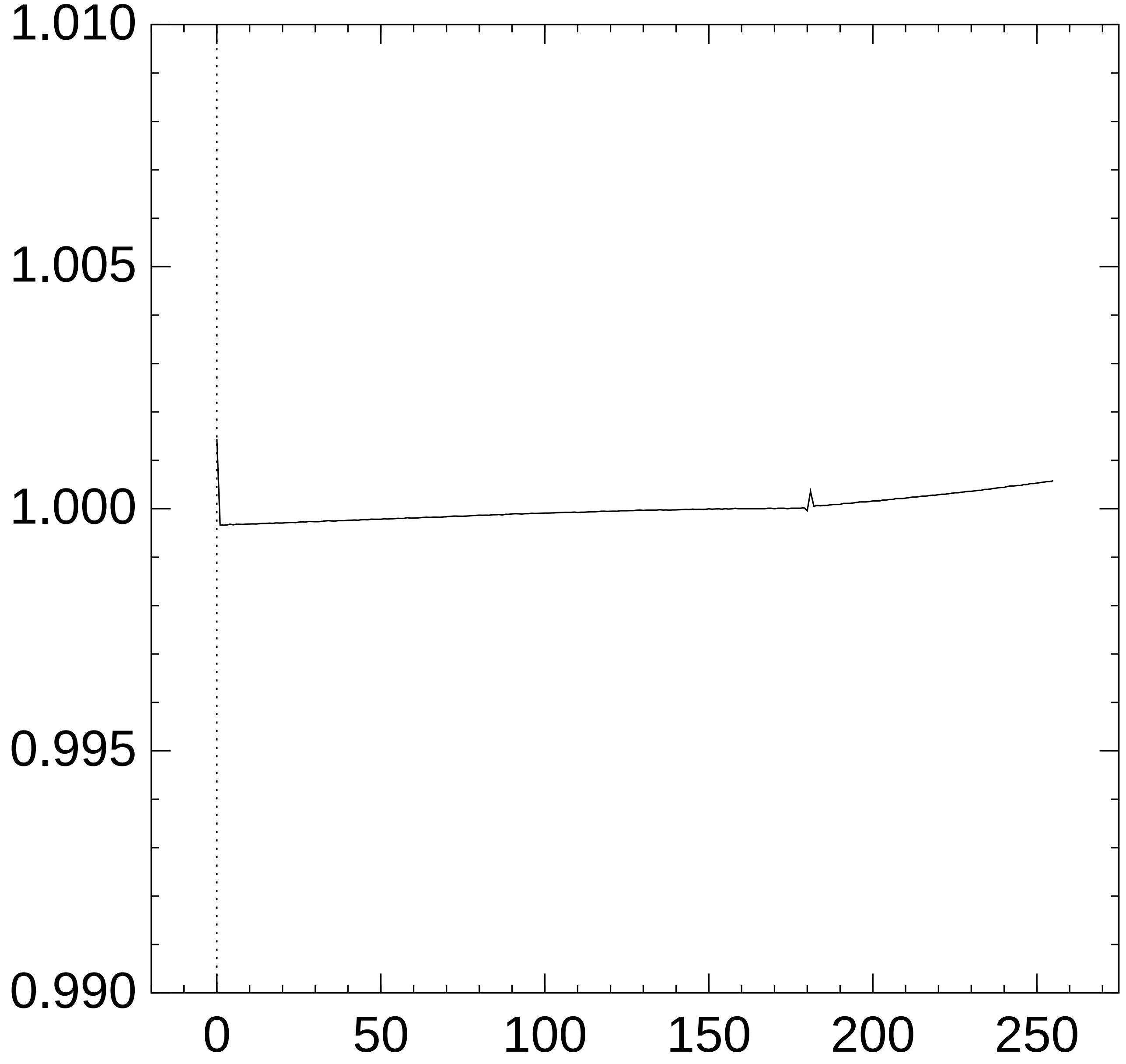
Graph of $256\,\Pr[z_{179} = x]$:



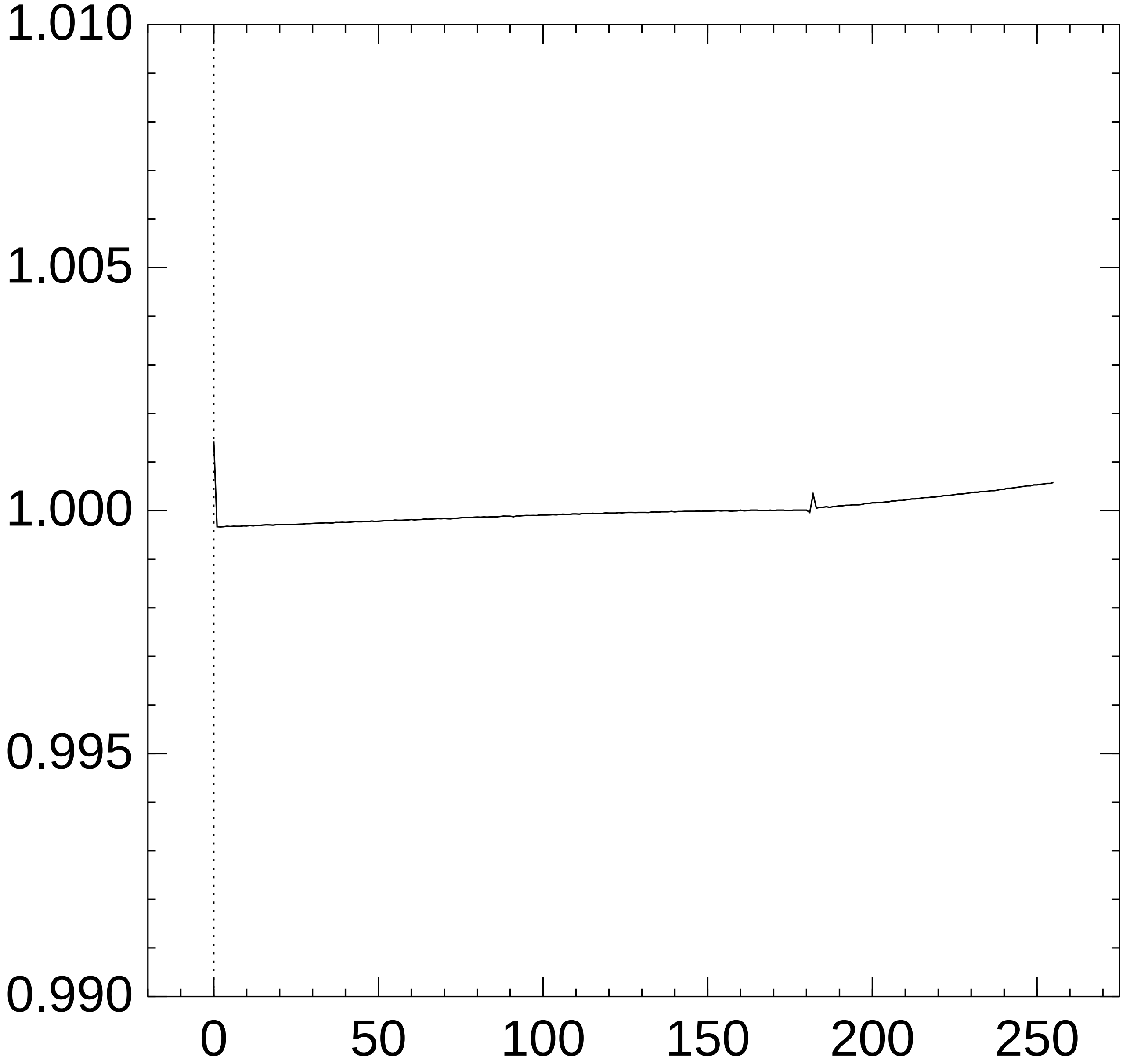
Graph of $256\,\mathrm{Pr}[z_{180} = x]$:



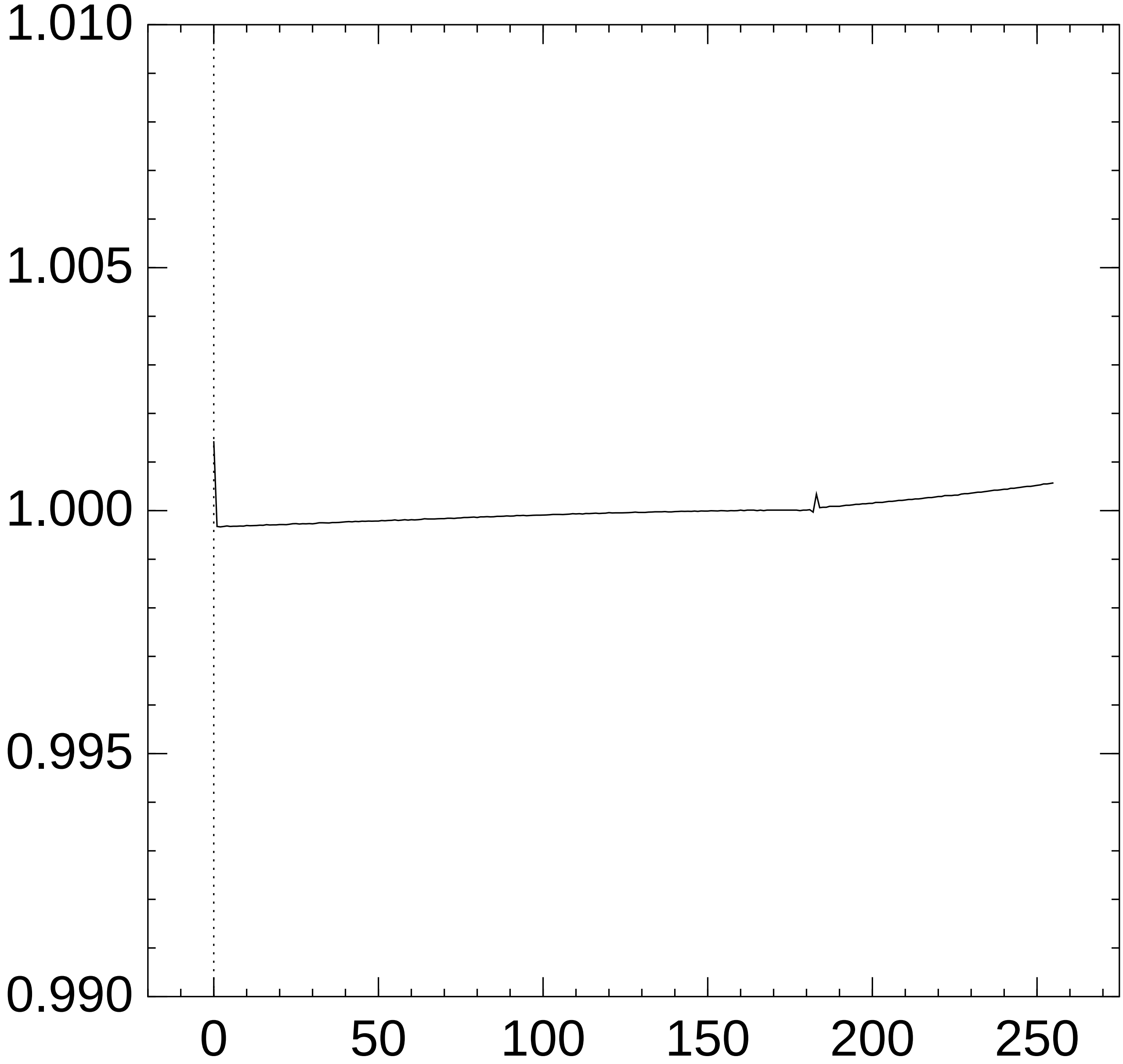
Graph of $256\,\Pr[z_{181} = x]$:



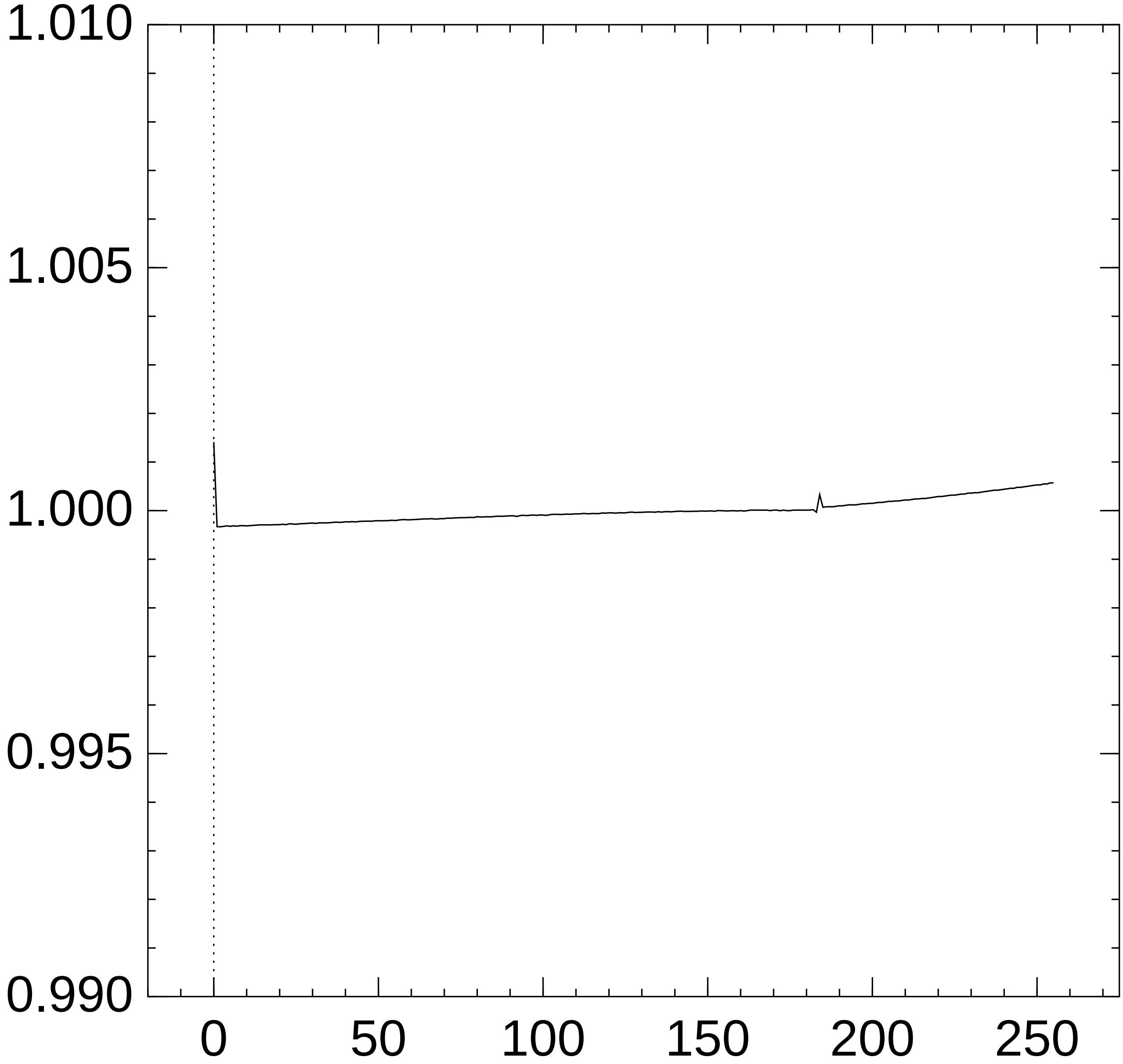
Graph of $256\,\Pr[z_{182} = x]$:



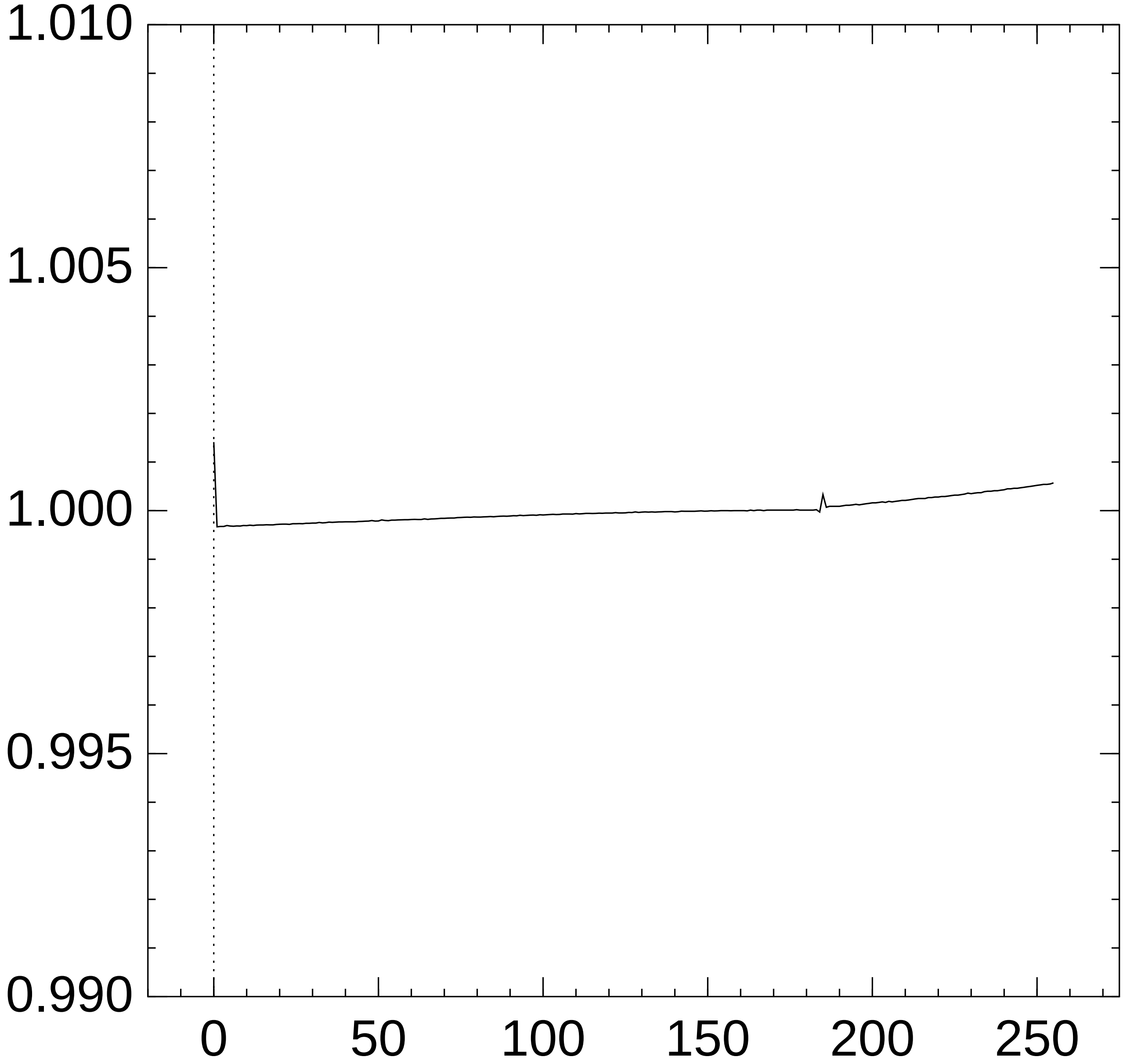
Graph of $256\,\Pr[z_{183} = x]$:



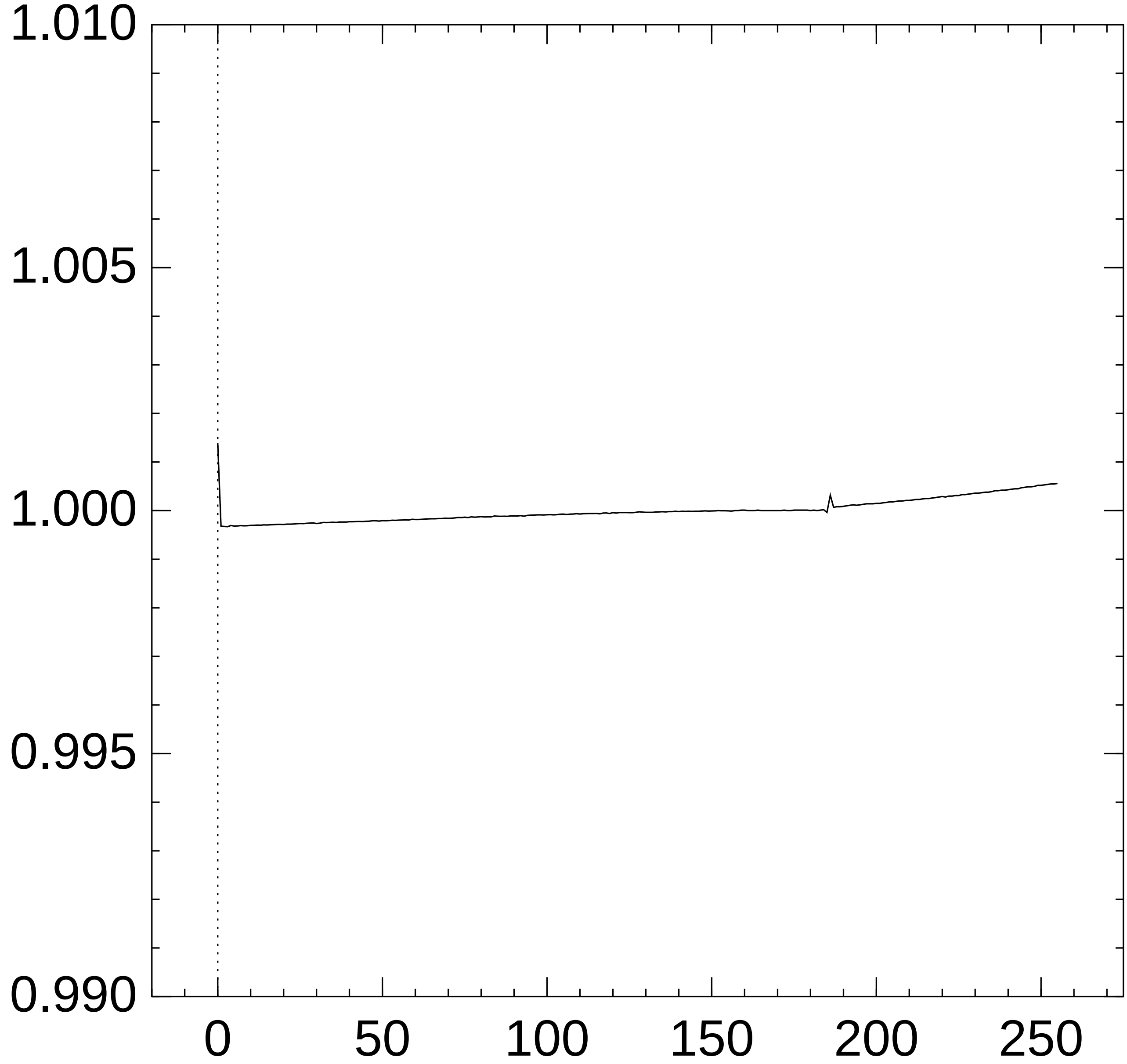
Graph of $256 \Pr[z_{184} = x]$:



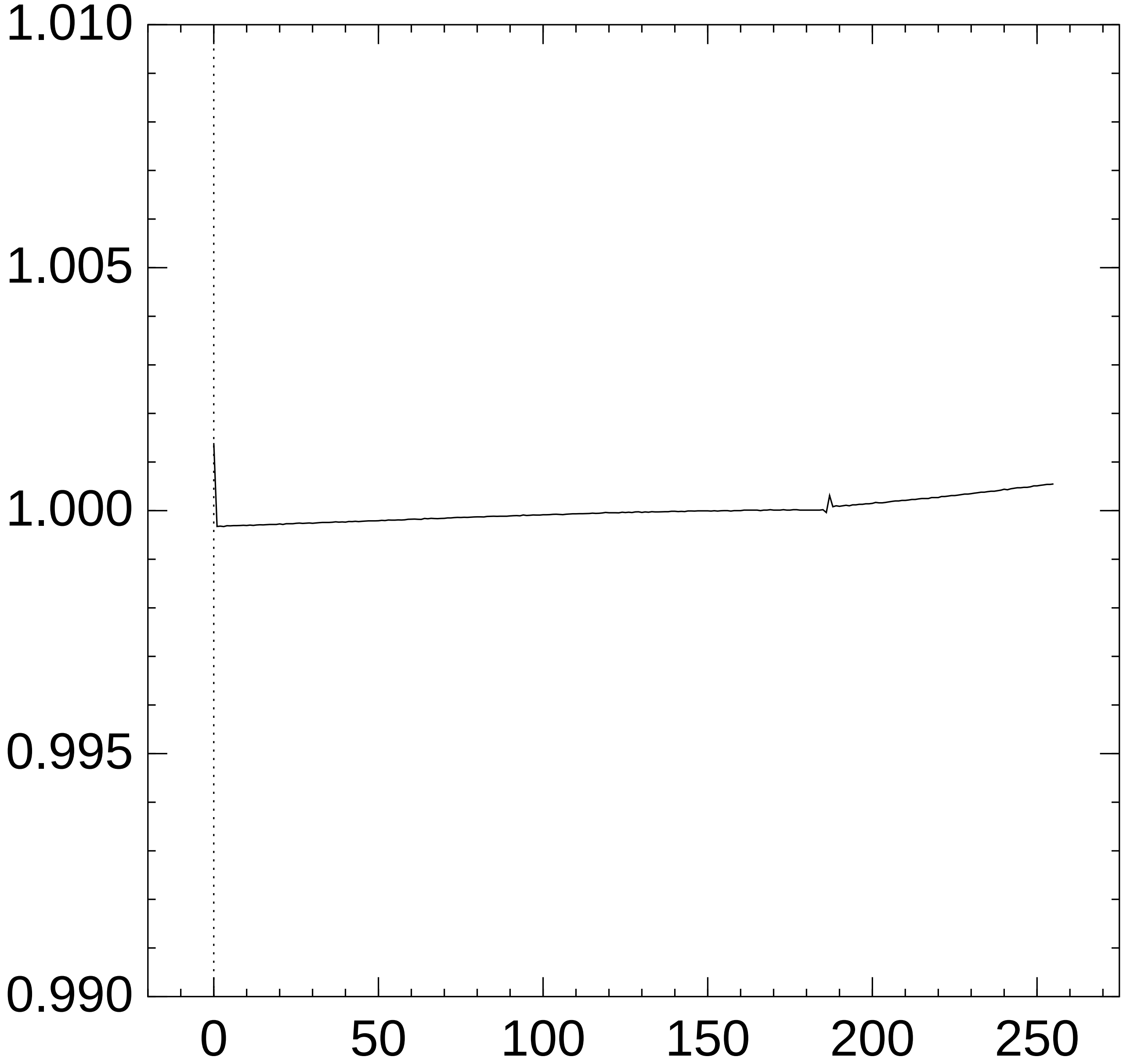
Graph of $256\,\Pr[z_{185} = x]$:



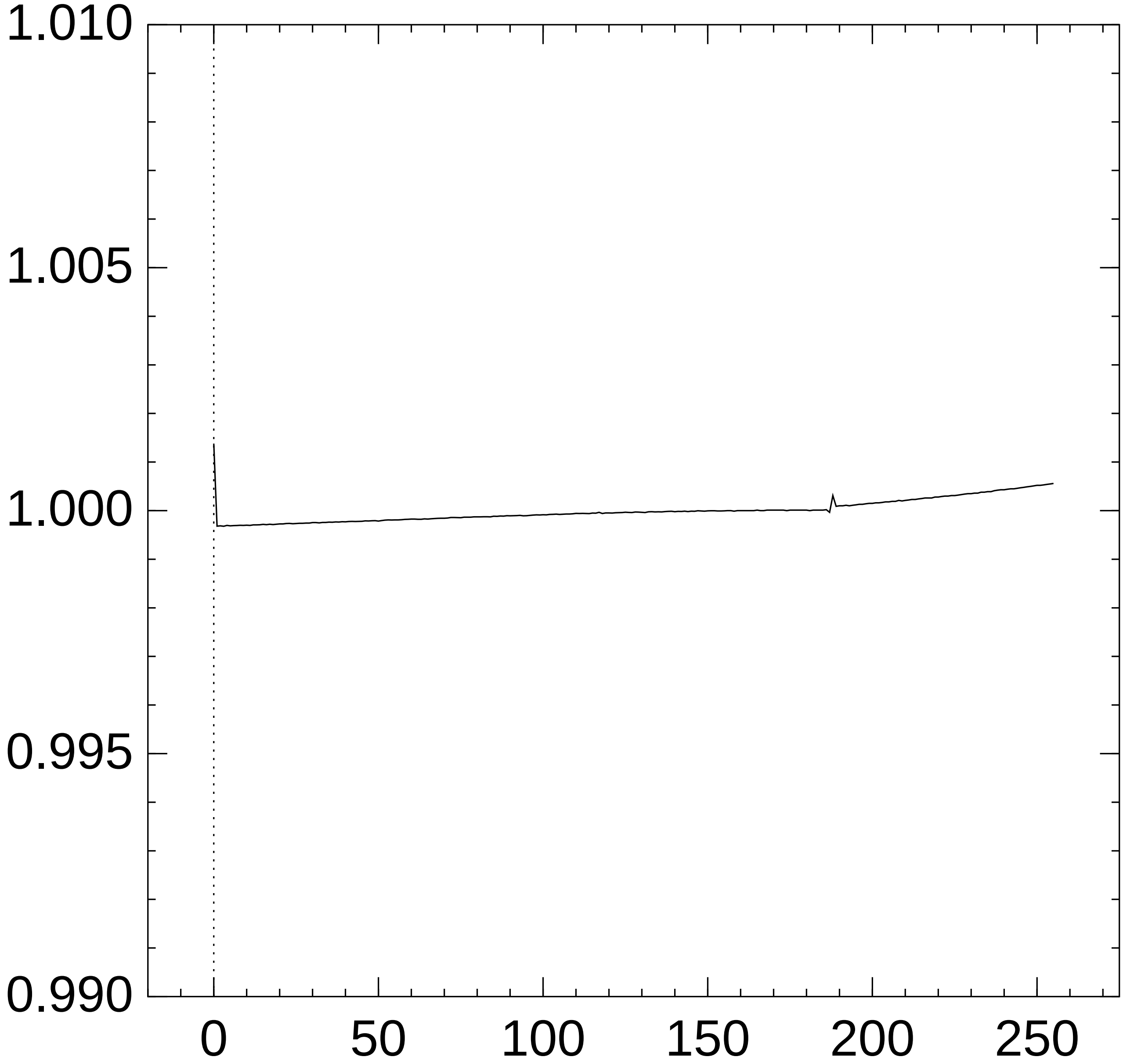
Graph of $256 \Pr[z_{186} = x]$:



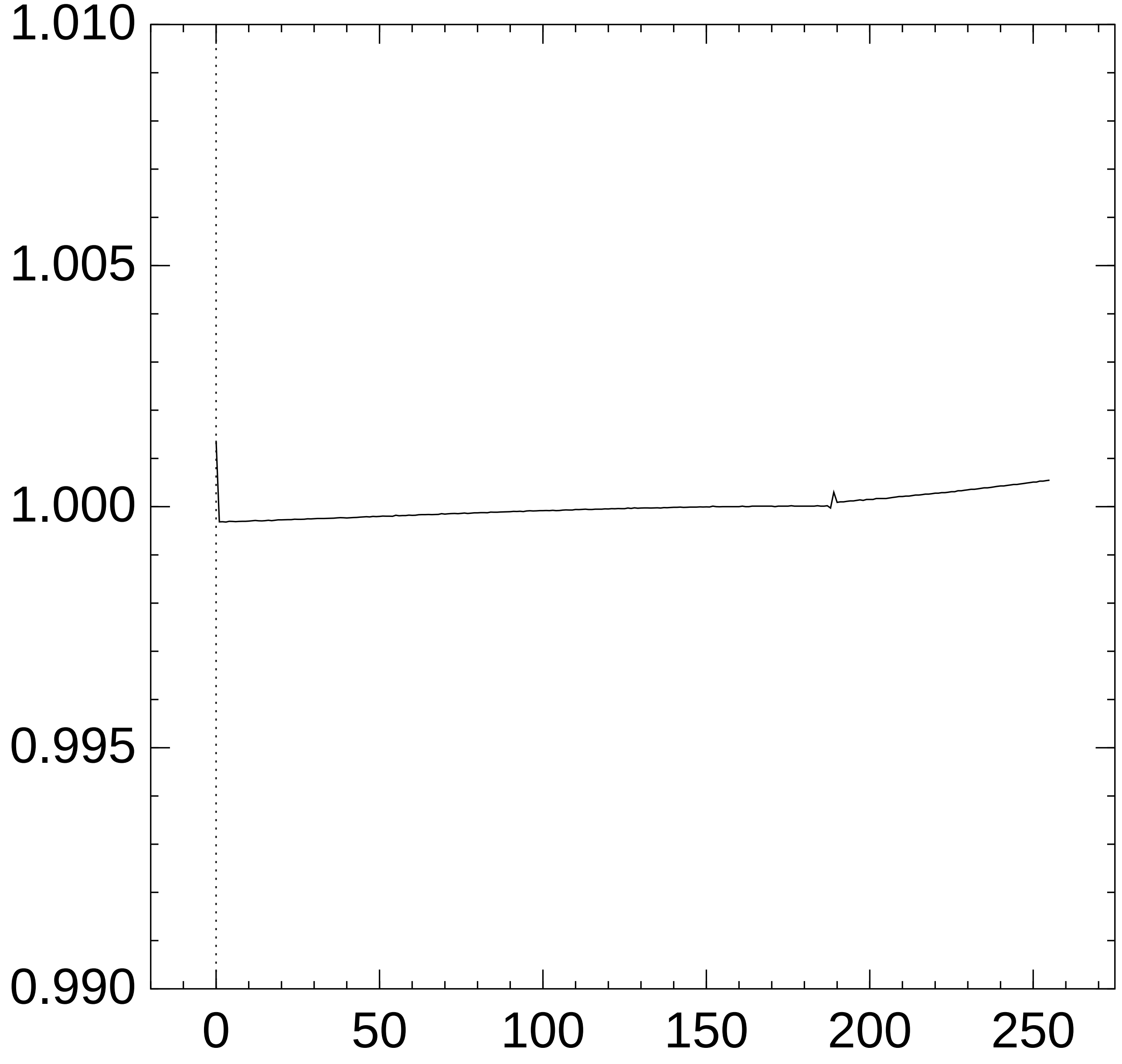
Graph of $256\,\mathrm{Pr}[z_{187} = x]$:



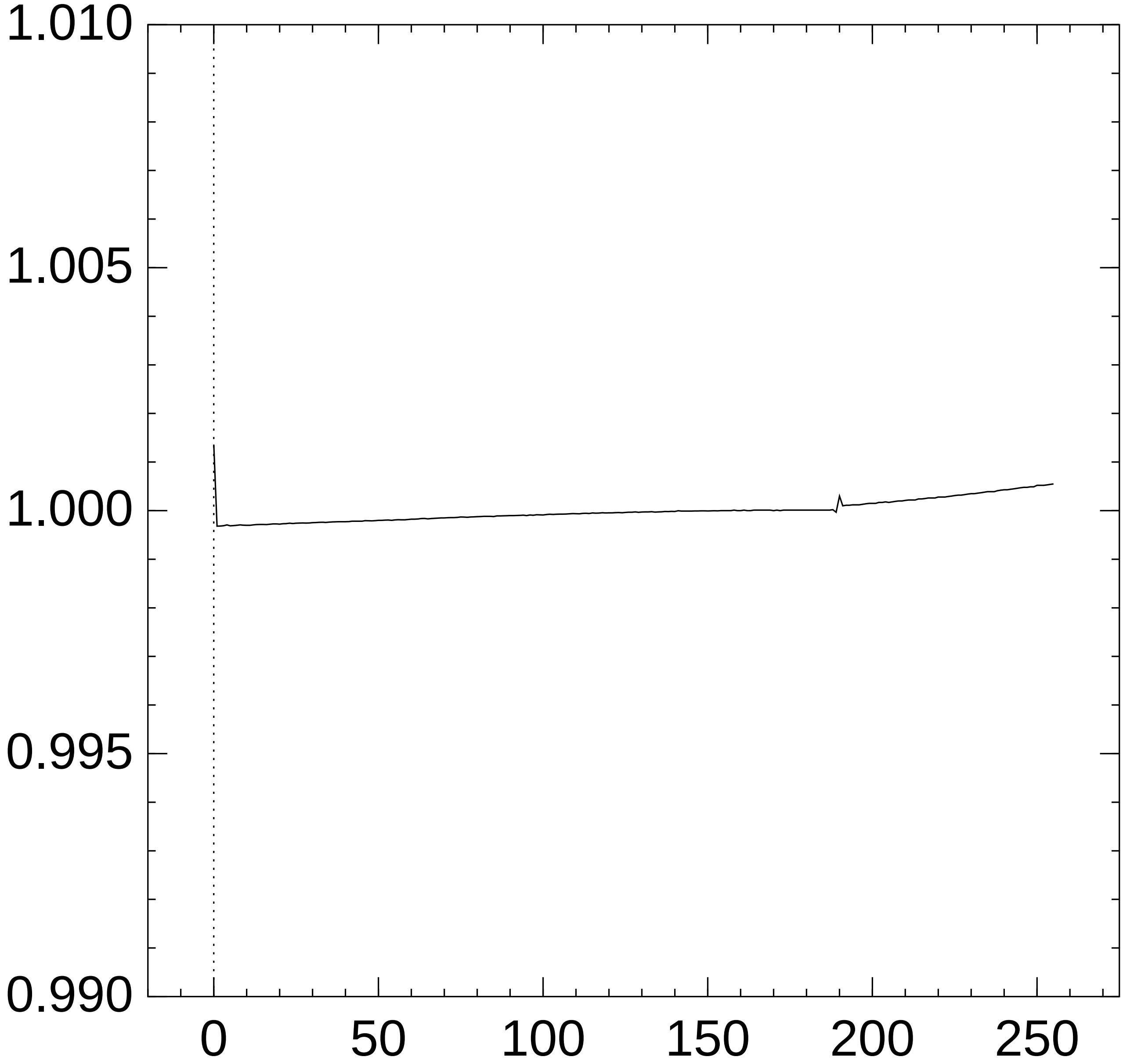
Graph of $256\,\Pr[z_{188} = x]$:



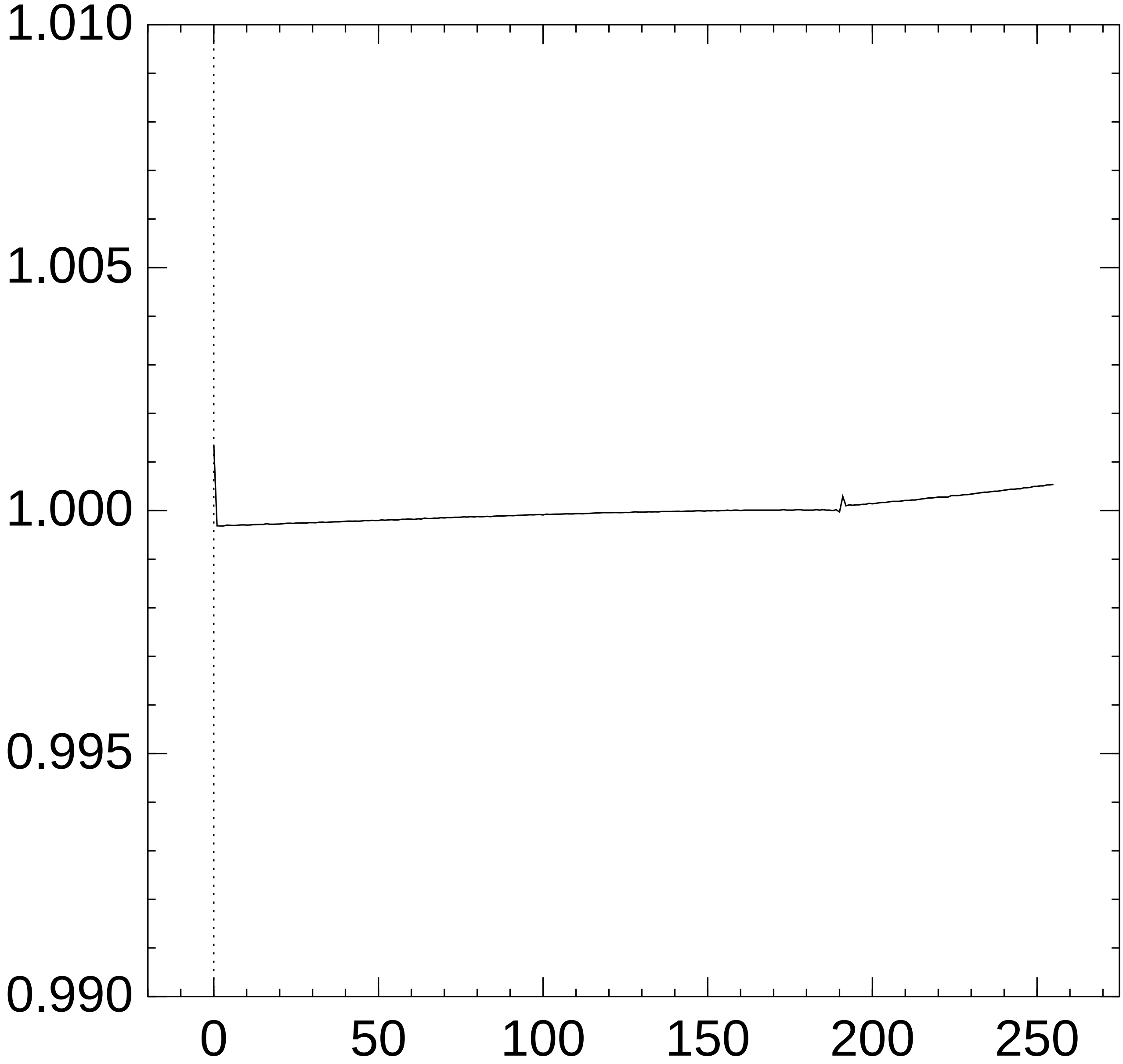
Graph of $256\,\mathrm{Pr}[z_{189} = x]$:



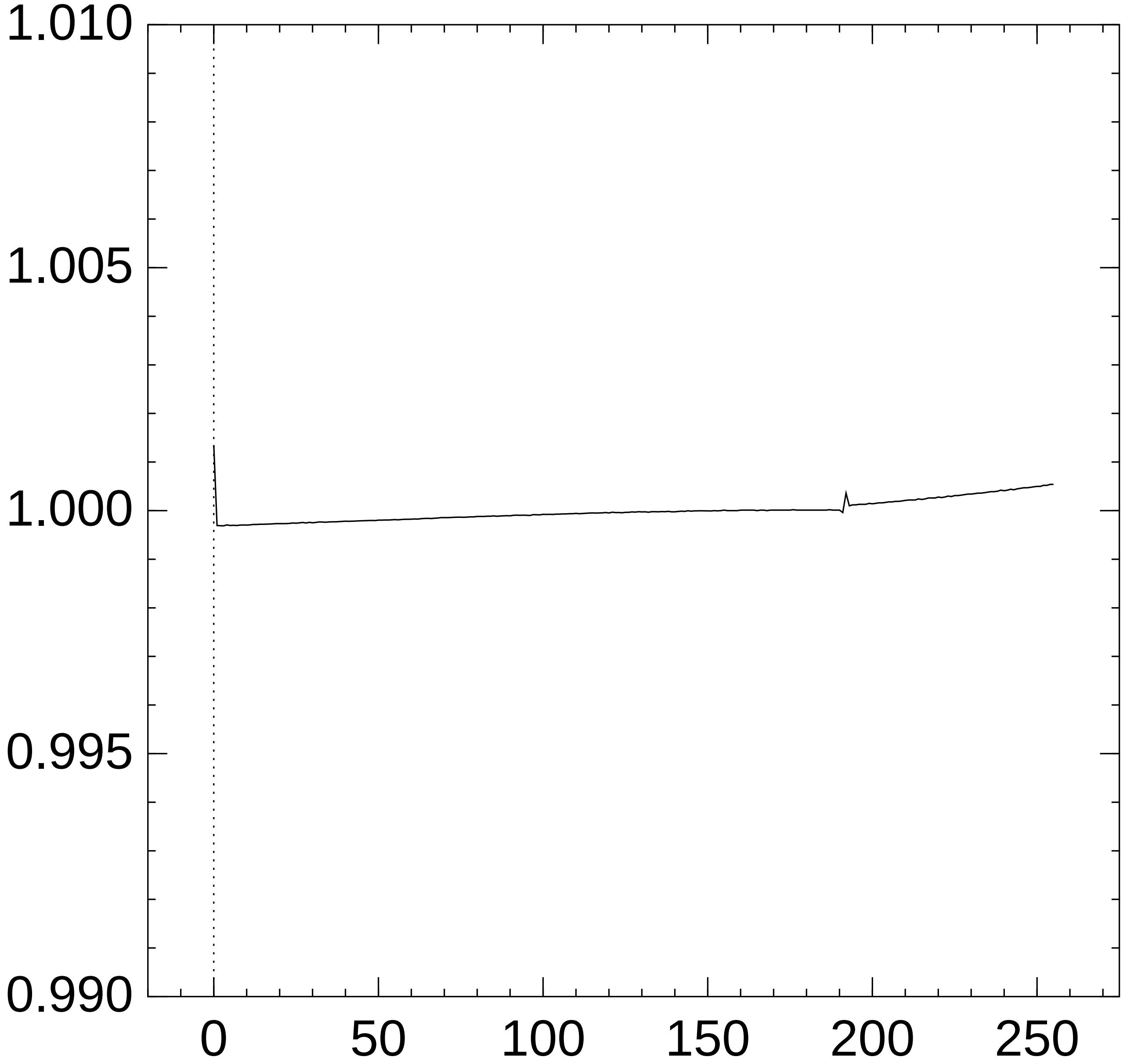
Graph of $256\,\Pr[z_{190} = x]$:



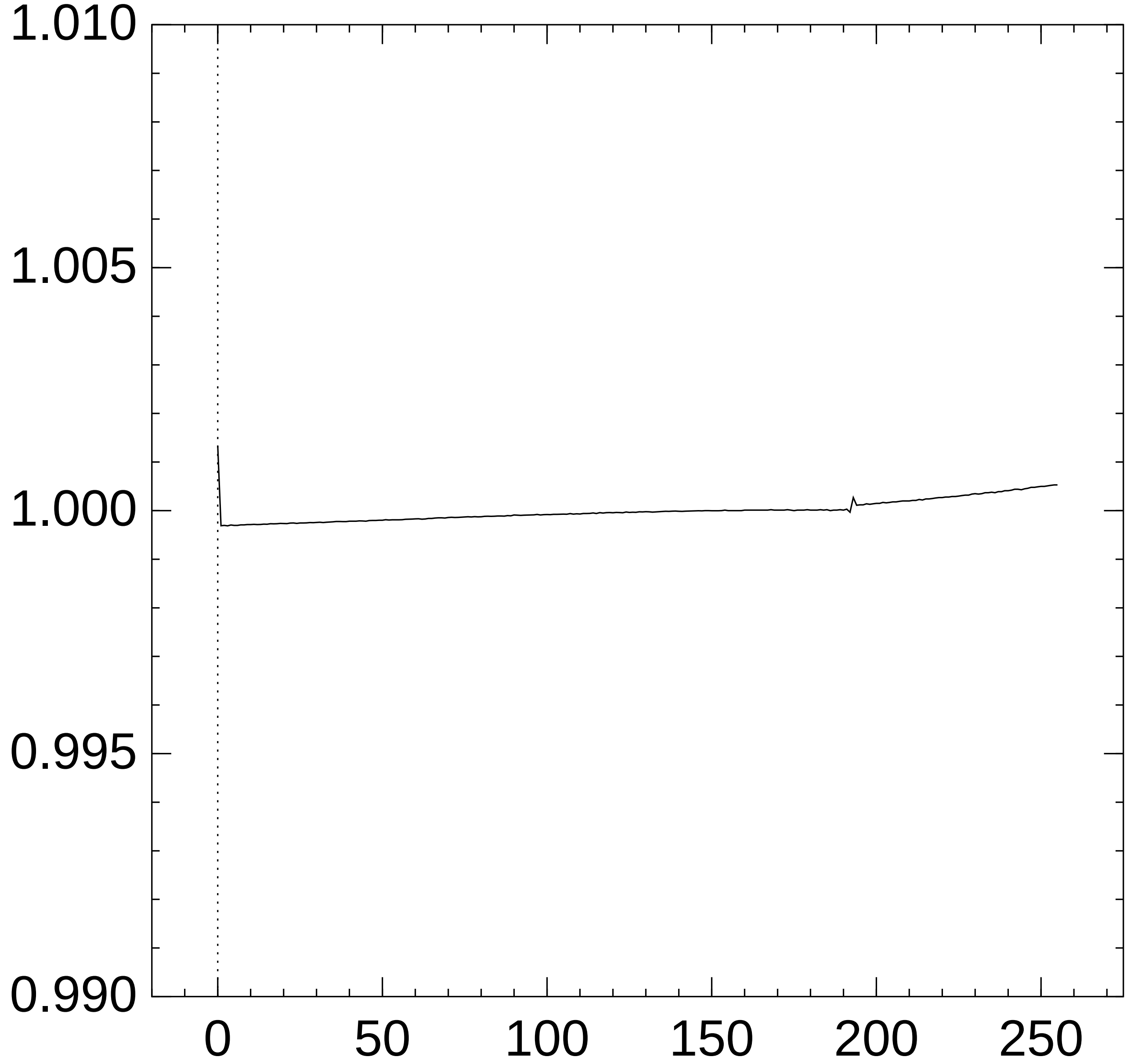
Graph of $256\,\Pr[z_{191} = x]$:



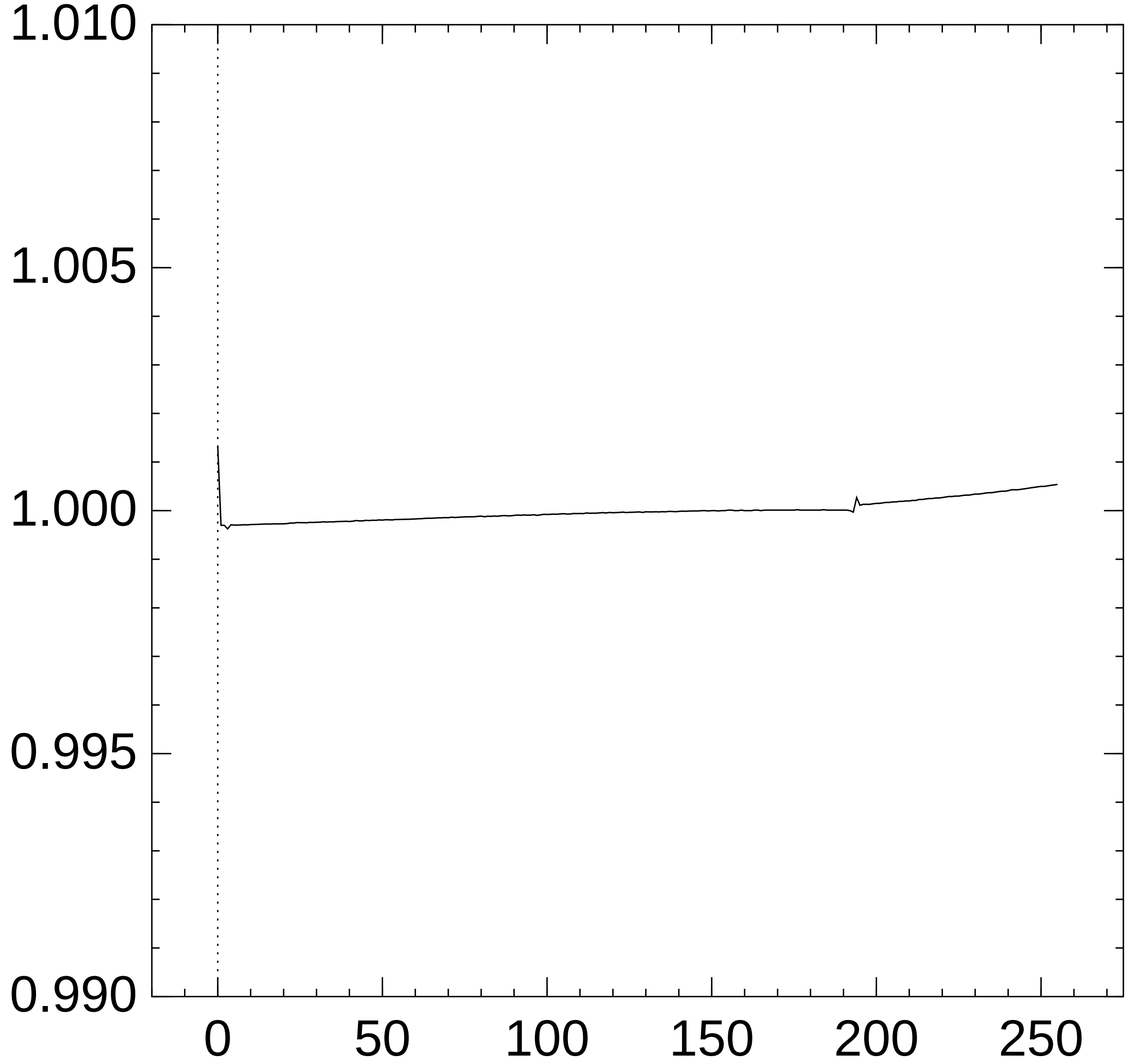
Graph of $256\,\Pr[z_{192} = x]$:



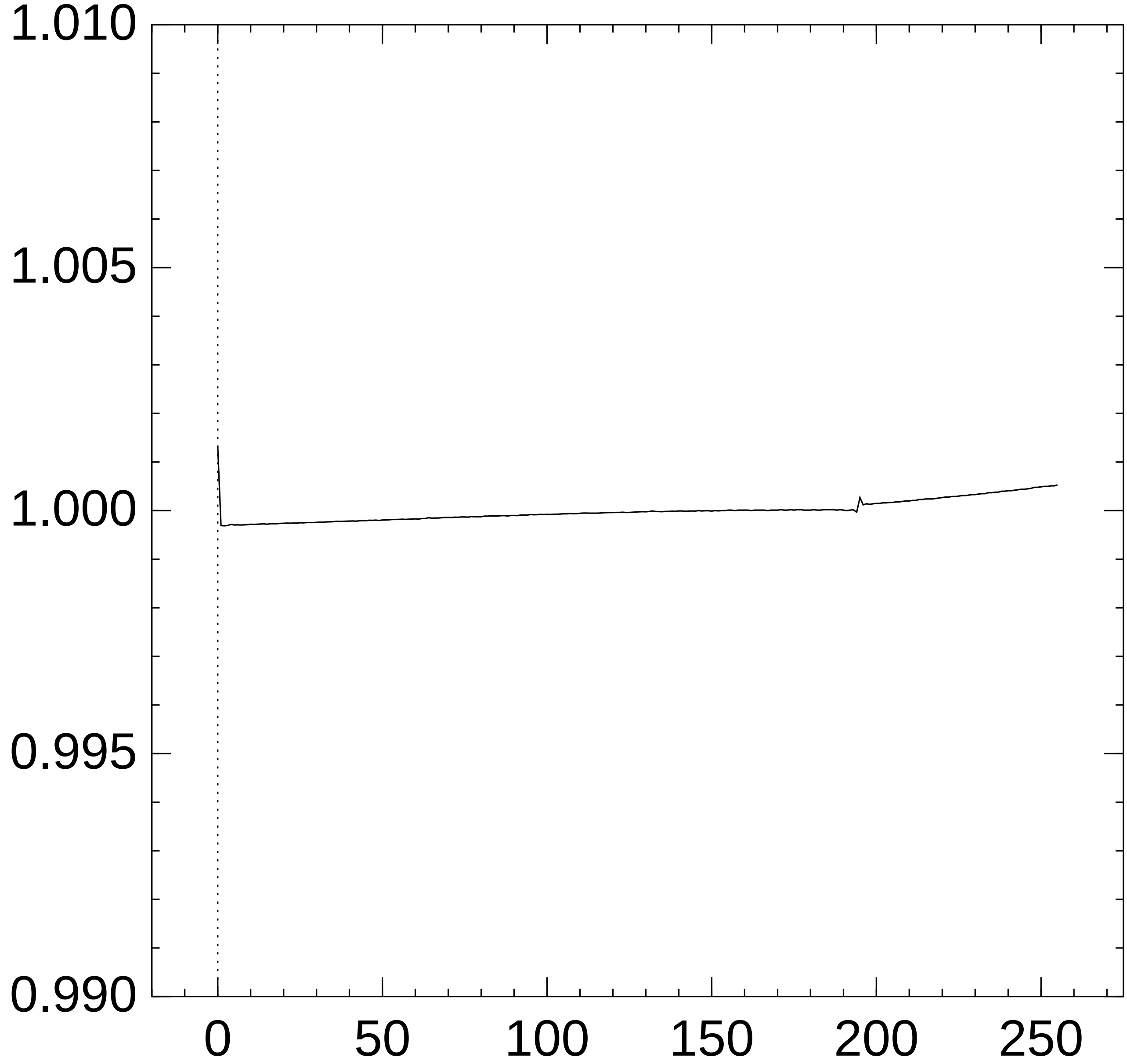
Graph of $256\,\Pr[z_{193} = x]$:



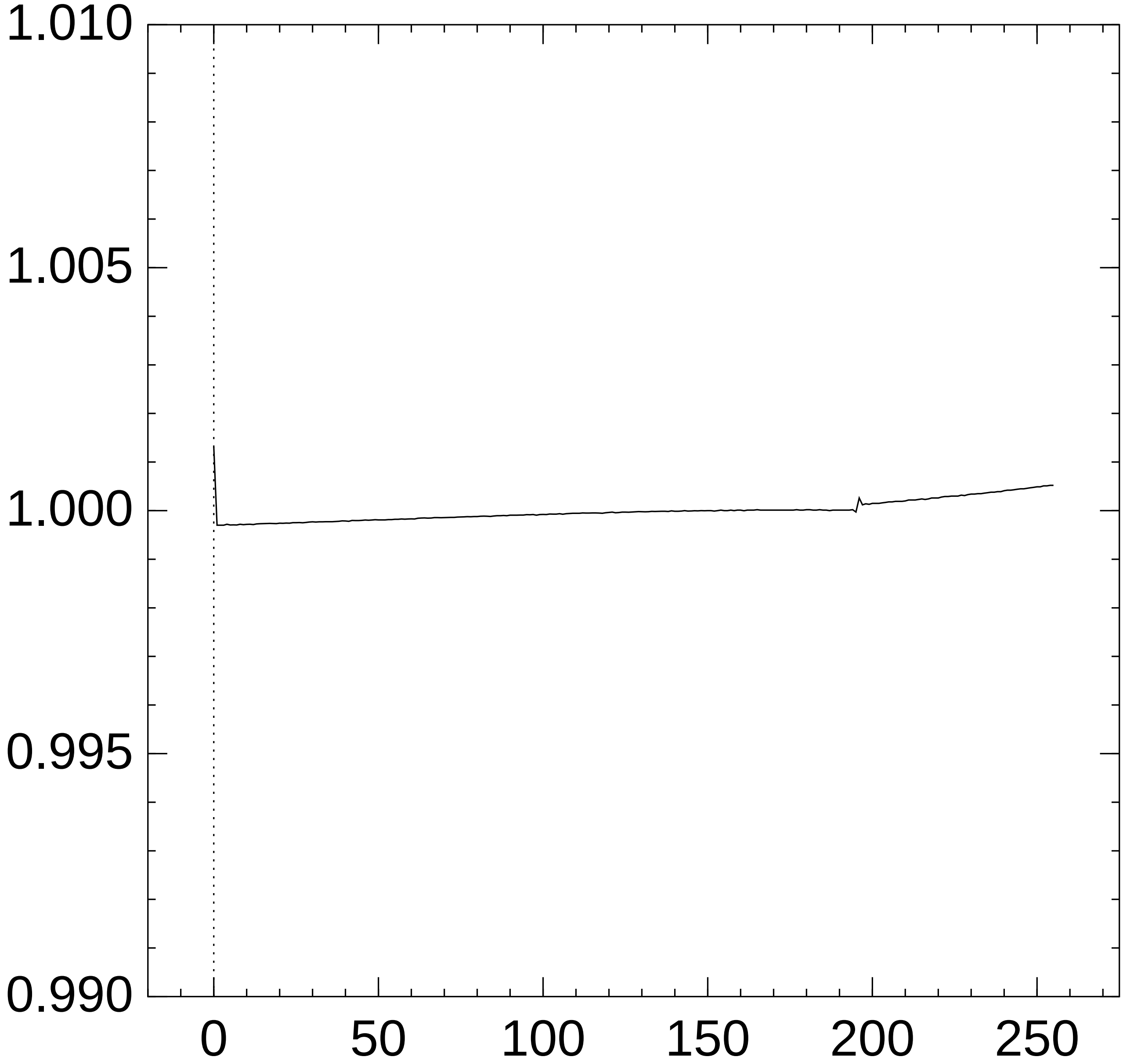
Graph of $256\,\Pr[z_{194} = x]$:



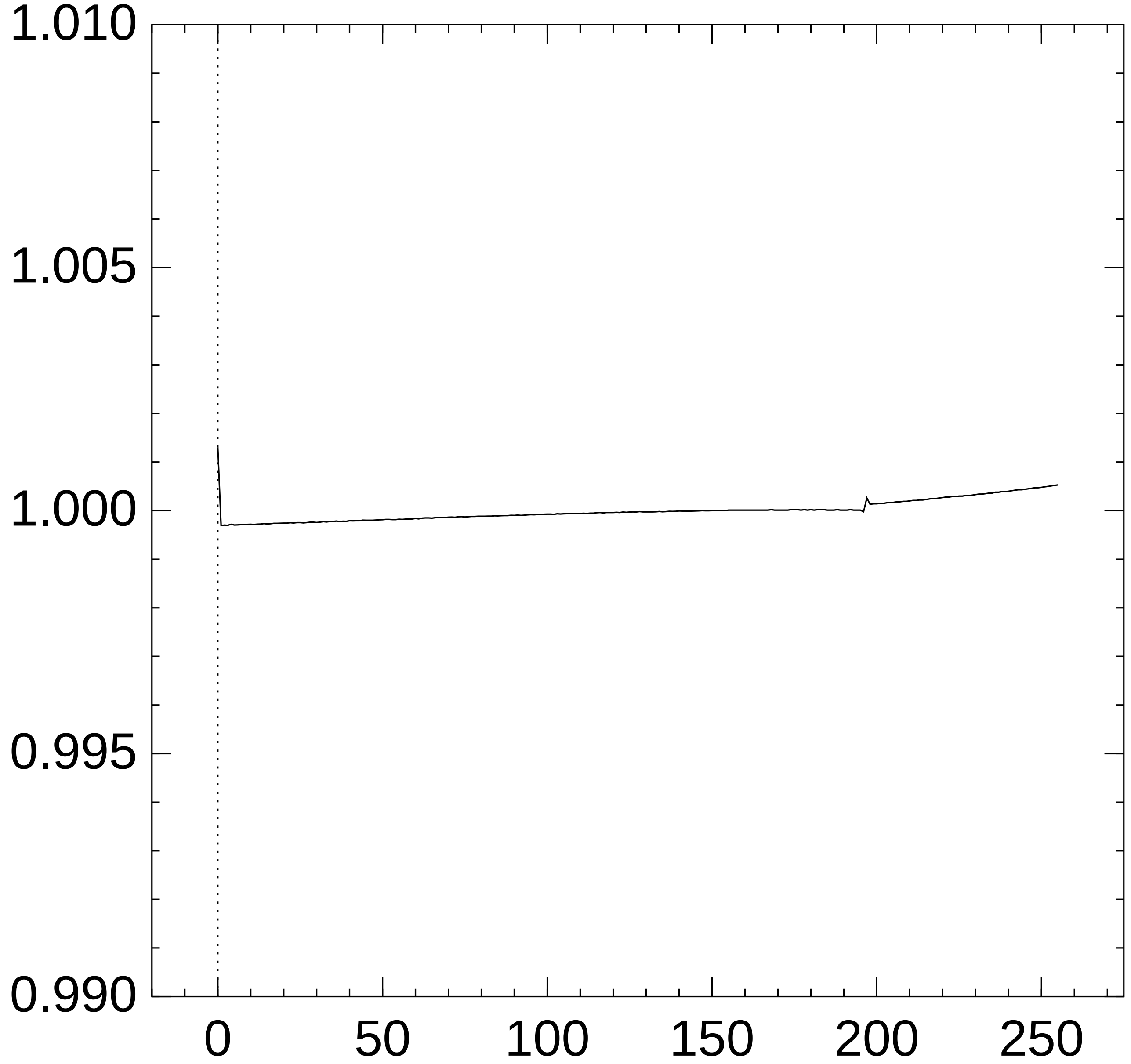
Graph of $256\,\mathrm{Pr}[z_{195} = x]$:



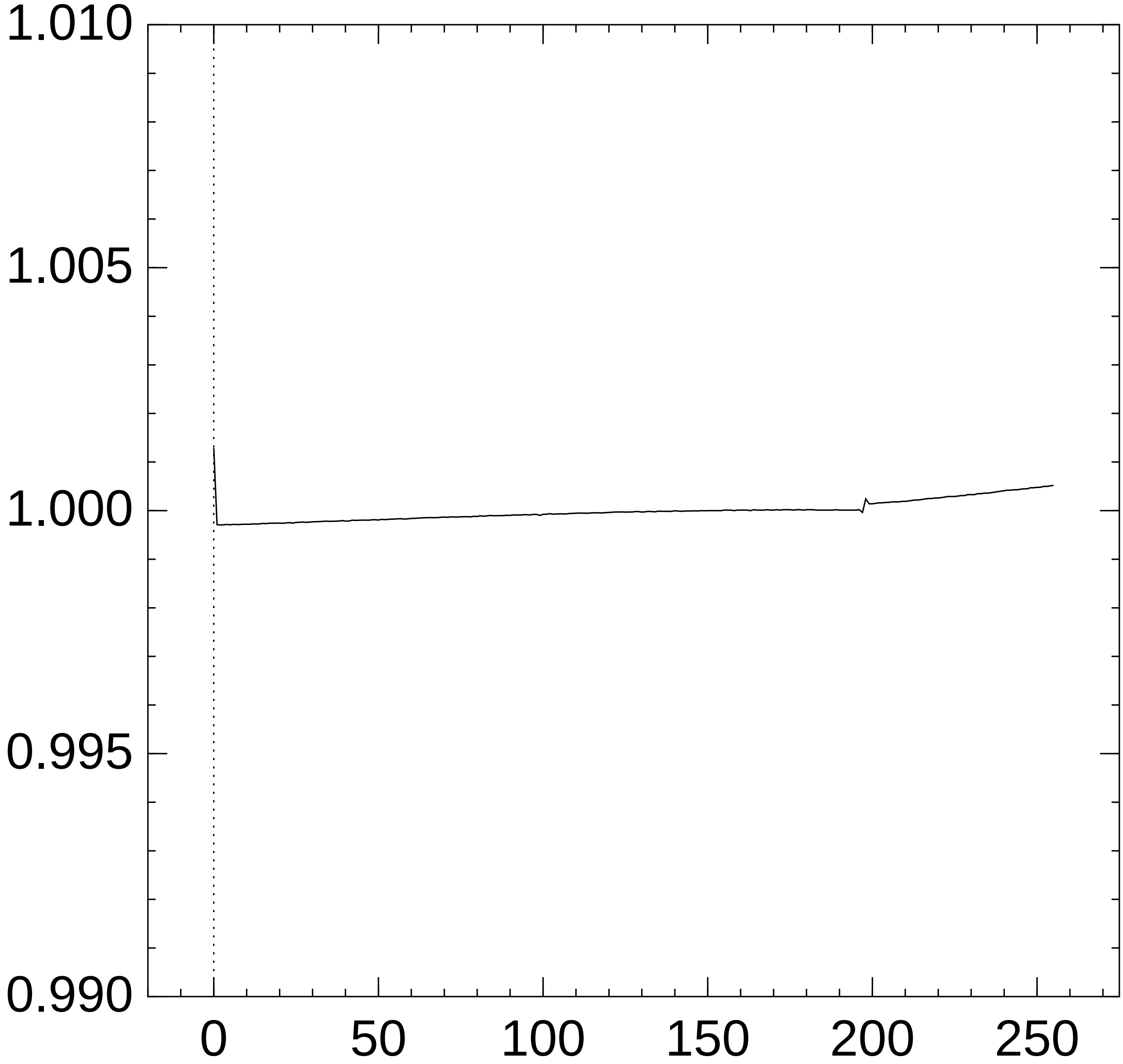
Graph of $256\,\mathrm{Pr}[z_{196} = x]$:



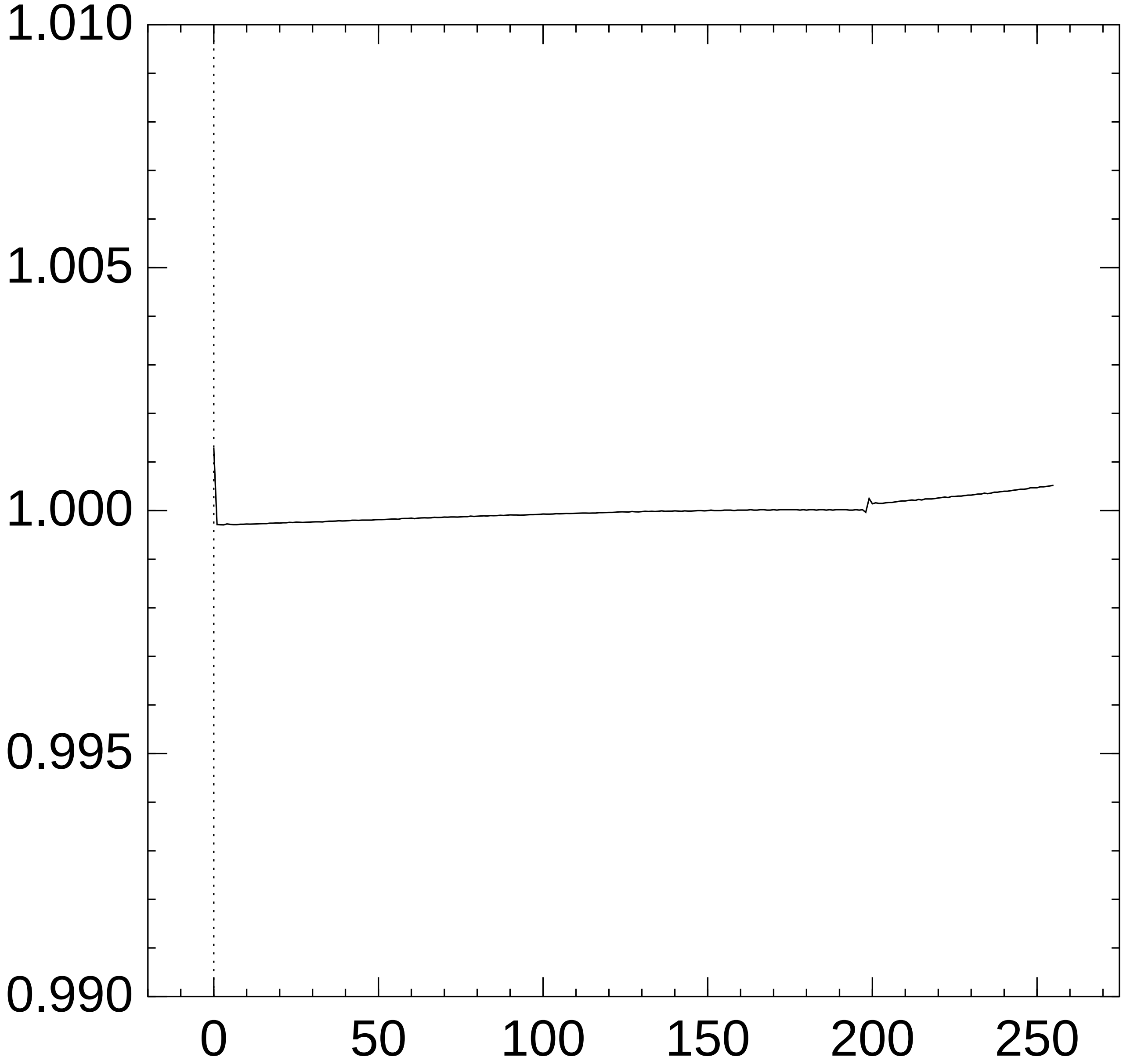
Graph of $256\,\Pr[z_{197} = x]$:



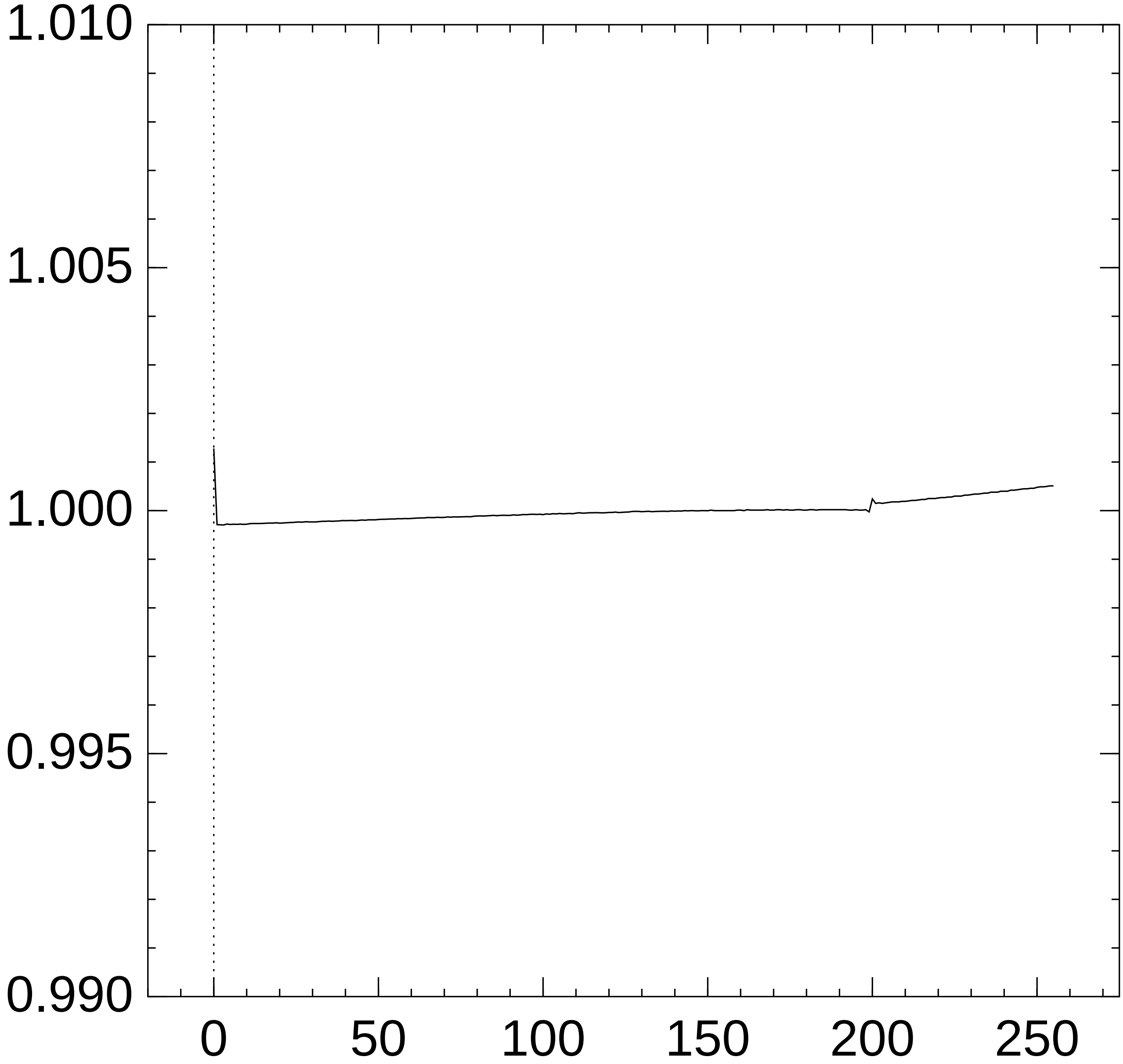
Graph of $256\,\Pr[z_{198} = x]$:



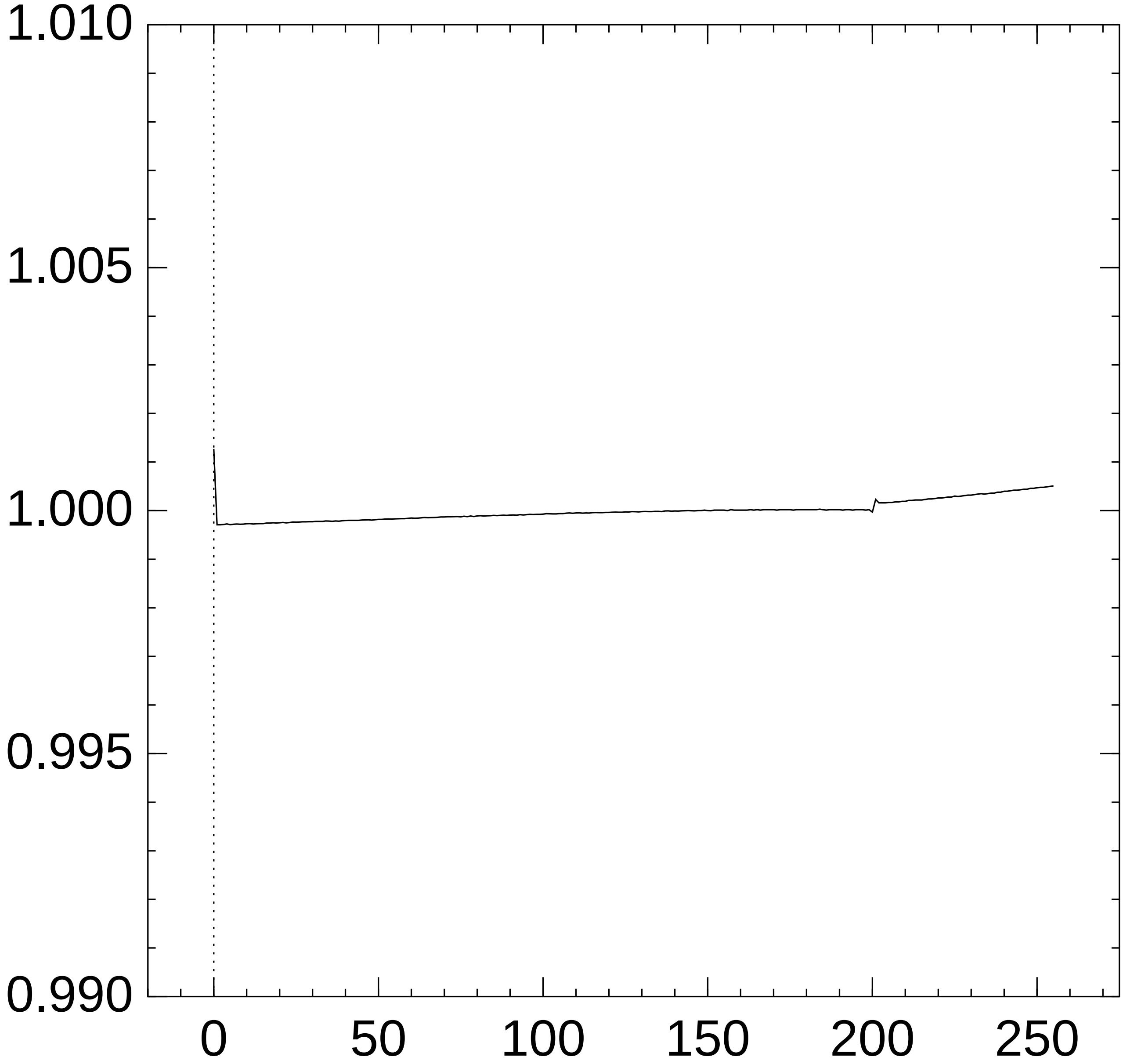
Graph of $256 \Pr[z_{199} = x]$:



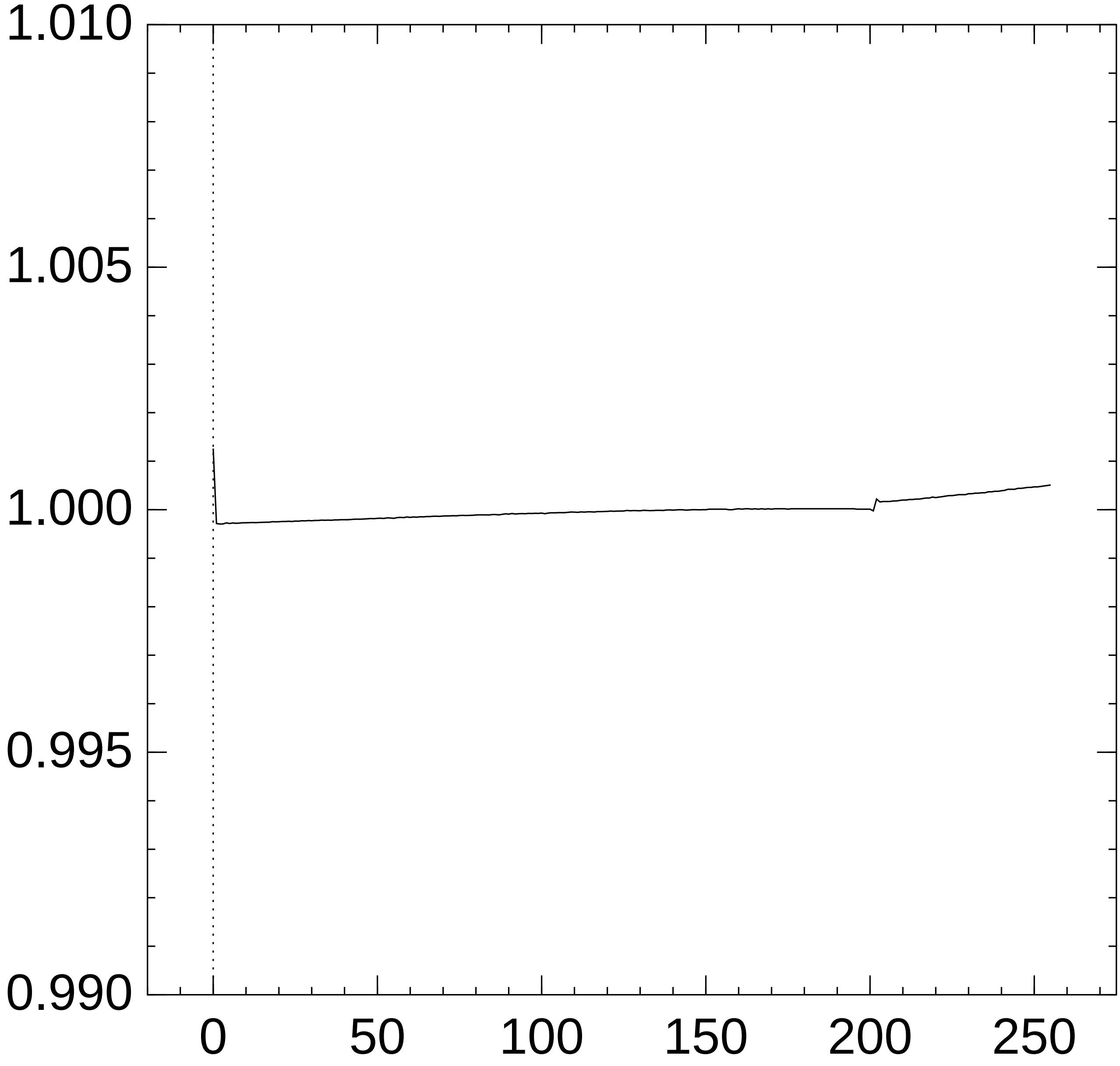
Graph of $256\,\mathrm{Pr}[z_{200} = x]$:



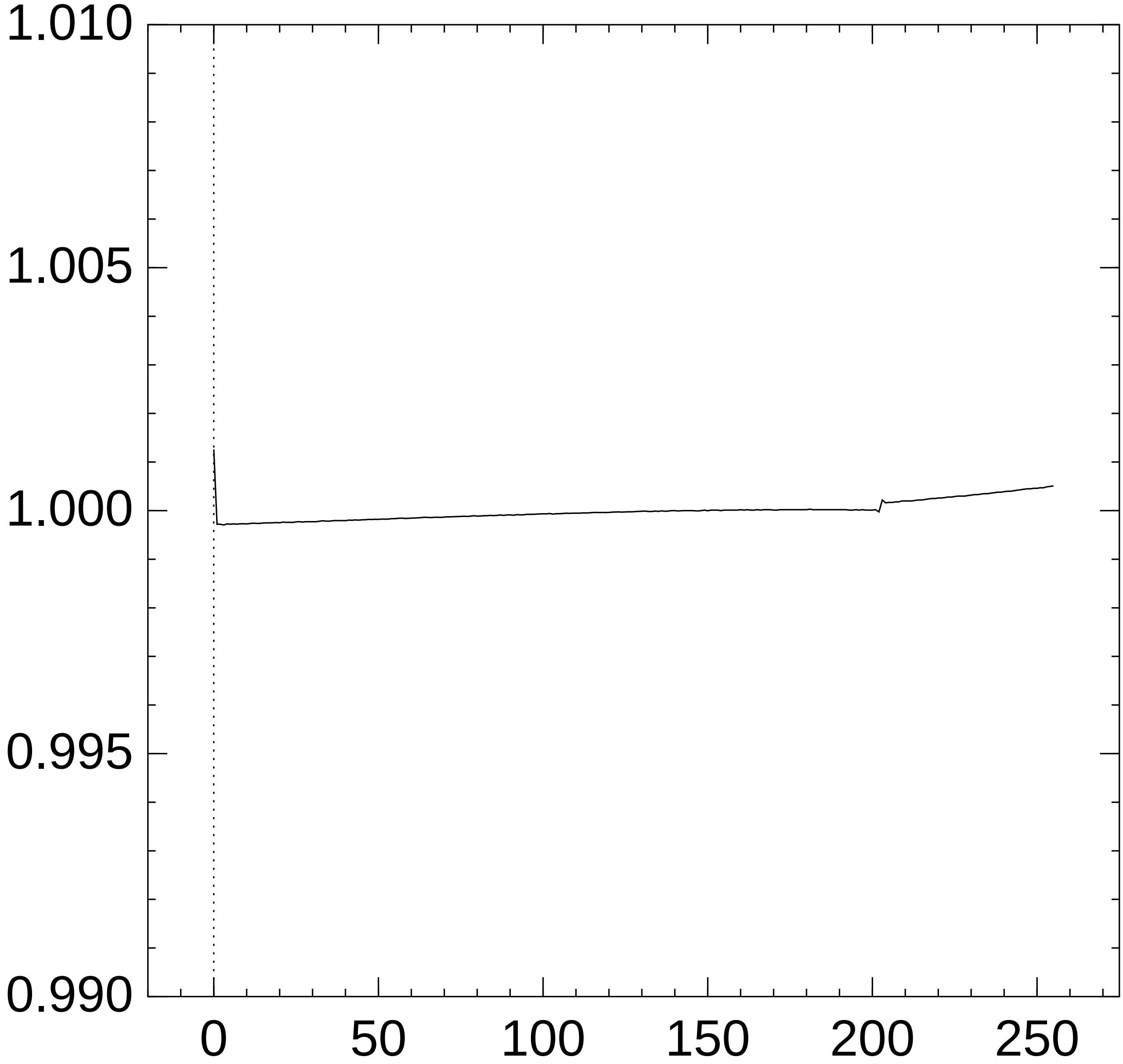
Graph of $256\,\Pr[z_{201} = x]$:



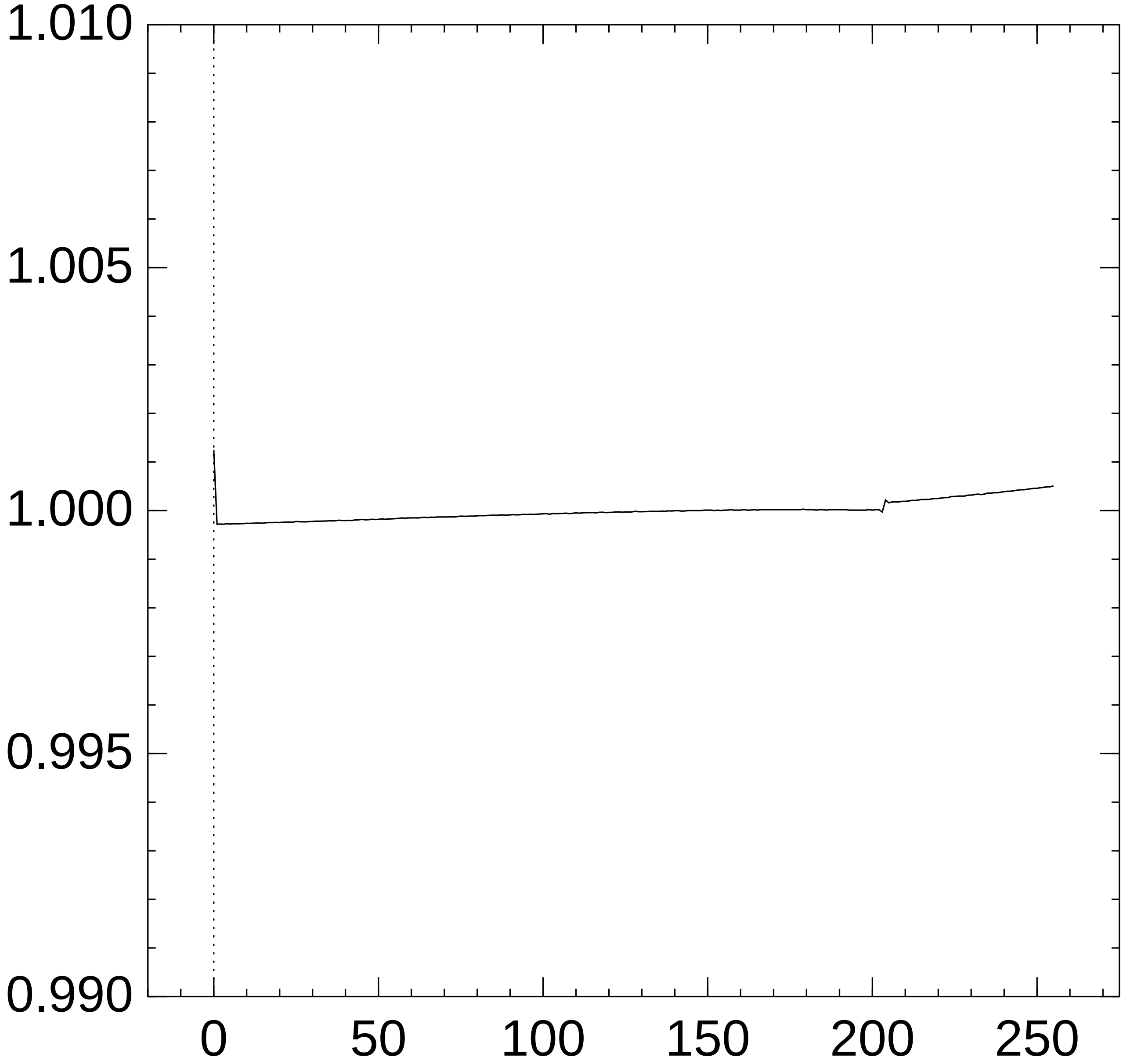
Graph of $256\,\Pr[z_{202} = x]$:



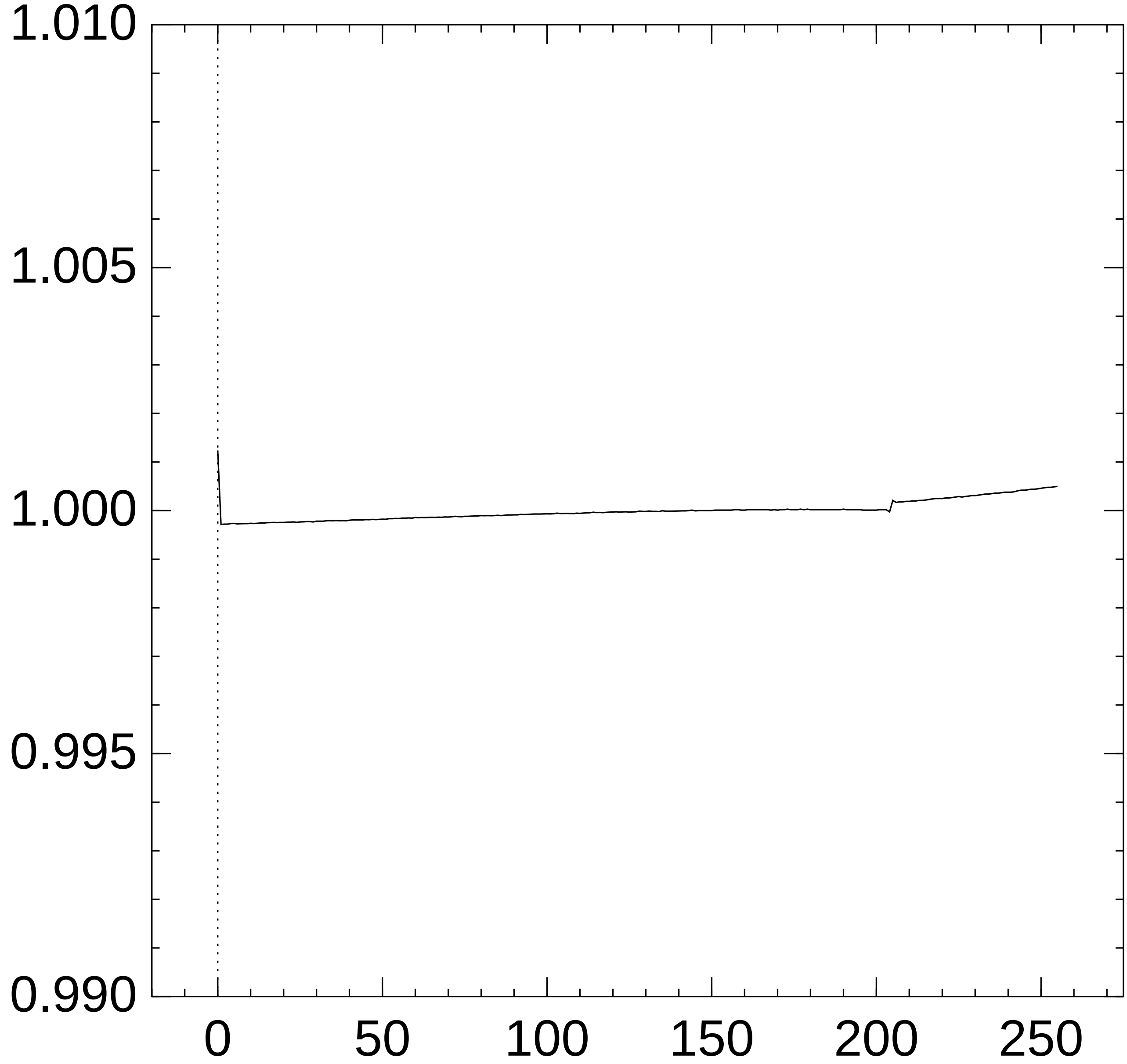
Graph of $256\,\Pr[z_{203} = x]$:



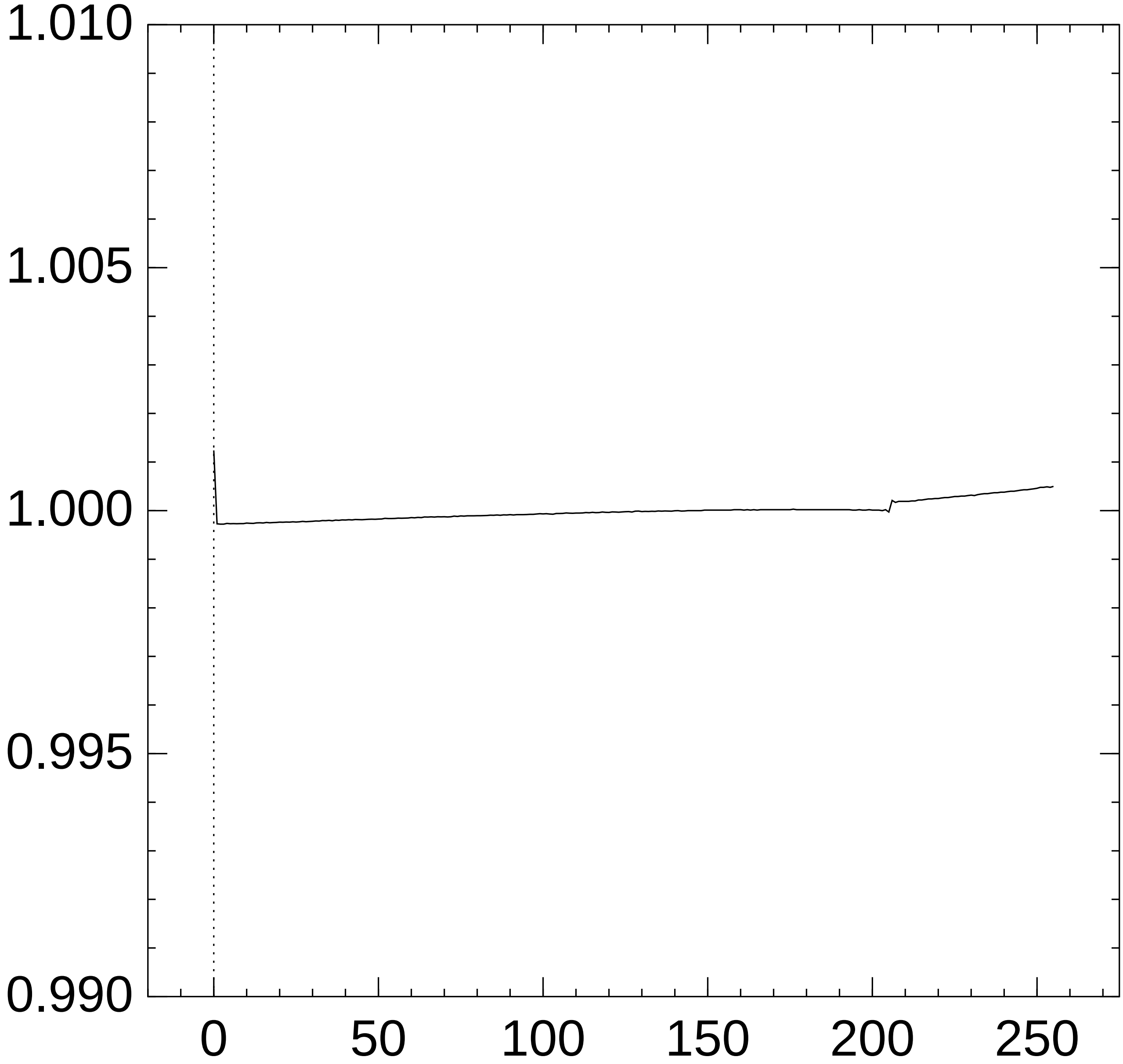
Graph of $256\,\Pr[z_{204} = x]$:



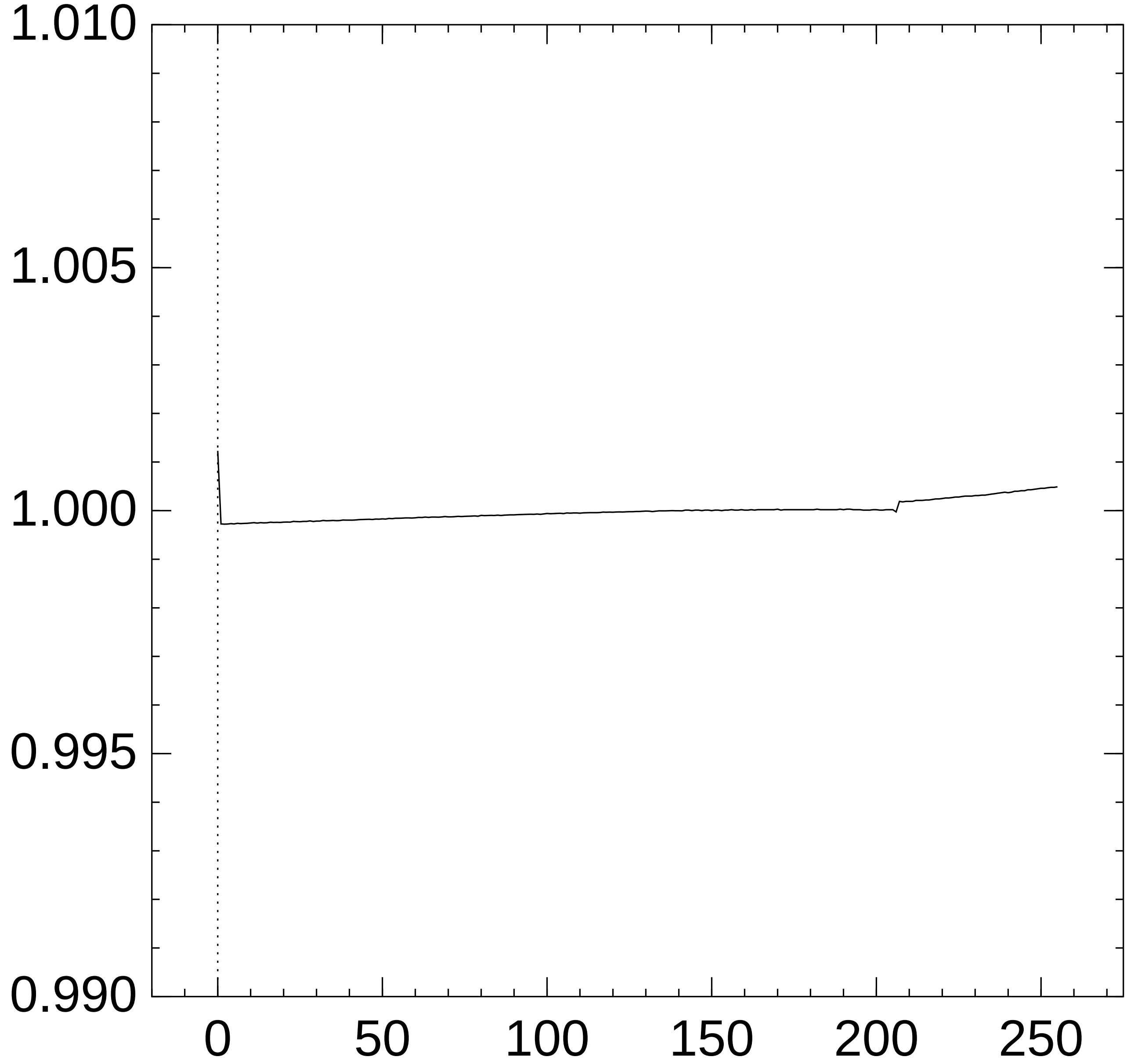
Graph of $256\,\Pr[z_{205} = x]$:



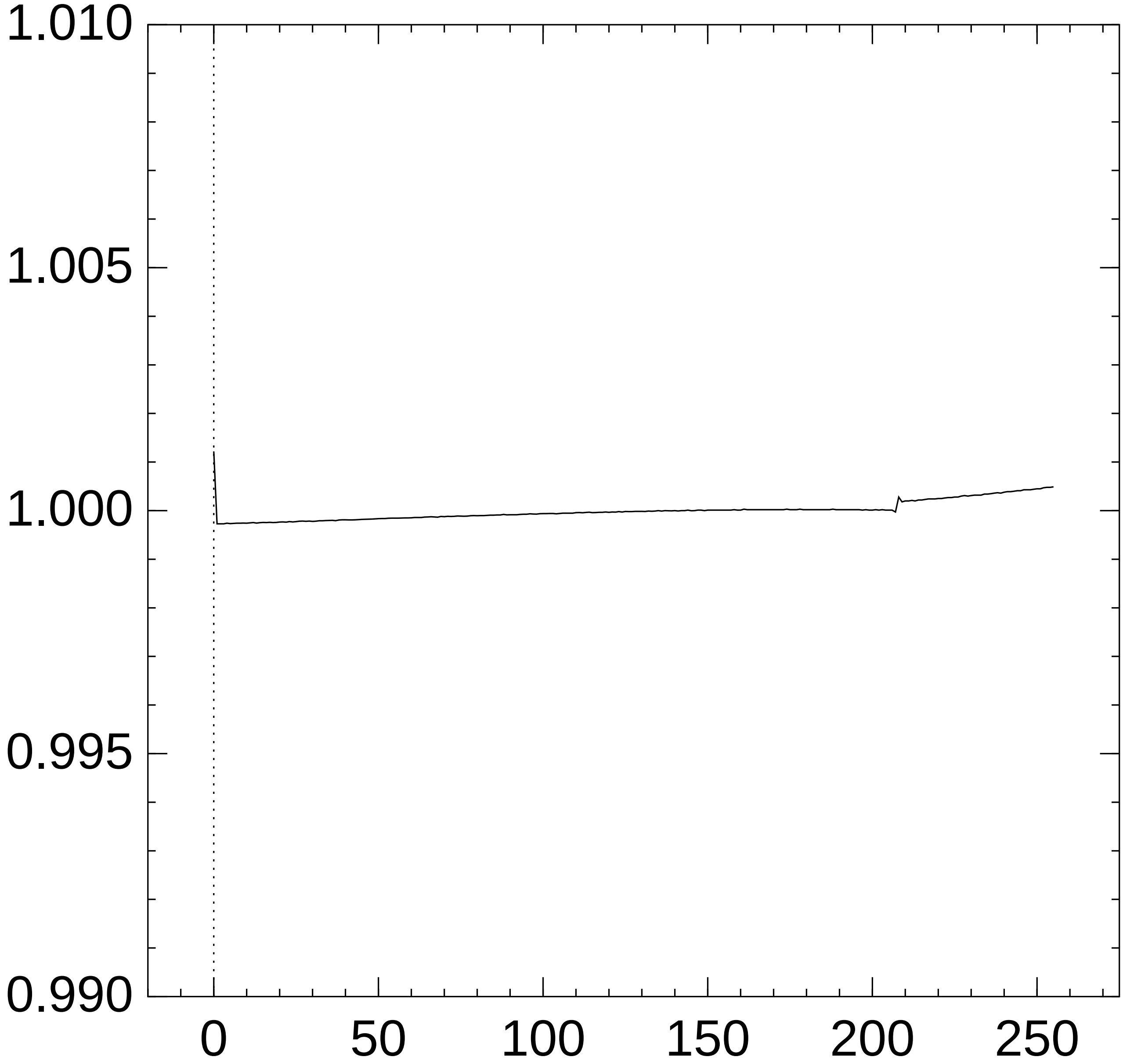
Graph of $256\,\Pr[z_{206} = x]$:



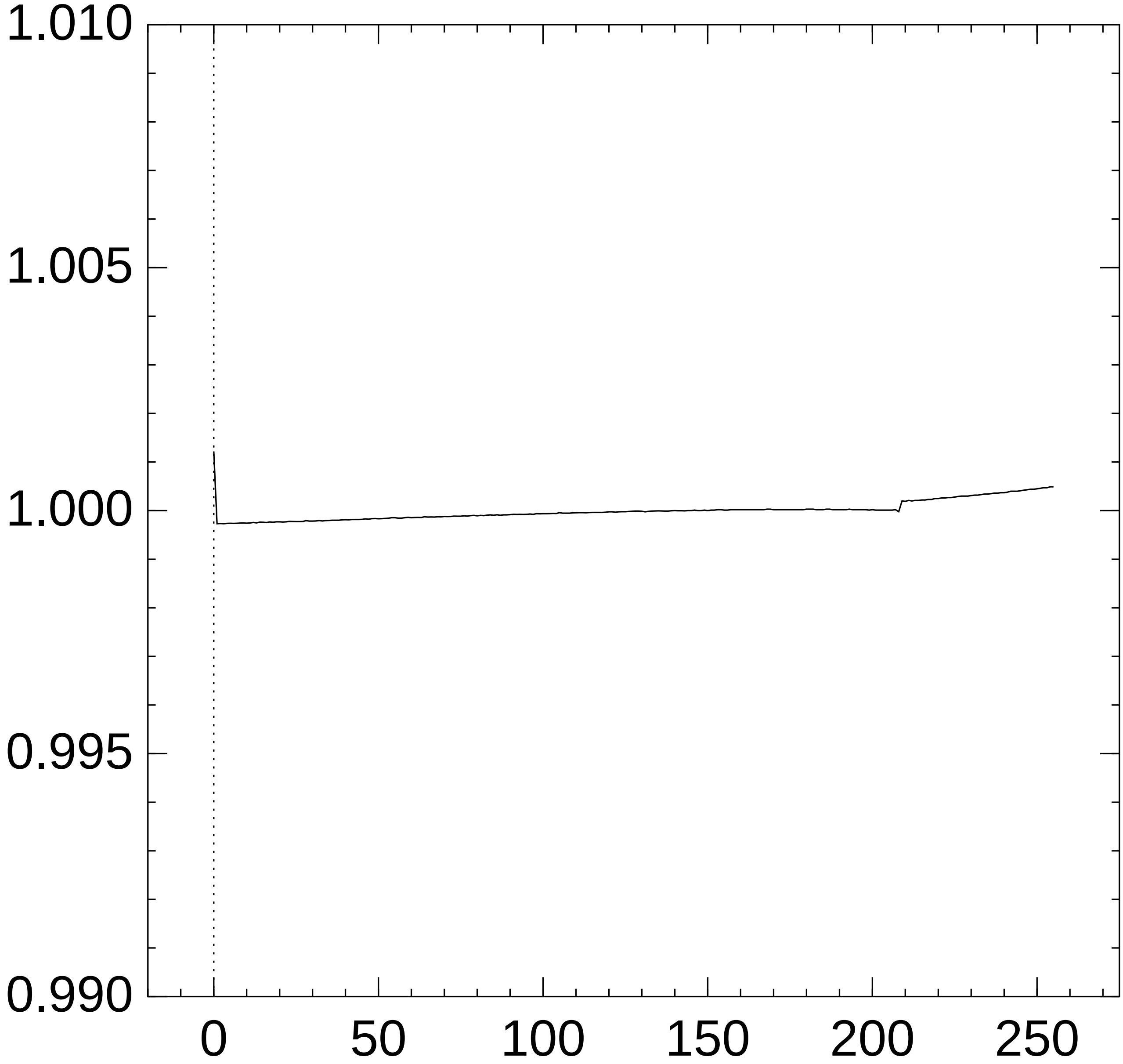
Graph of $256\,\Pr[z_{207} = x]$:



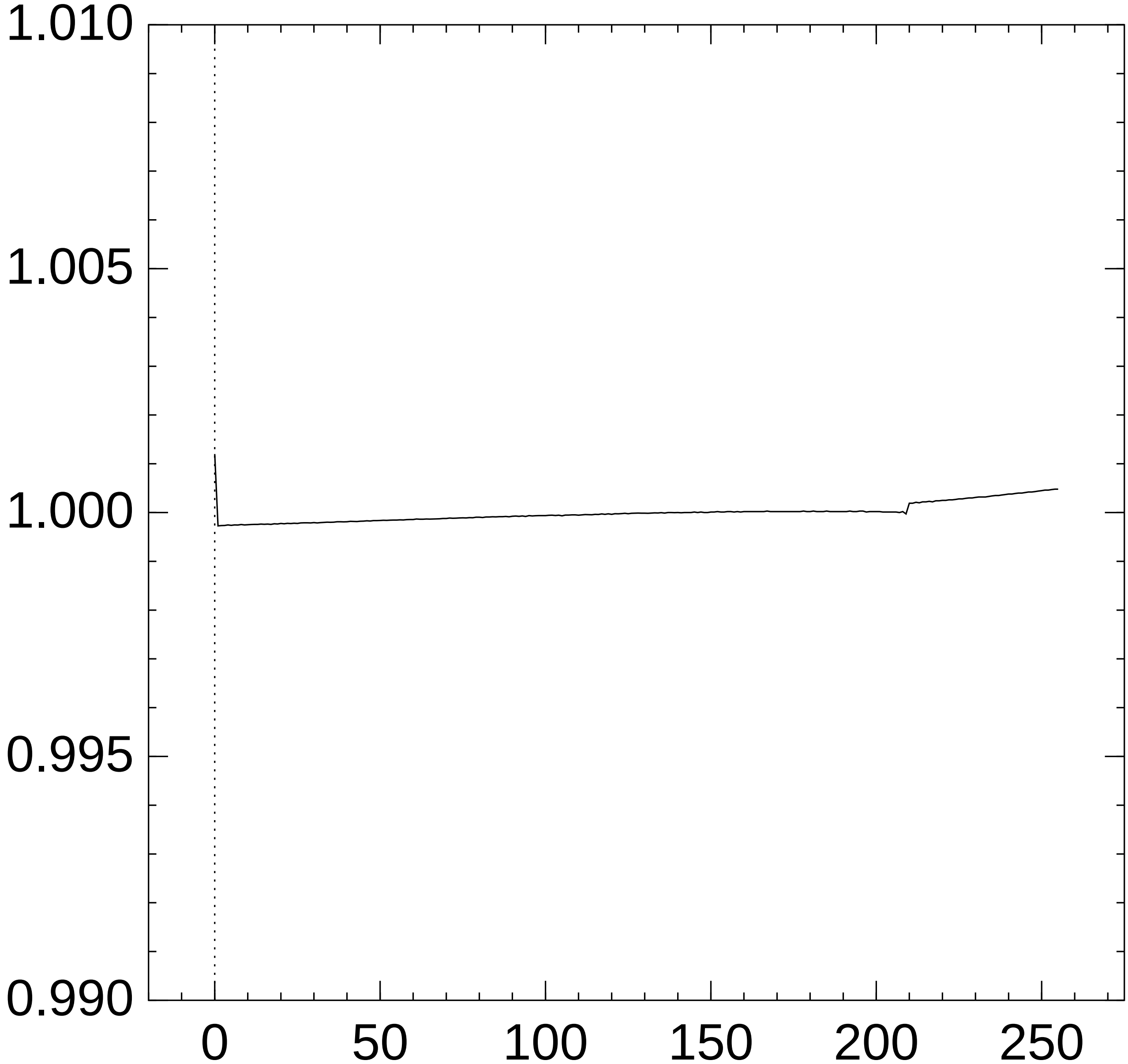
Graph of $256\,\Pr[z_{208} = x]$:



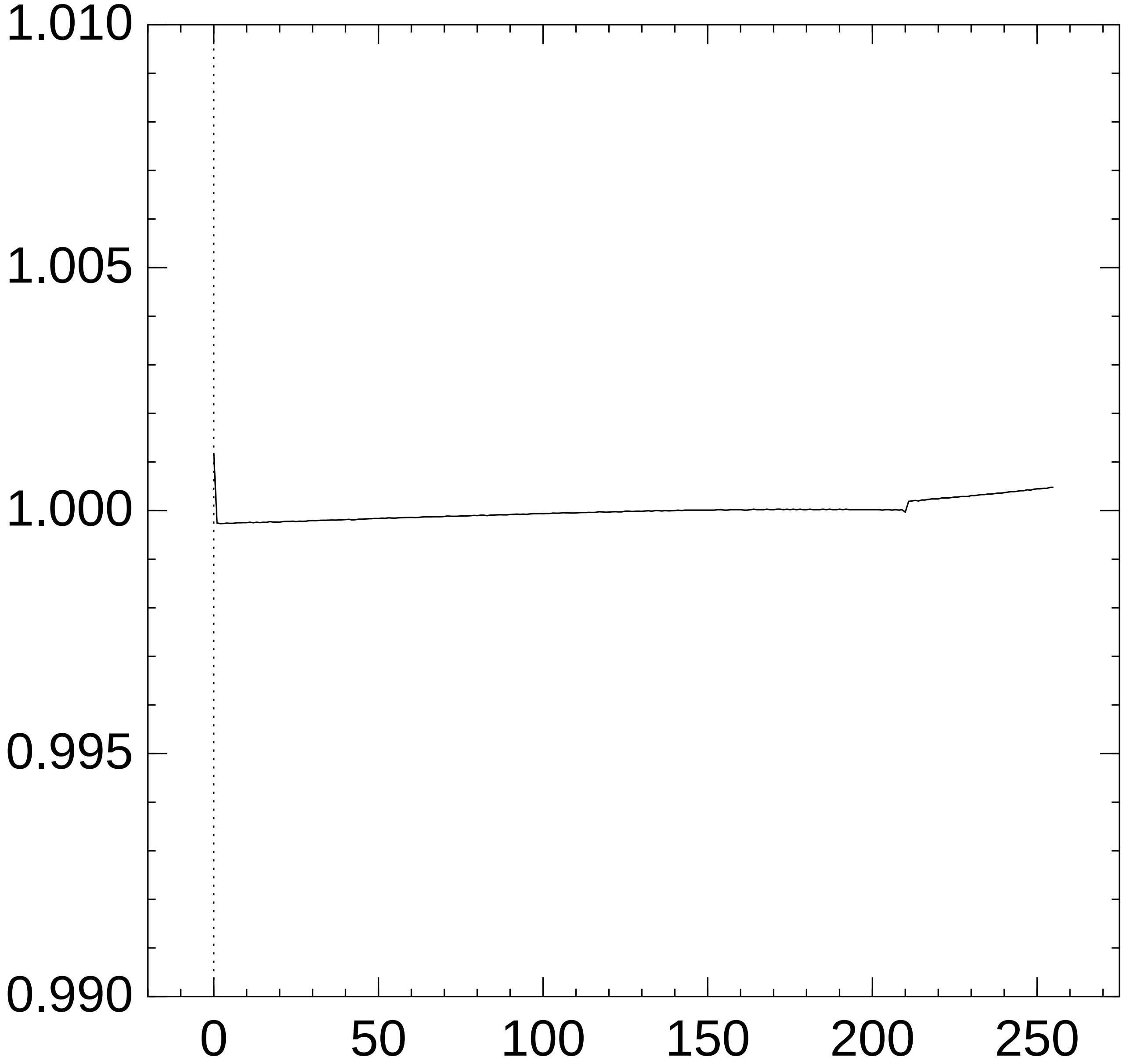
Graph of $256\,\mathrm{Pr}[z_{209} = x]$:



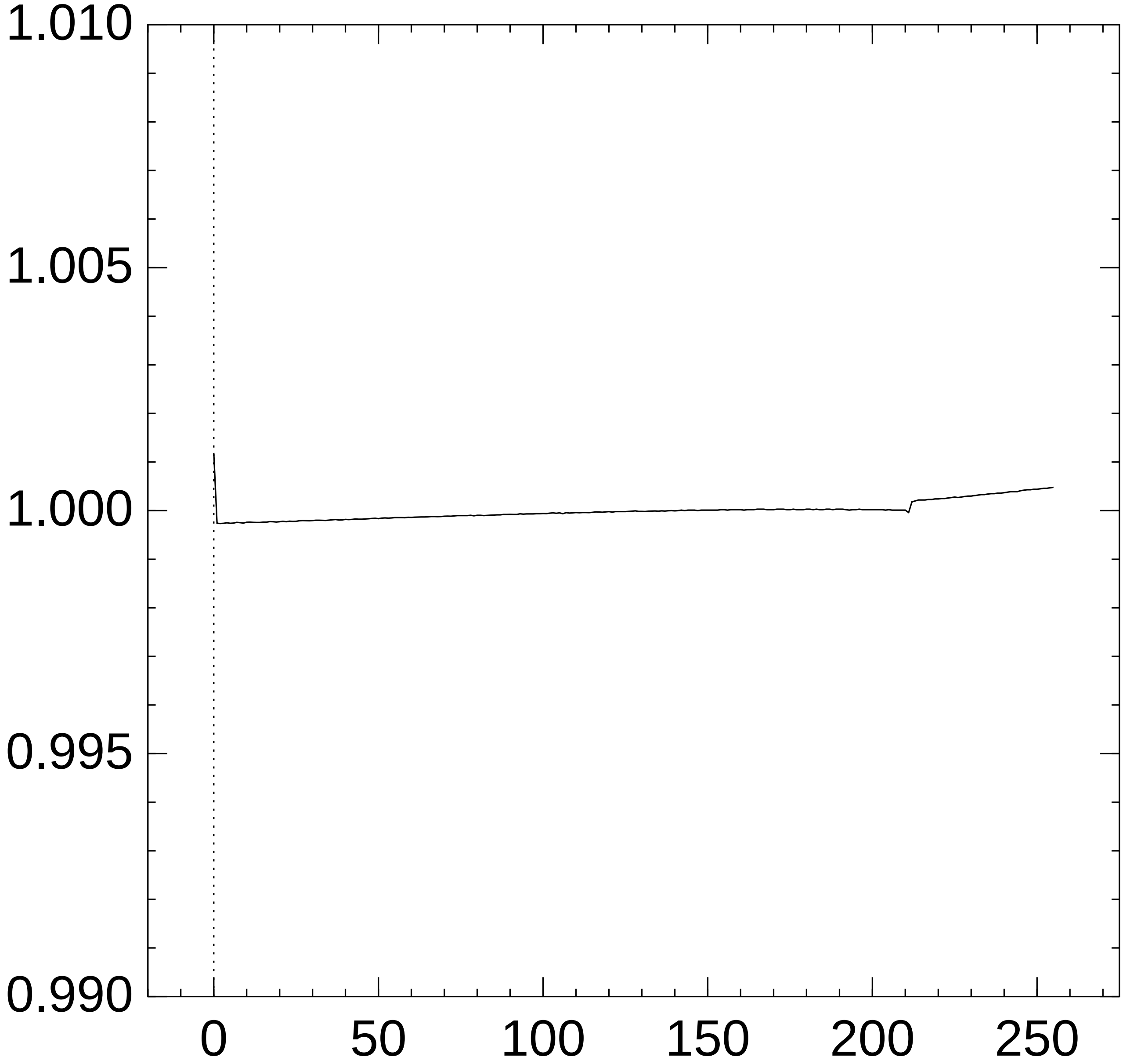
Graph of $256\,\Pr[z_{210} = x]$:



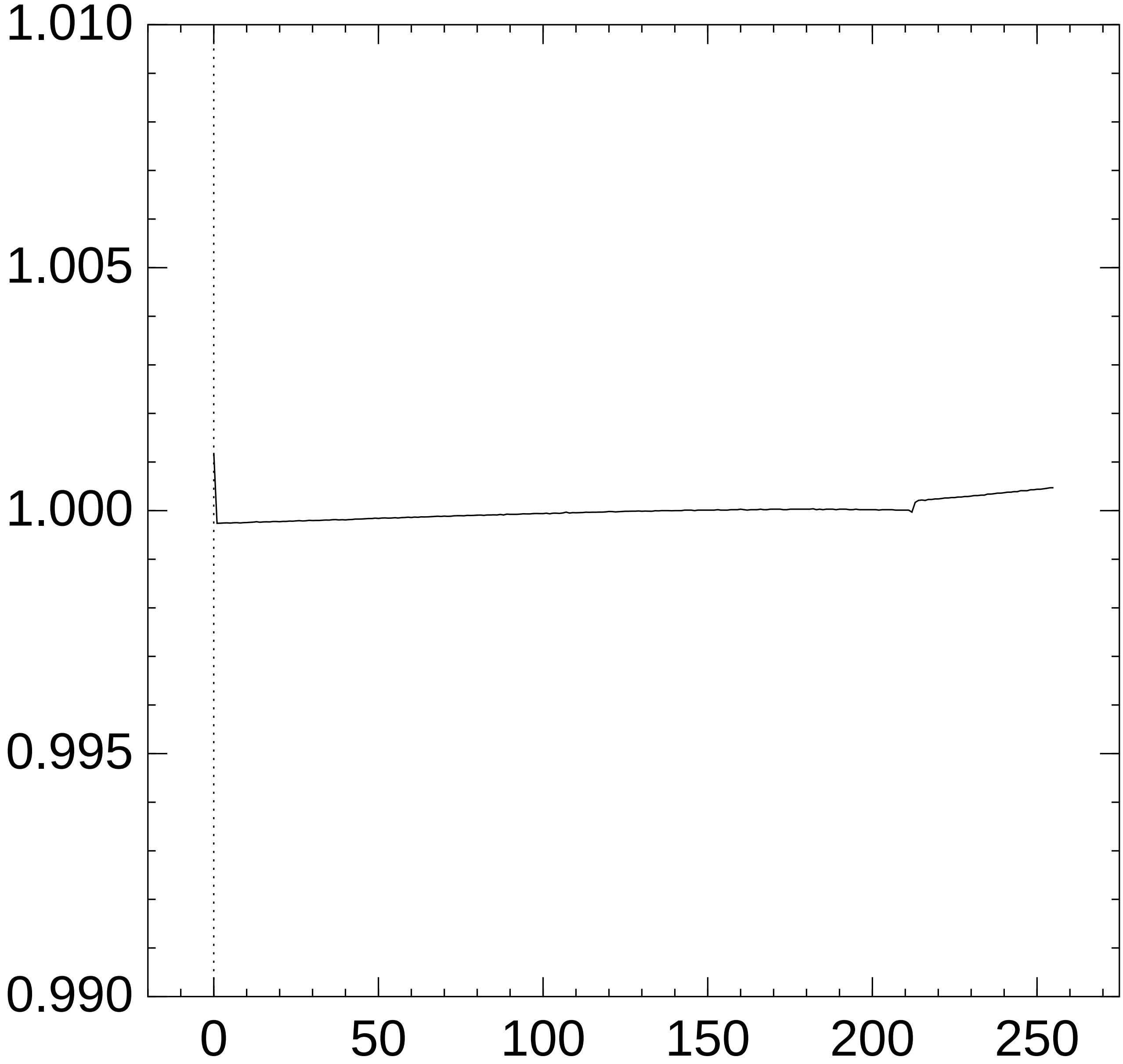
Graph of $256\,\Pr[z_{211} = x]$:



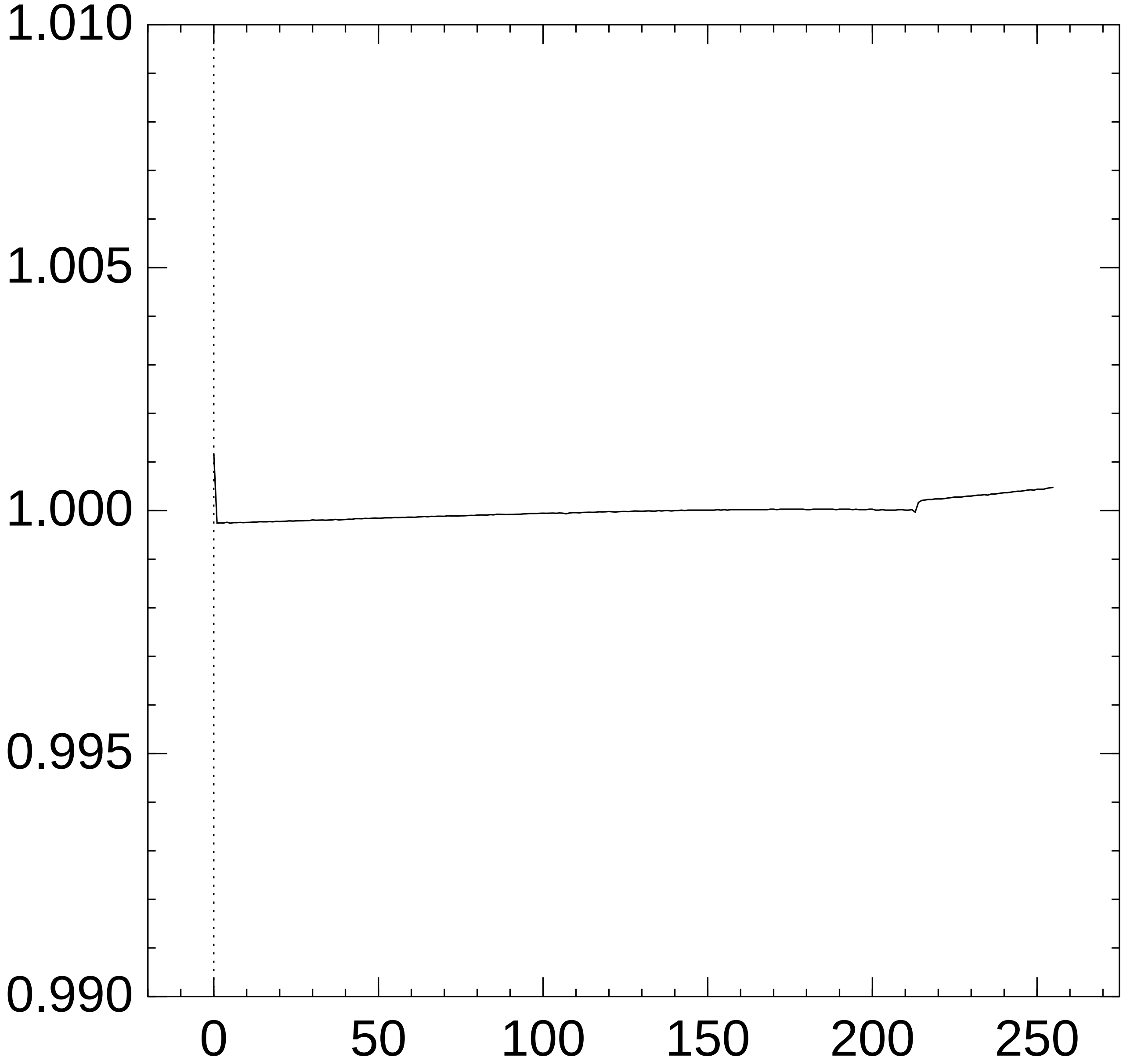
Graph of $256\,\Pr[z_{212} = x]$:



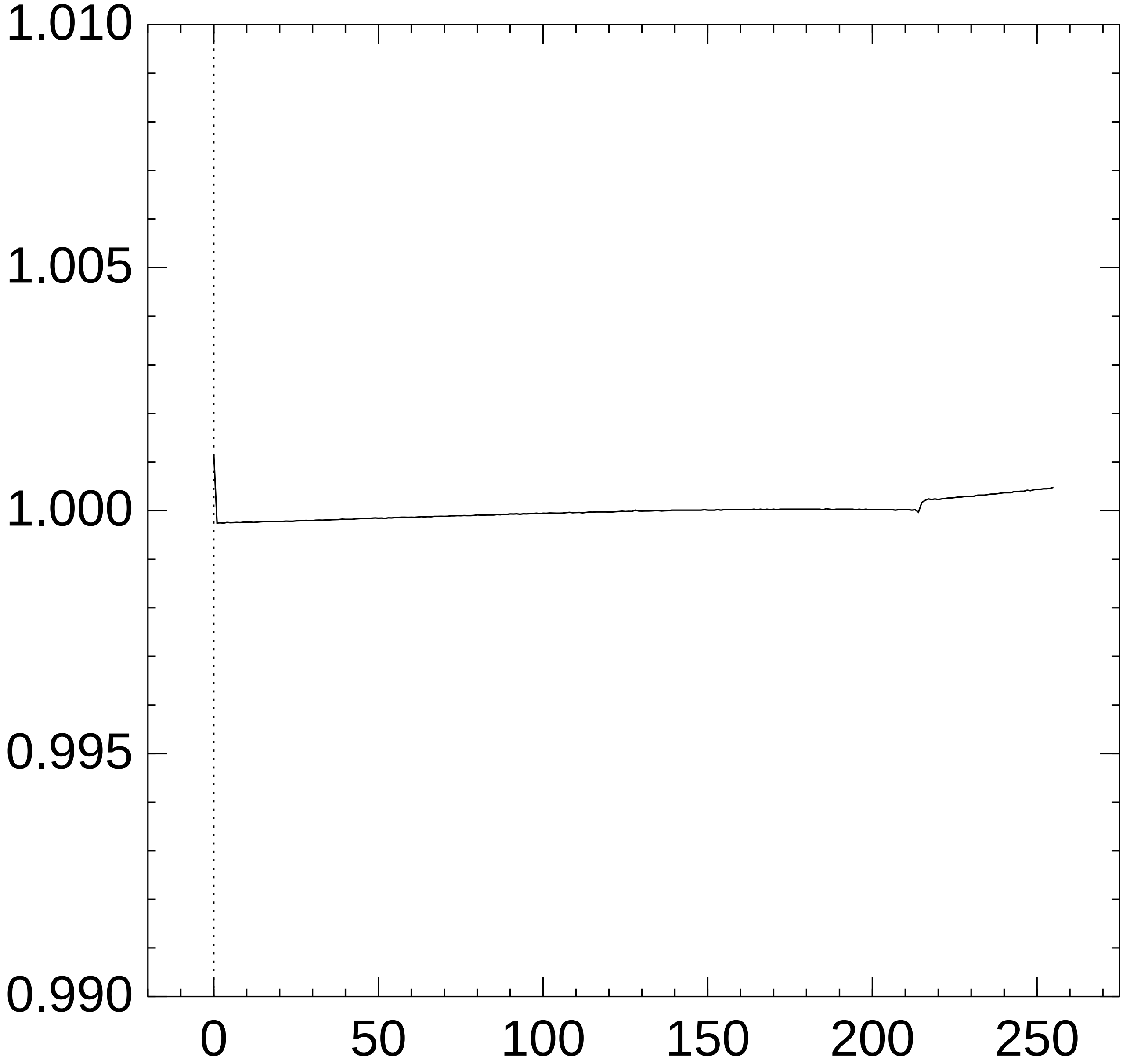
Graph of $256\,\Pr[z_{213} = x]$:



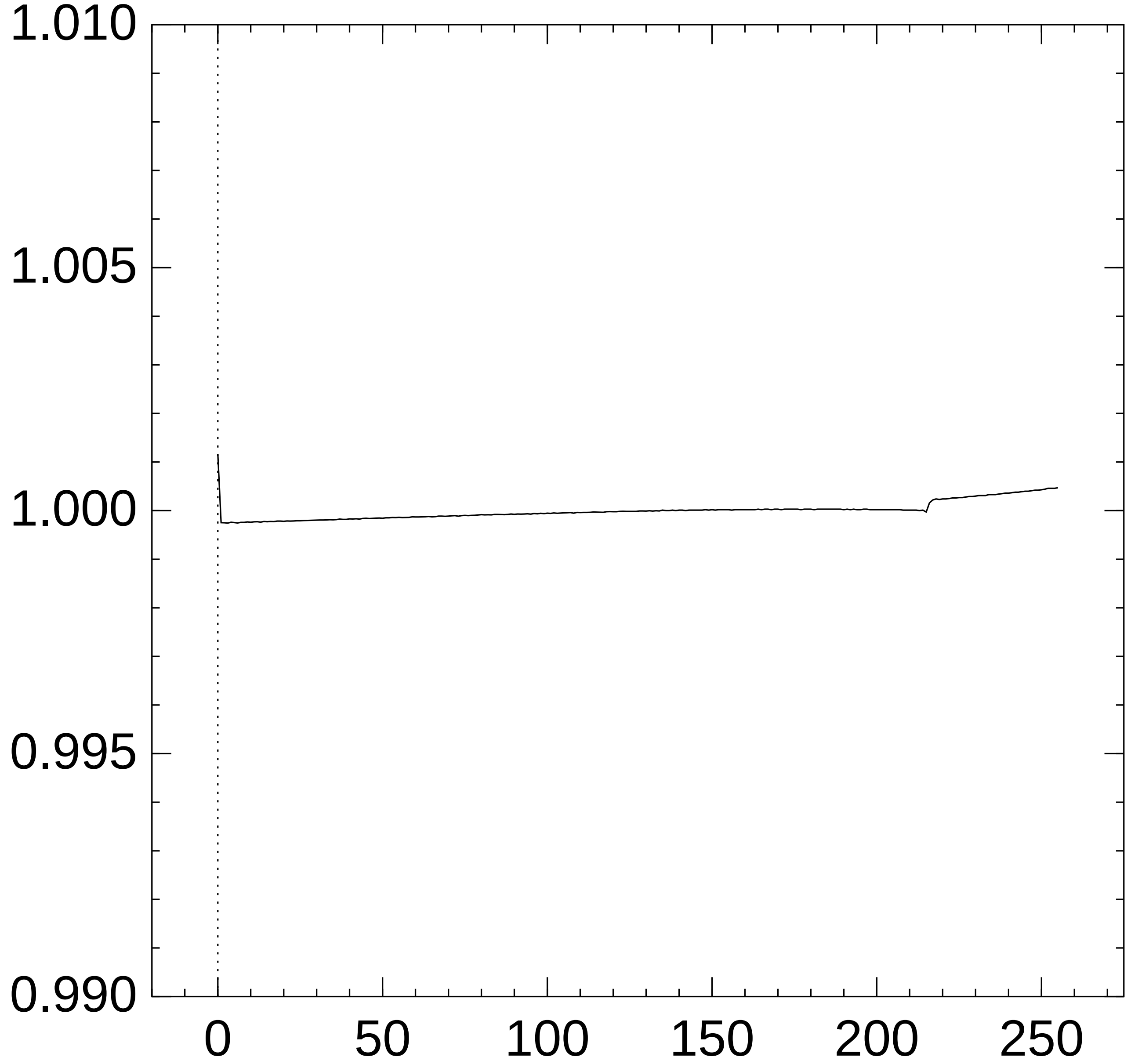
Graph of $256 \Pr[z_{214} = x]$:



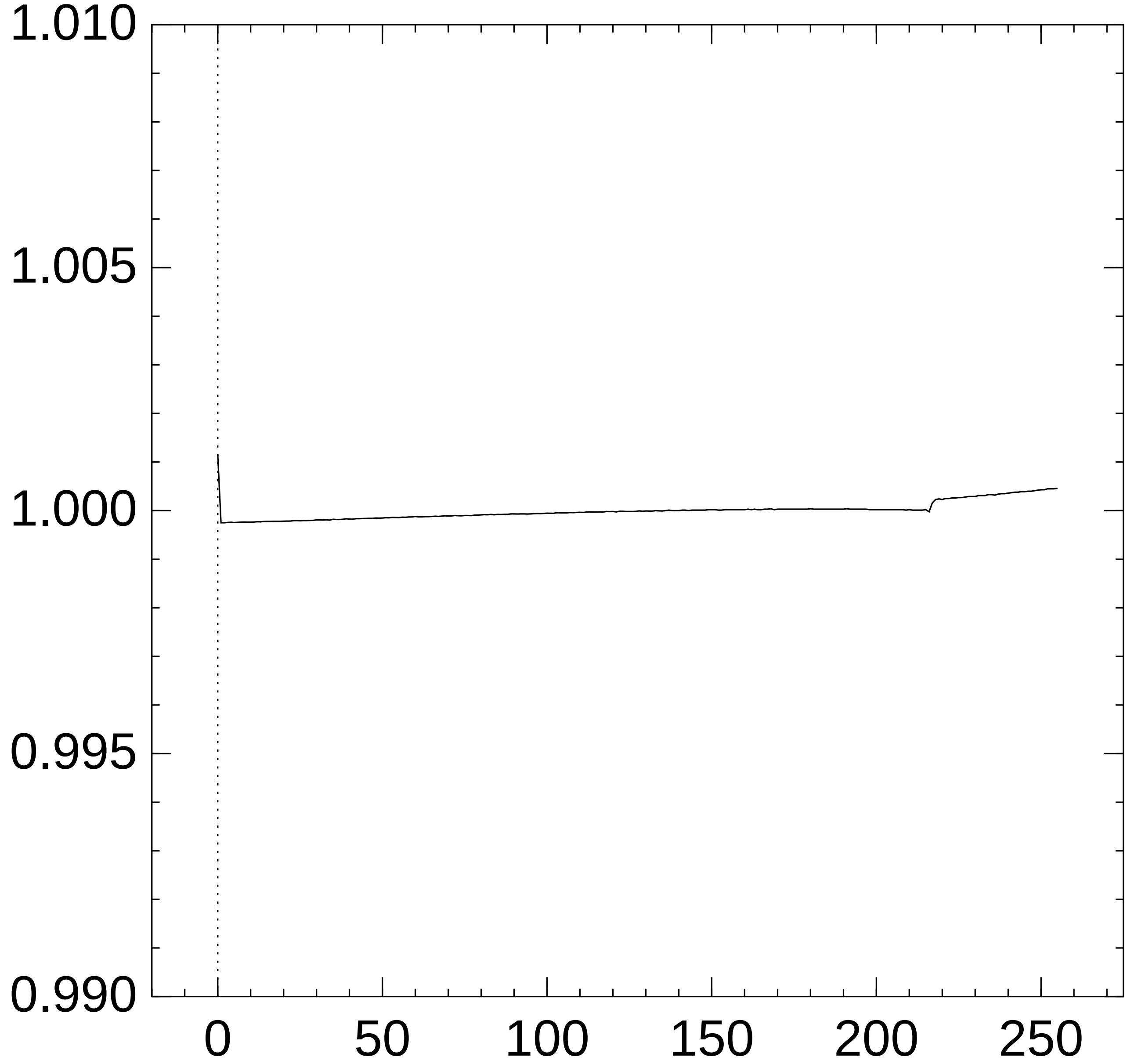
Graph of $256\,\Pr[z_{215} = x]$:



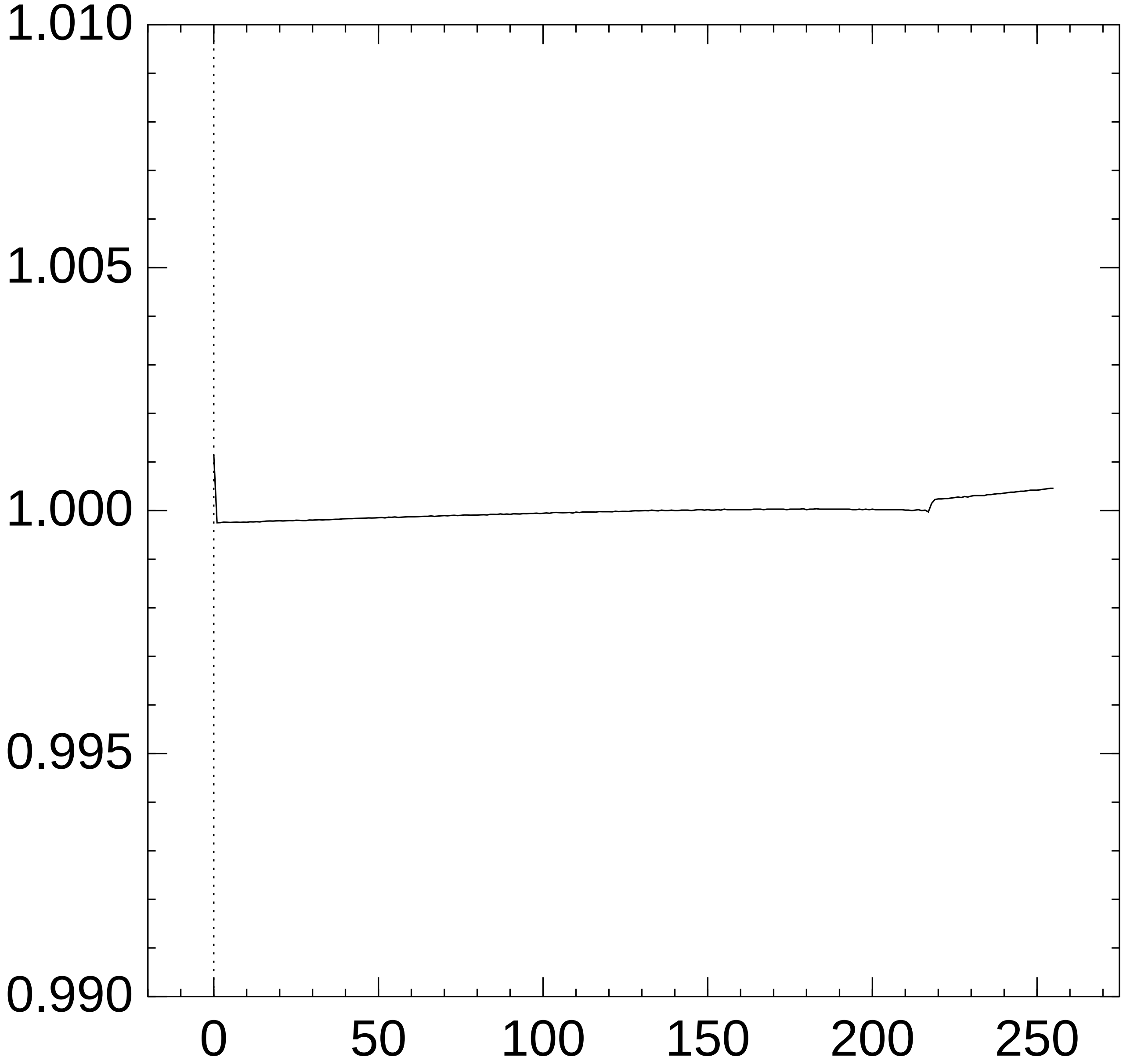
Graph of $256\,\mathrm{Pr}[z_{216} = x]$:



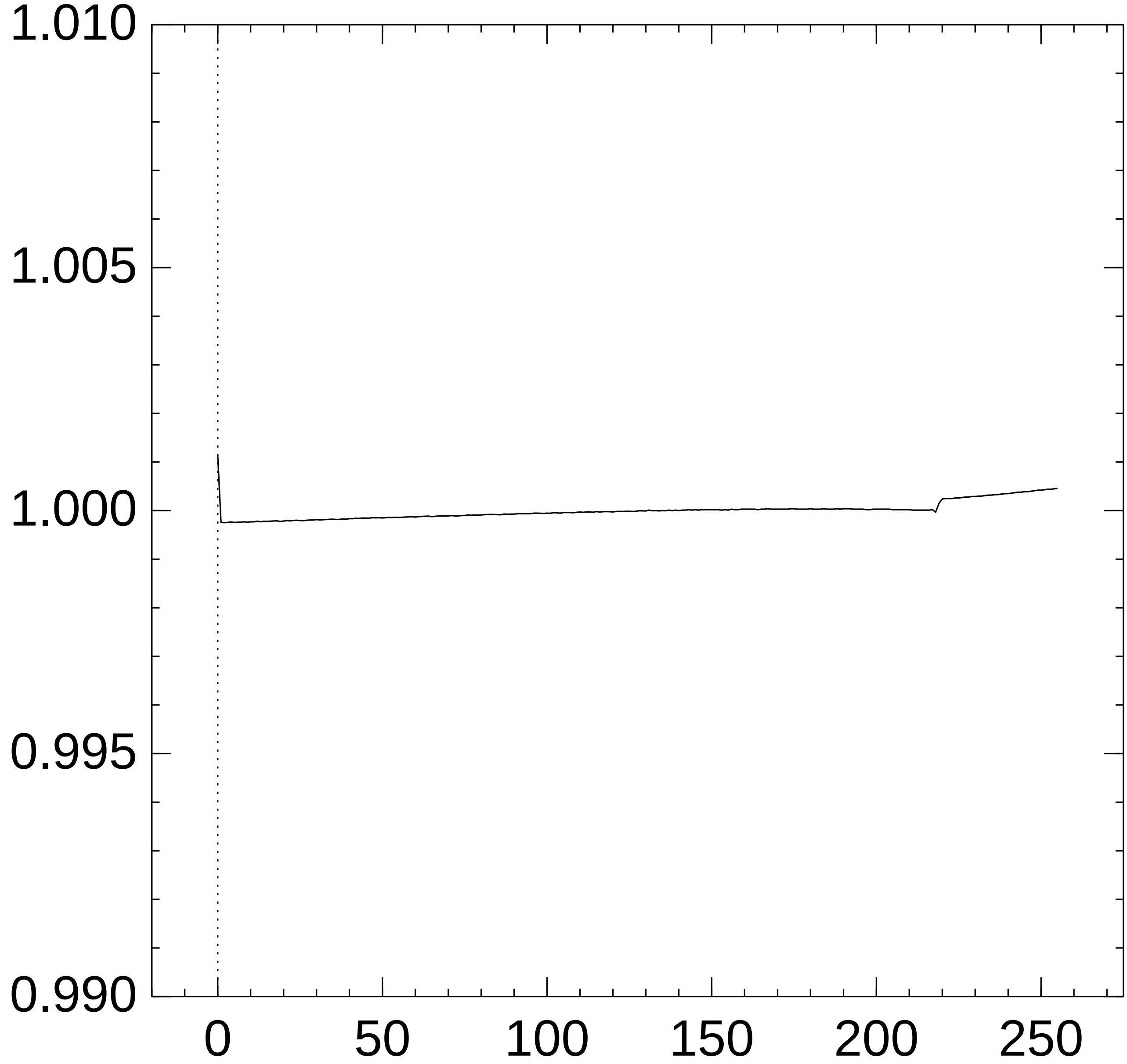
Graph of $256\,\Pr[z_{217} = x]$:



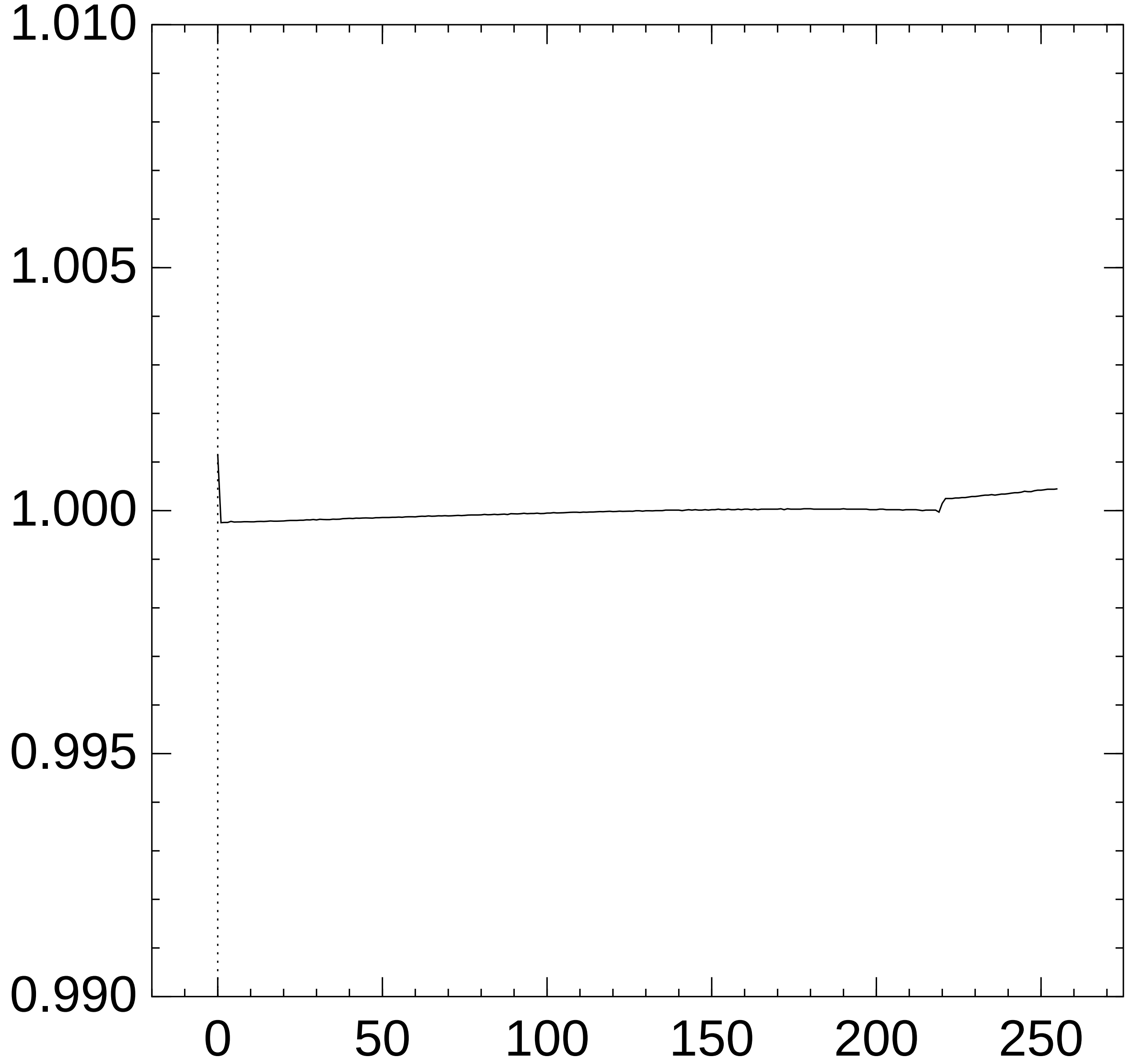
Graph of $256\,\Pr[z_{218} = x]$:



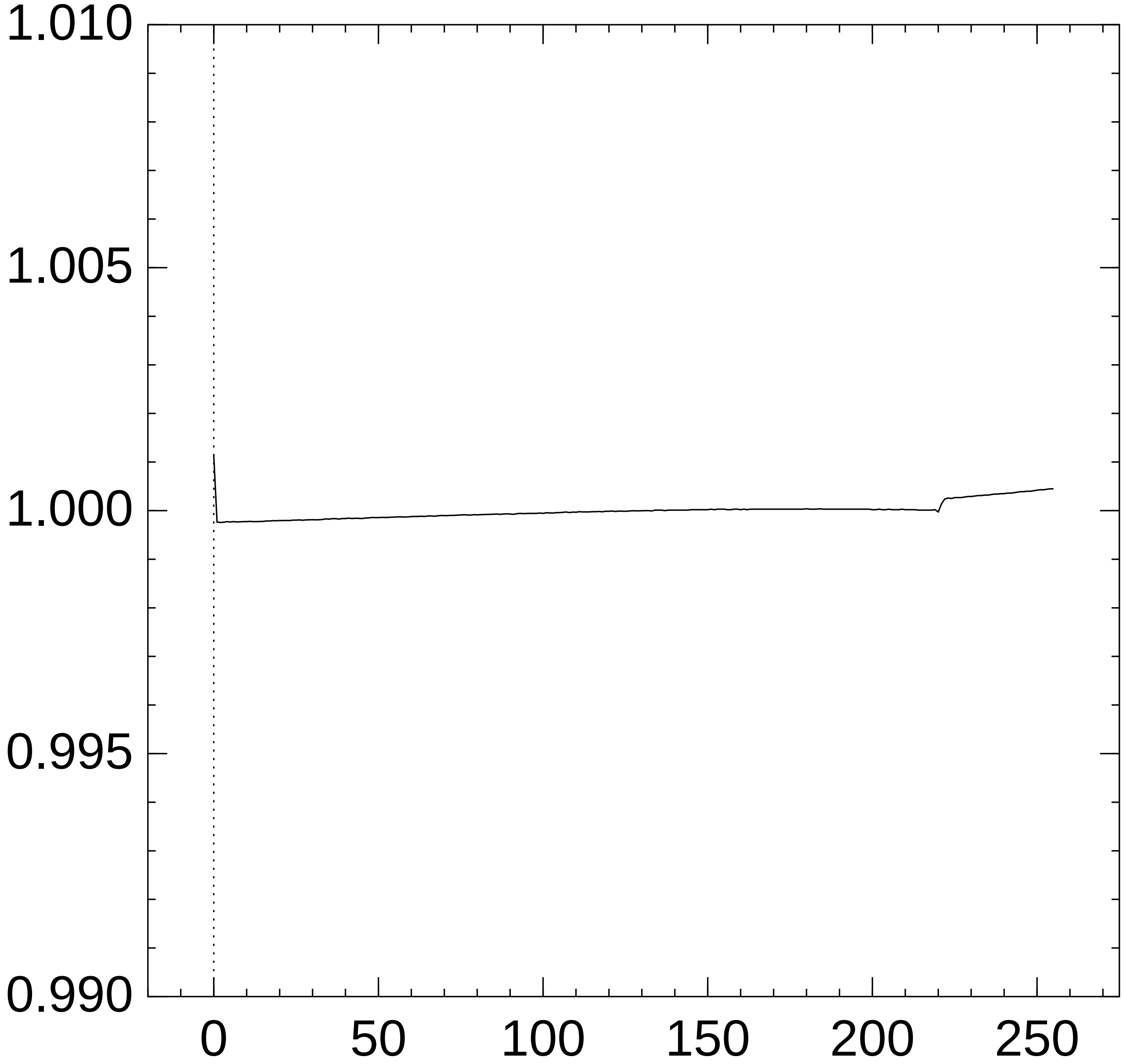
Graph of $256\,\Pr[z_{219} = x]$:



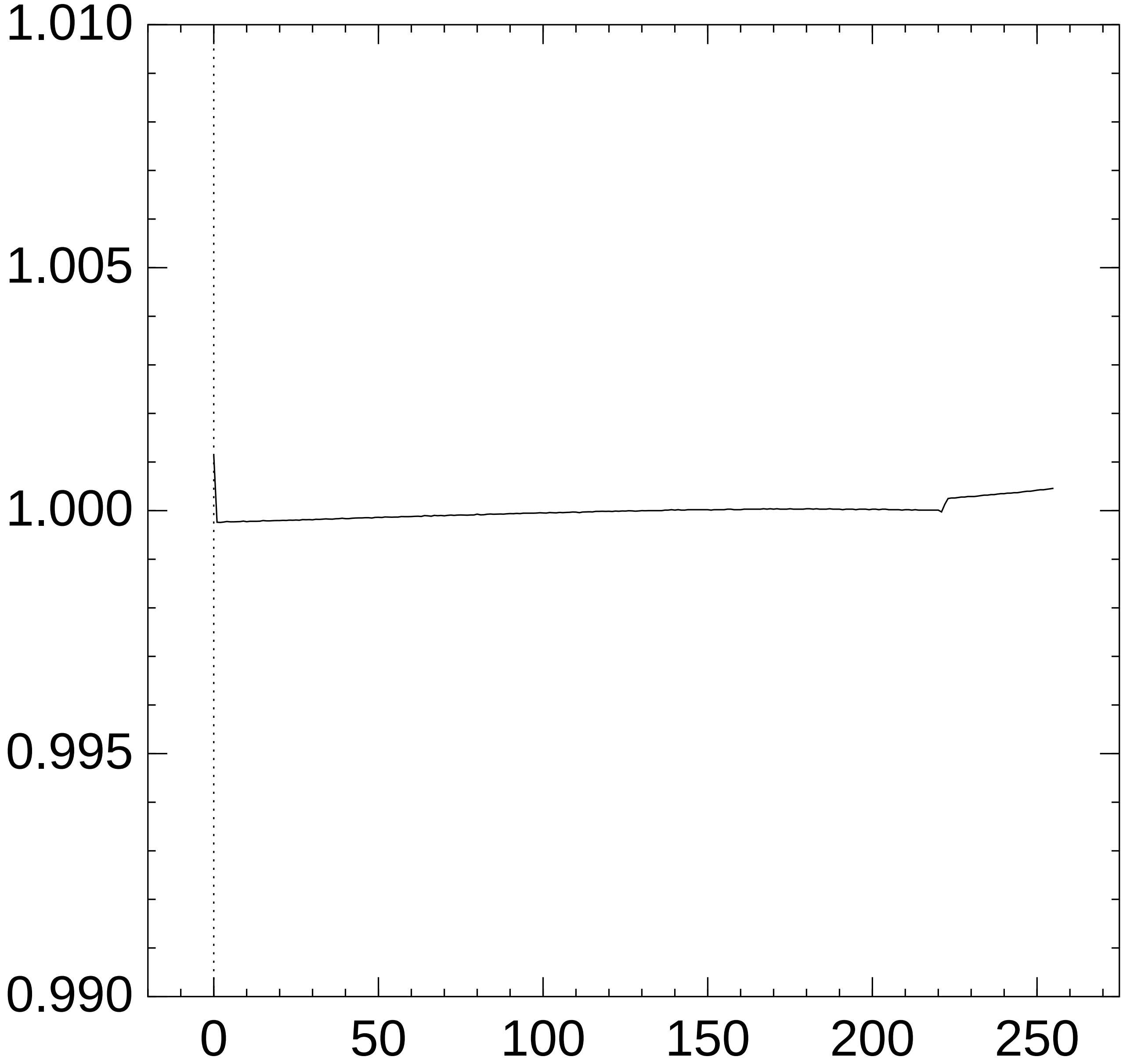
Graph of $256\,\Pr[z_{220} = x]$:



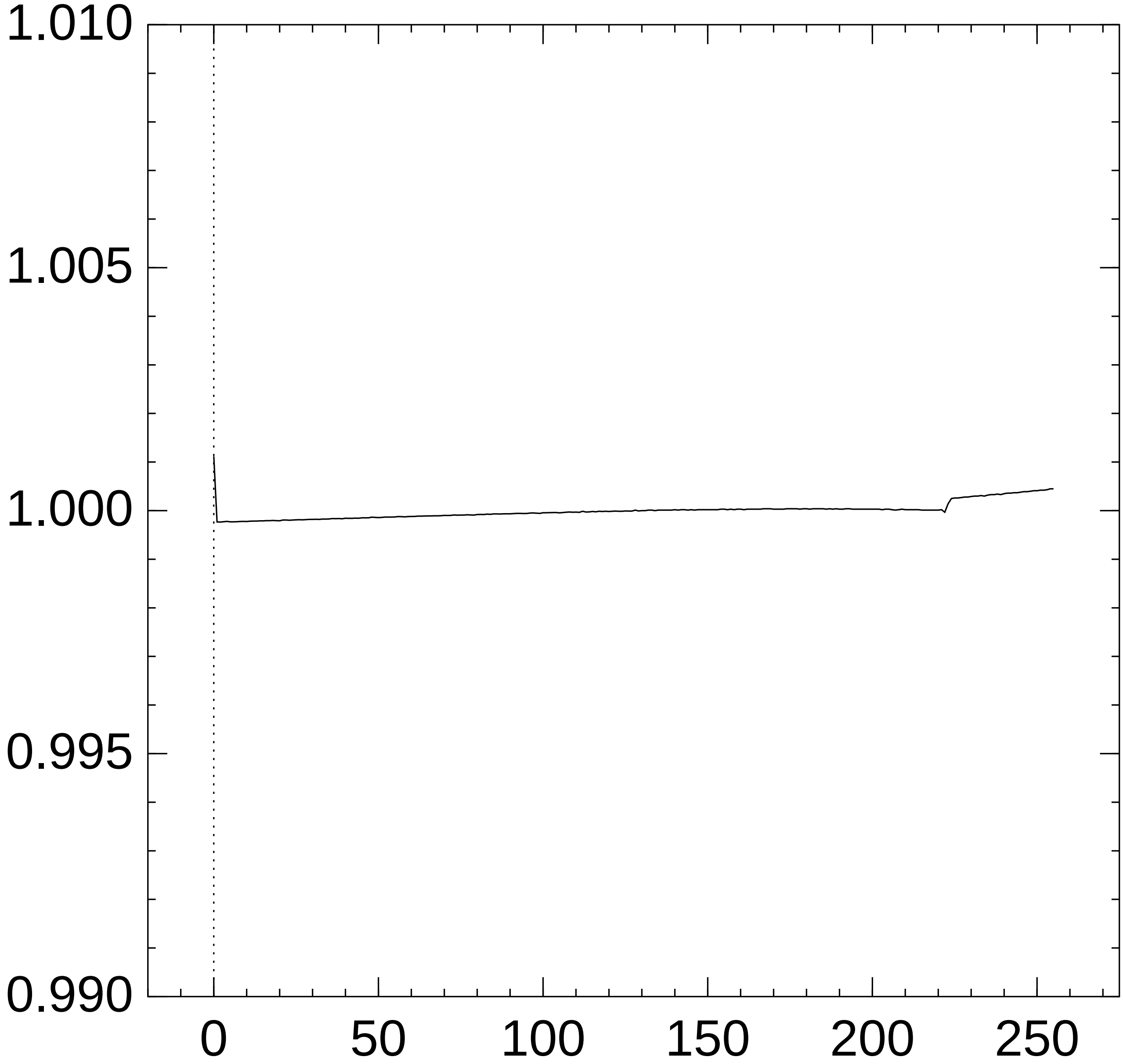
Graph of $256\,\Pr[z_{221} = x]$:



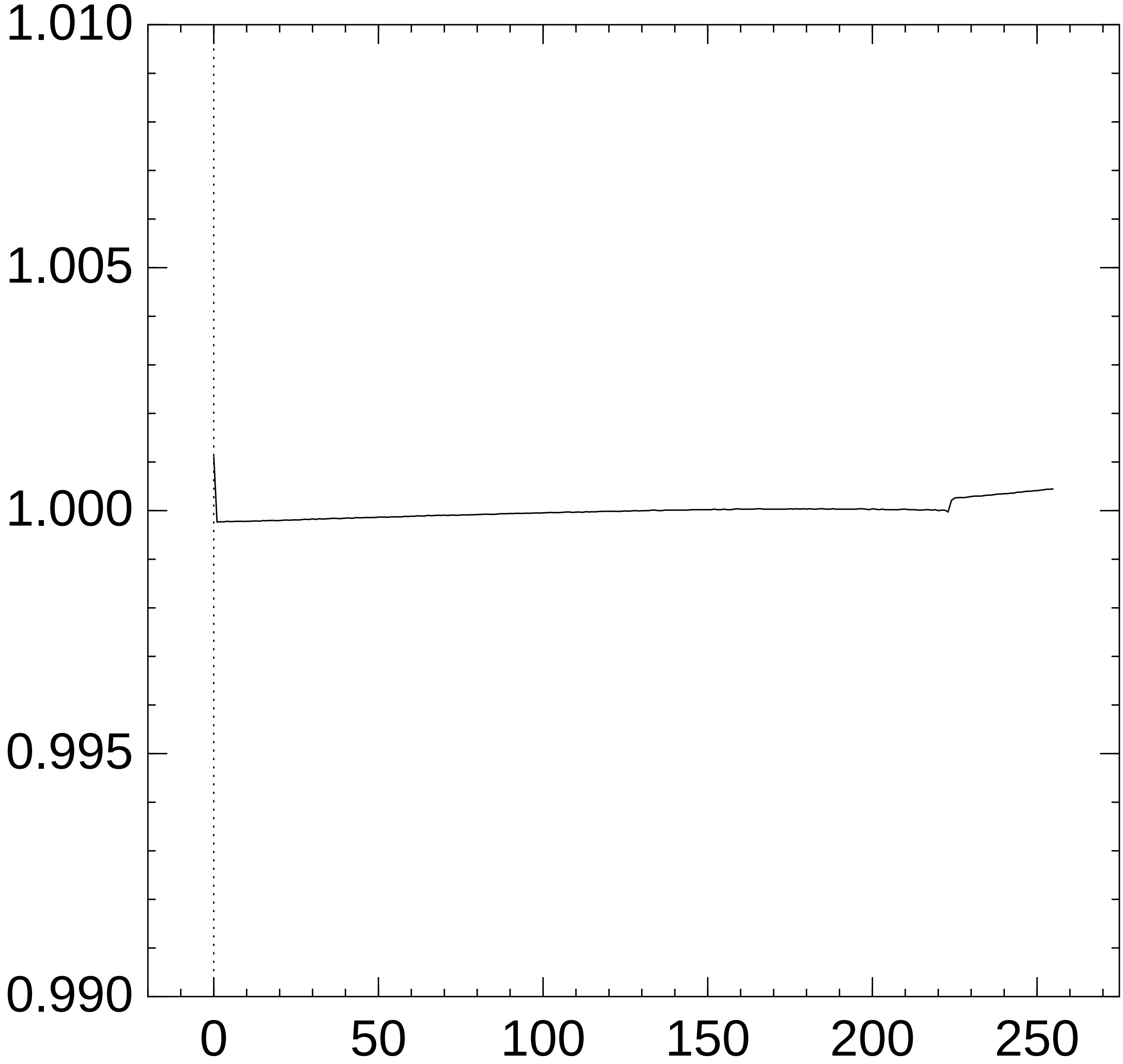
Graph of $256\,\Pr[z_{222} = x]$:



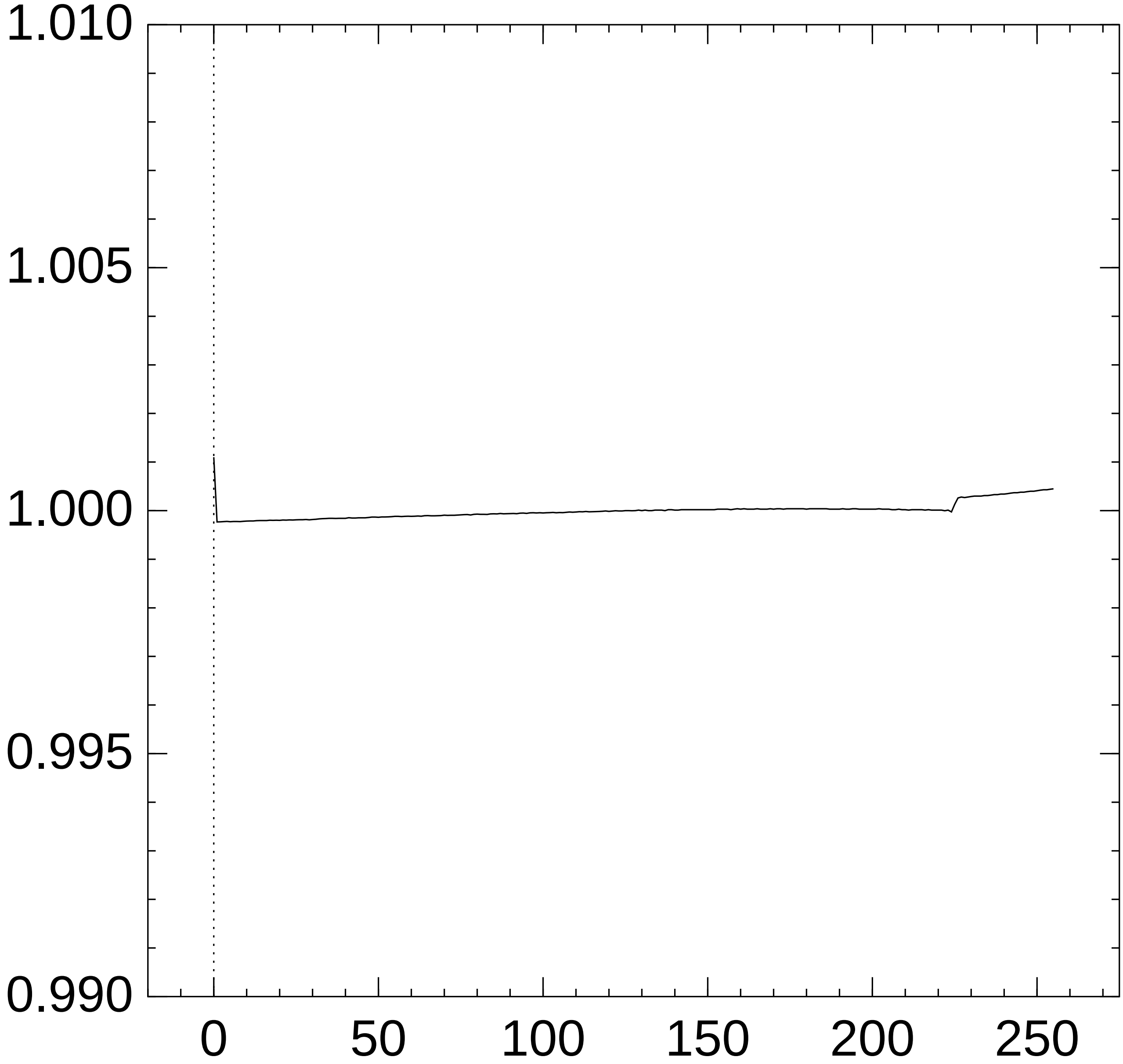
Graph of $256\,\Pr[z_{223} = x]$:



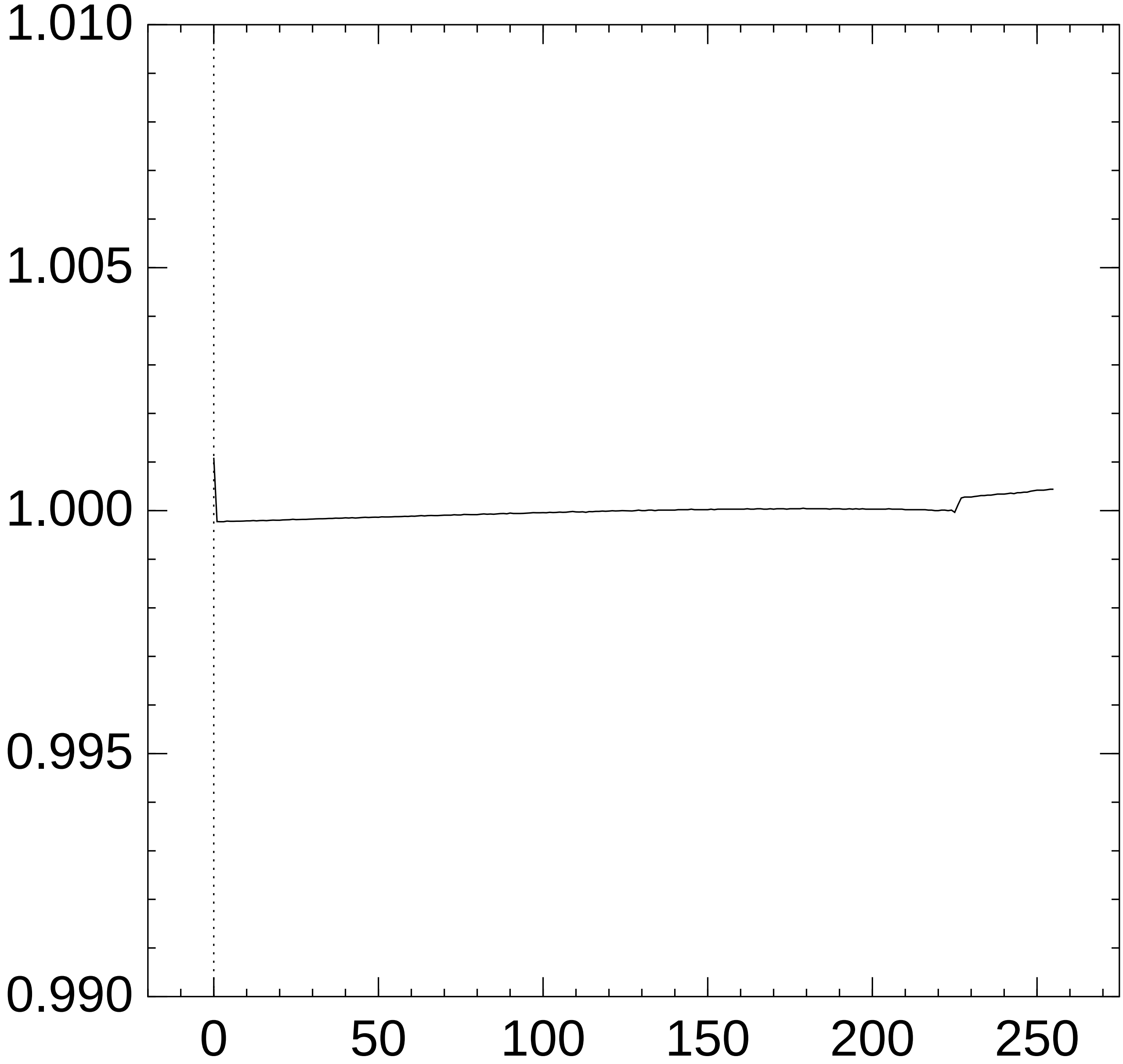
Graph of $256\,\mathrm{Pr}[z_{224} = x]$:



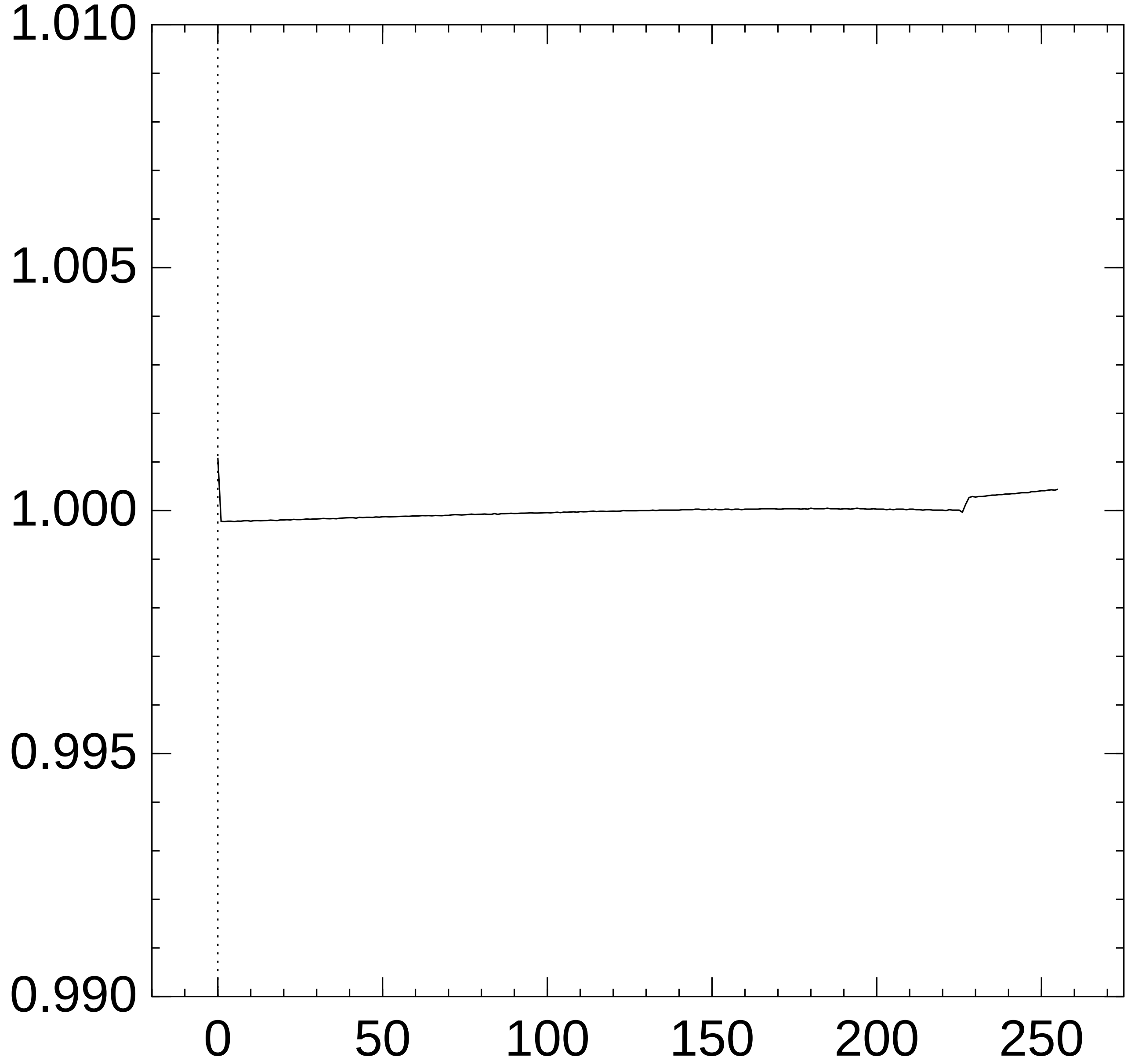
Graph of $256\,\Pr[z_{225} = x]$:



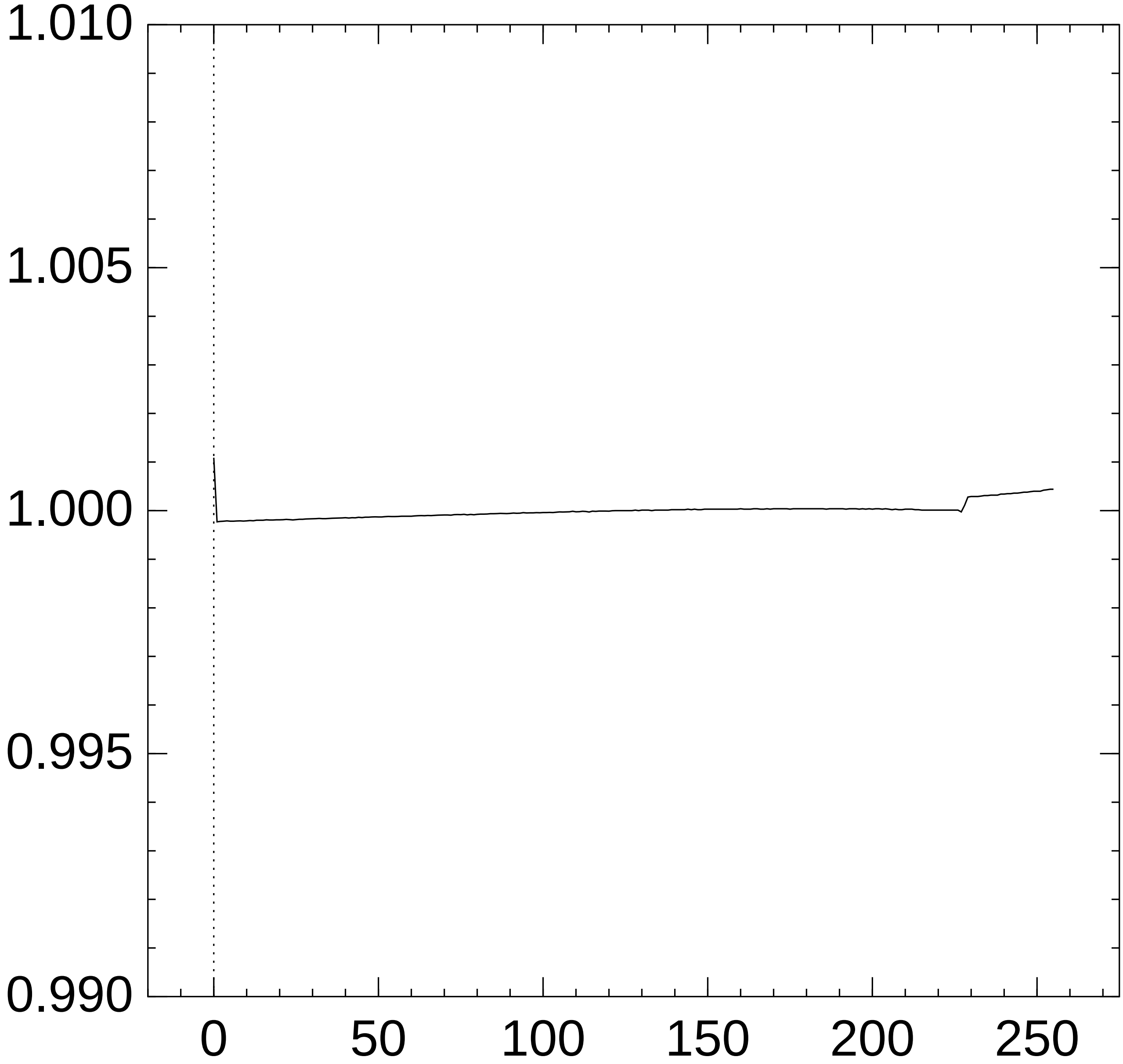
Graph of $256\,\mathrm{Pr}[z_{226} = x]$:



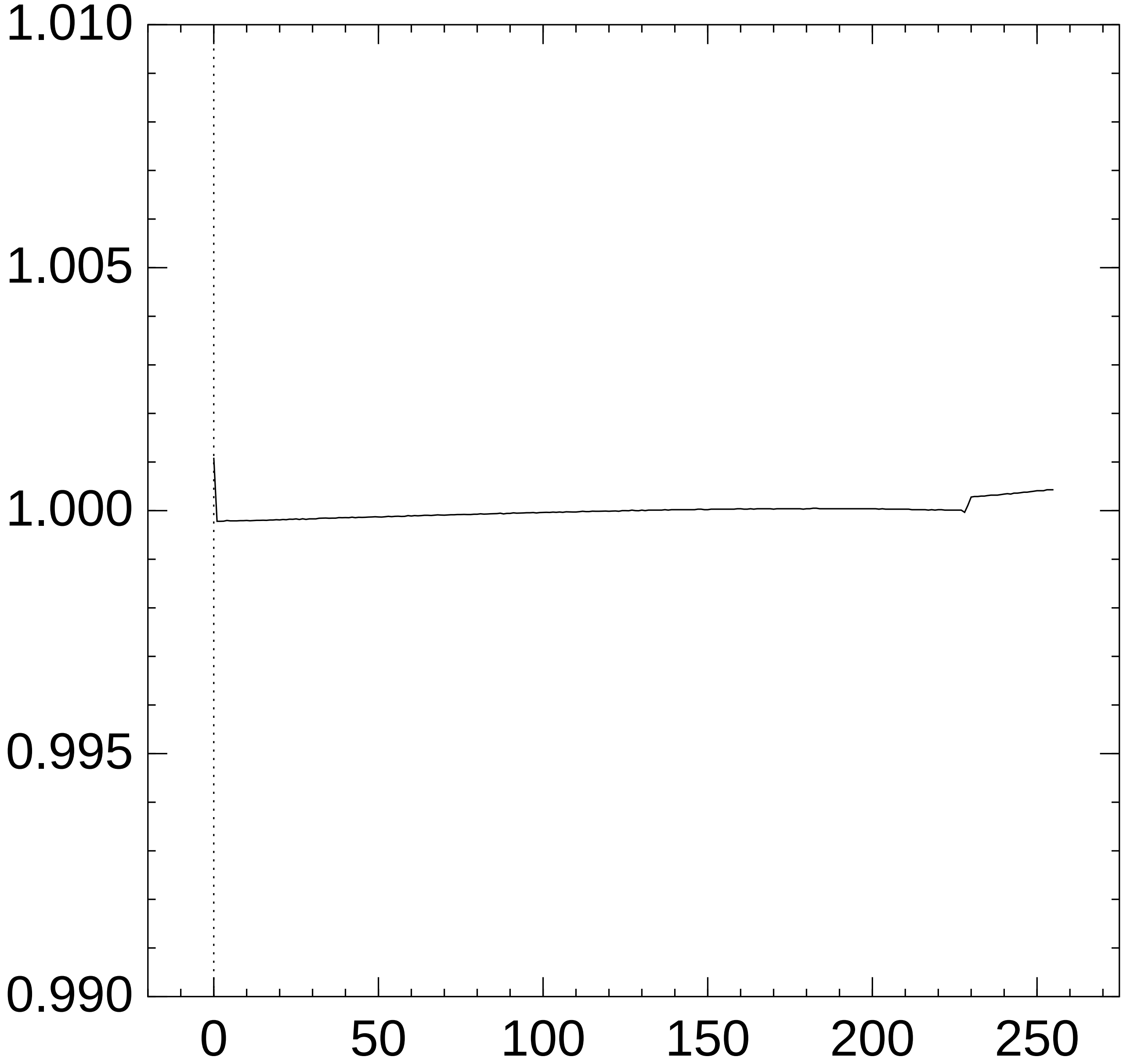
Graph of $256 \Pr[z_{227} = x]$:



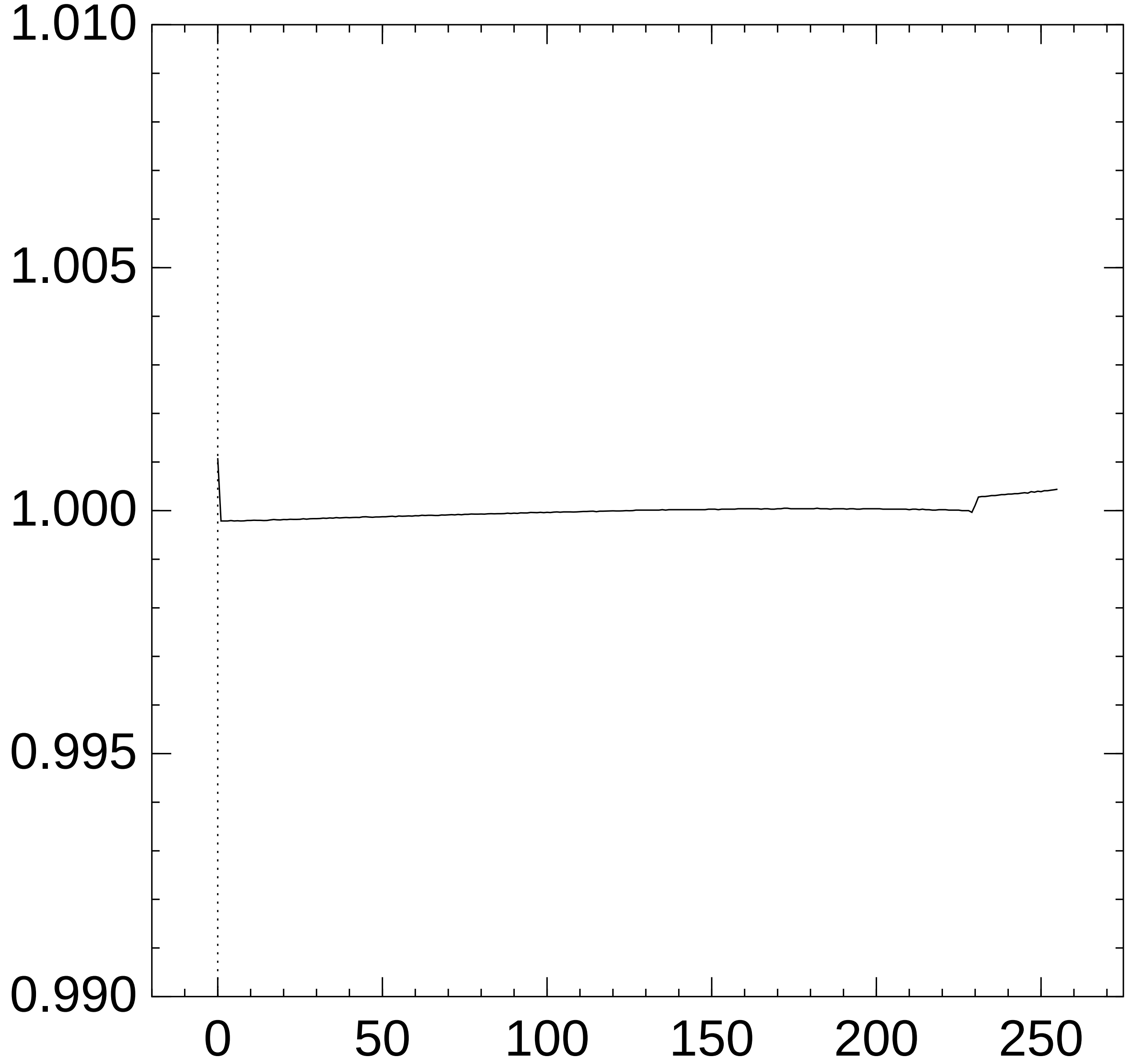
Graph of $256\,\Pr[z_{228} = x]$:



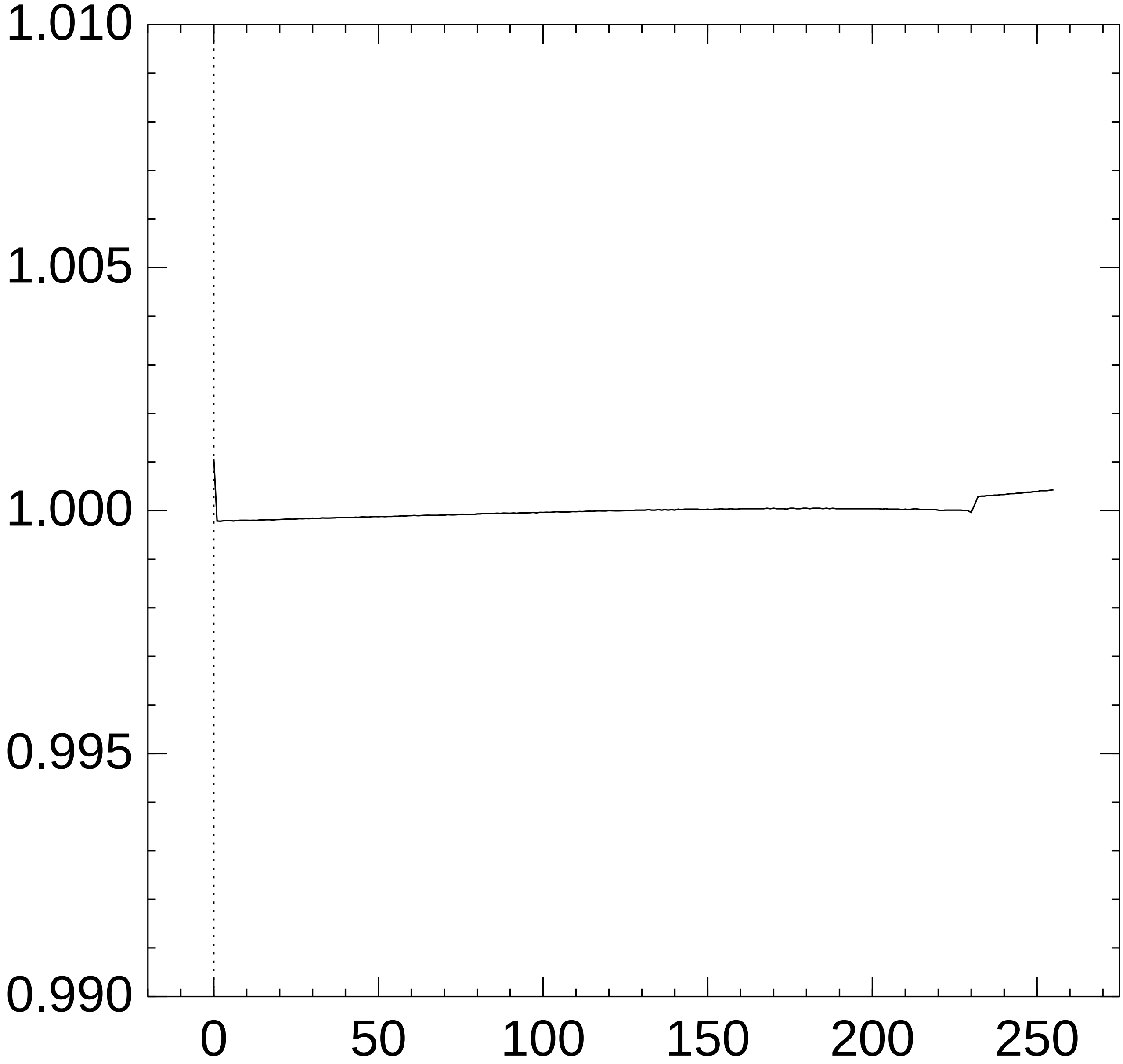
Graph of $256\,\Pr[z_{229} = x]$:



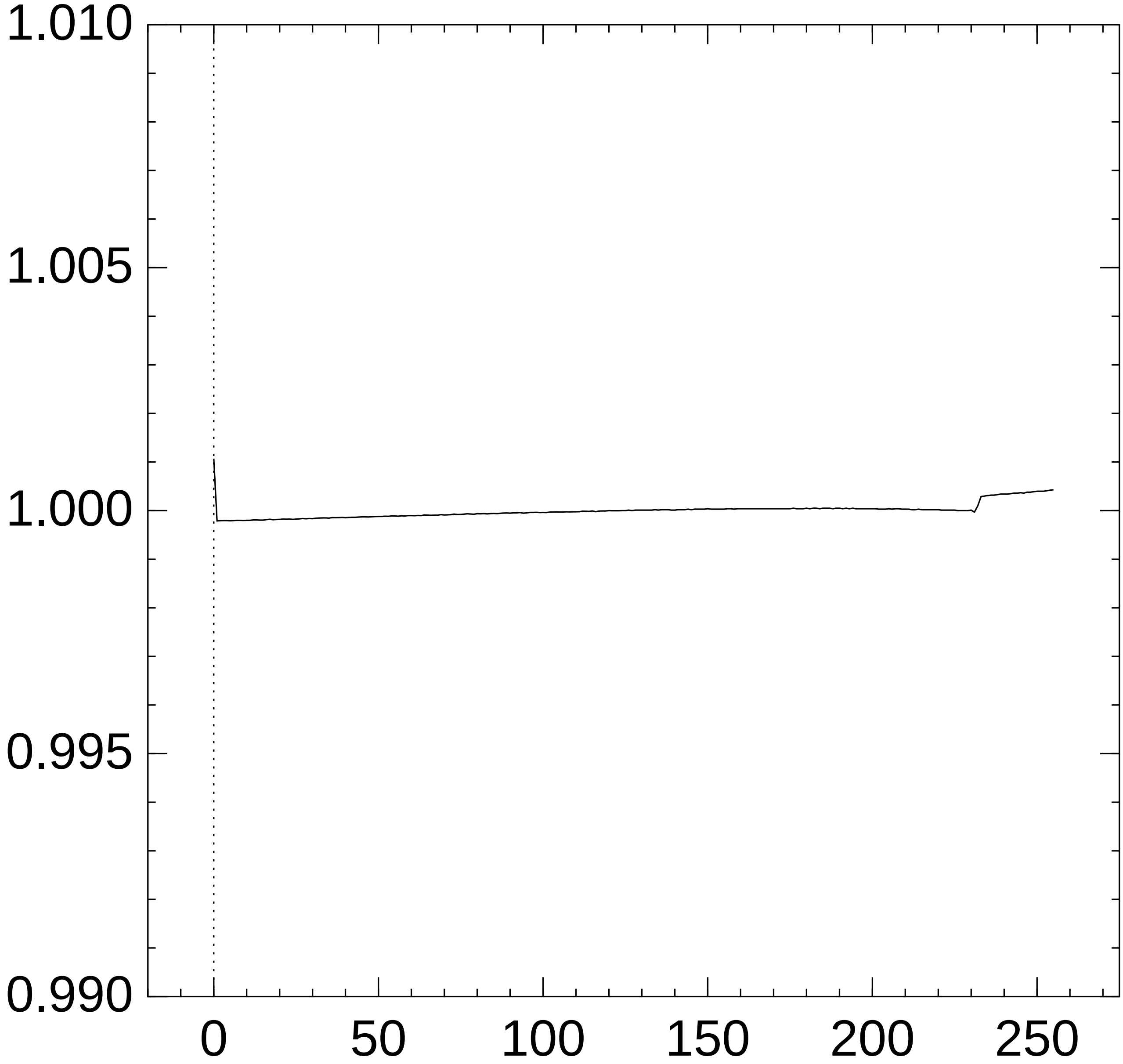
Graph of $256\,\Pr[z_{230} = x]$:



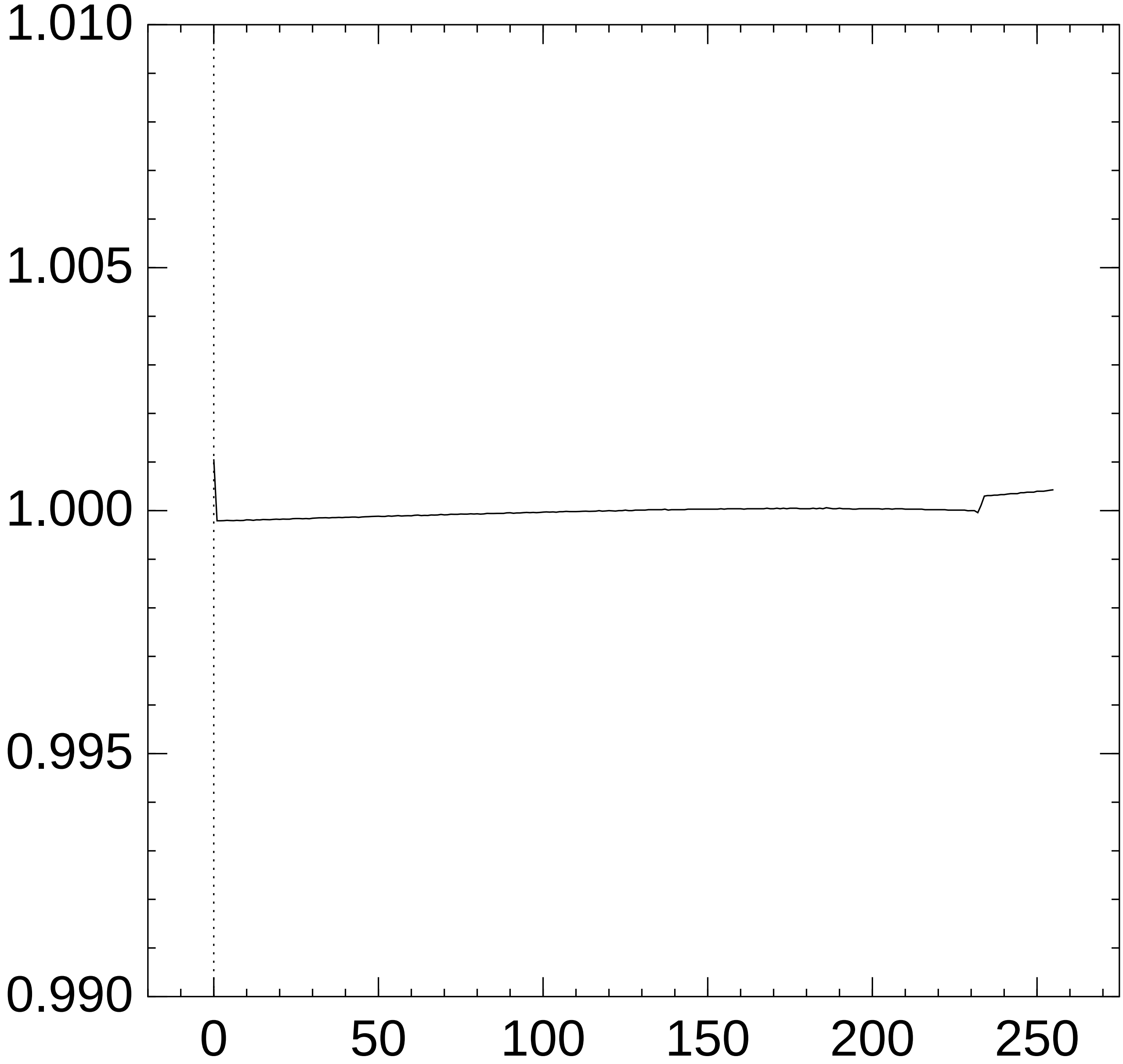
Graph of $256 \Pr[z_{231} = x]$:



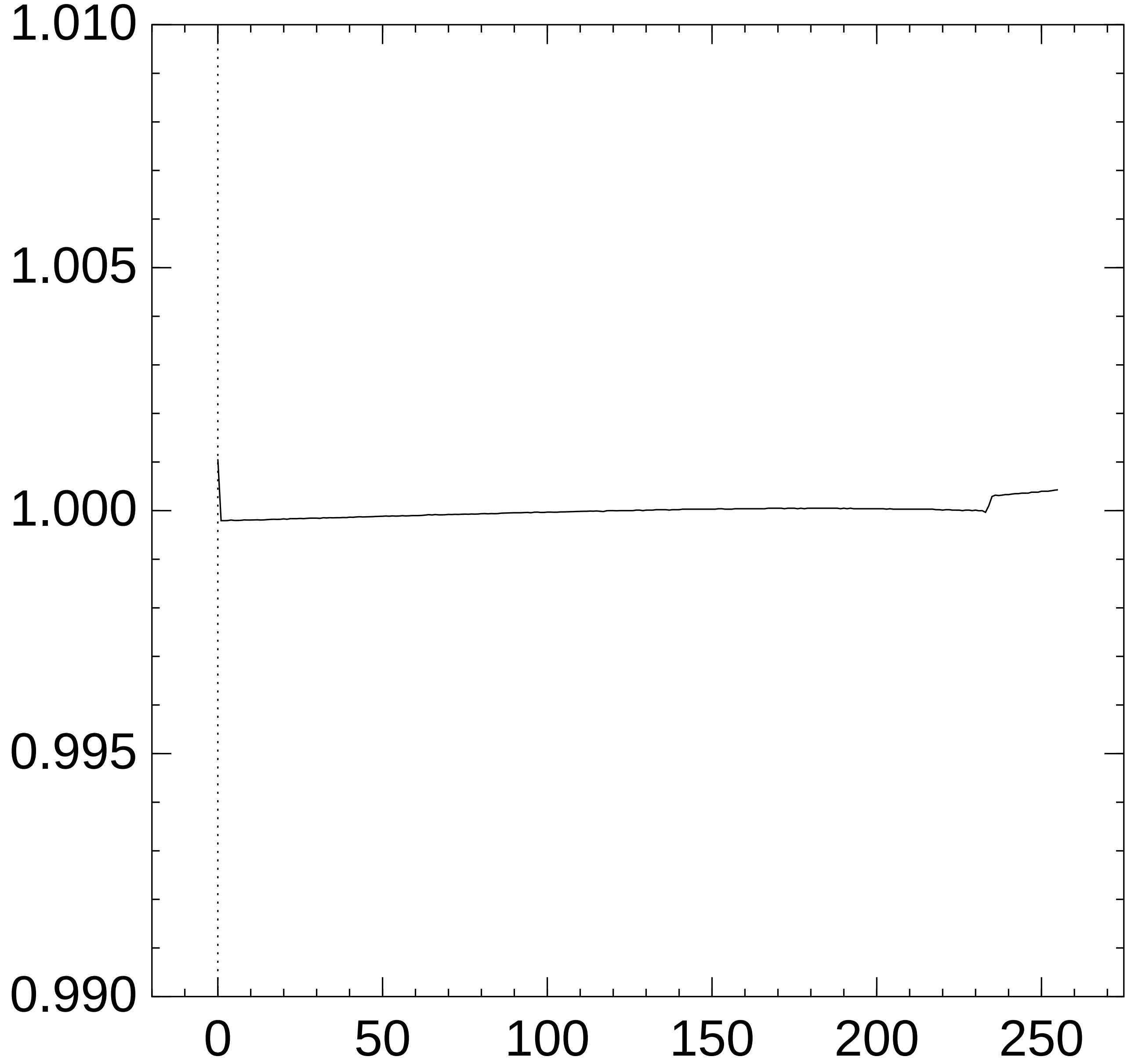
Graph of $256\,\Pr[z_{232} = x]$:



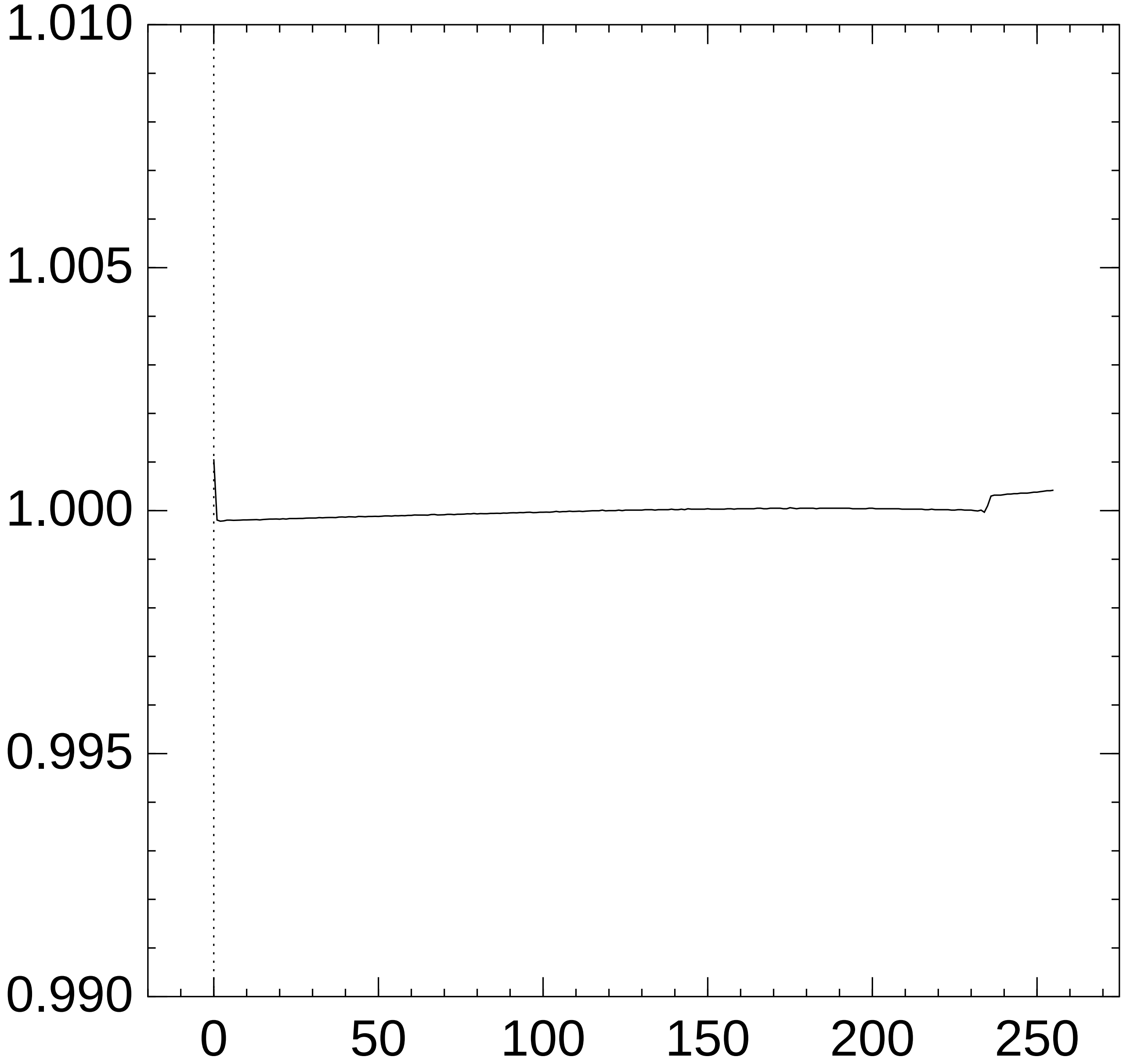
Graph of $256\,\Pr[z_{233} = x]$:



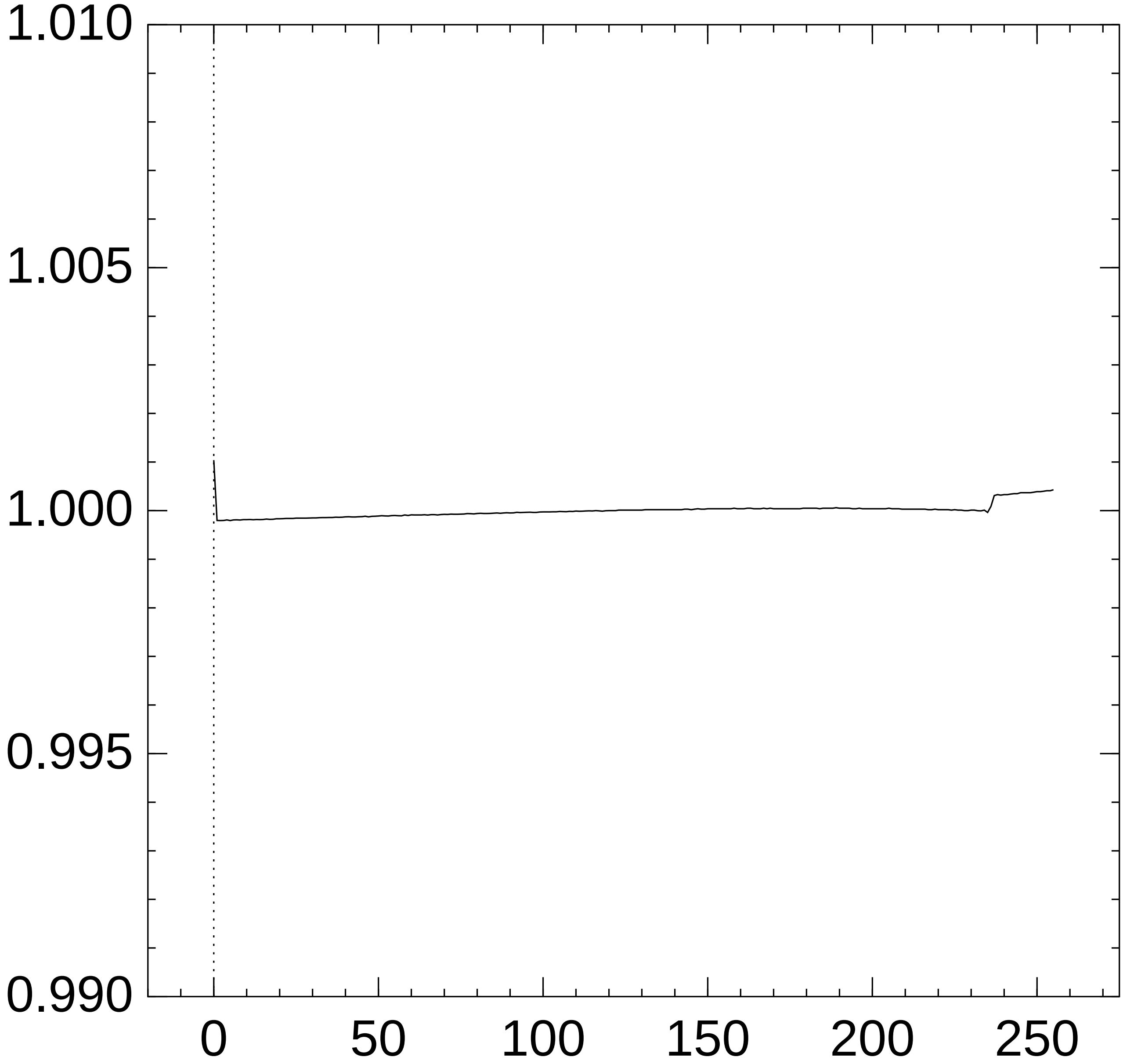
Graph of $256\,\mathrm{Pr}[z_{234} = x]$:



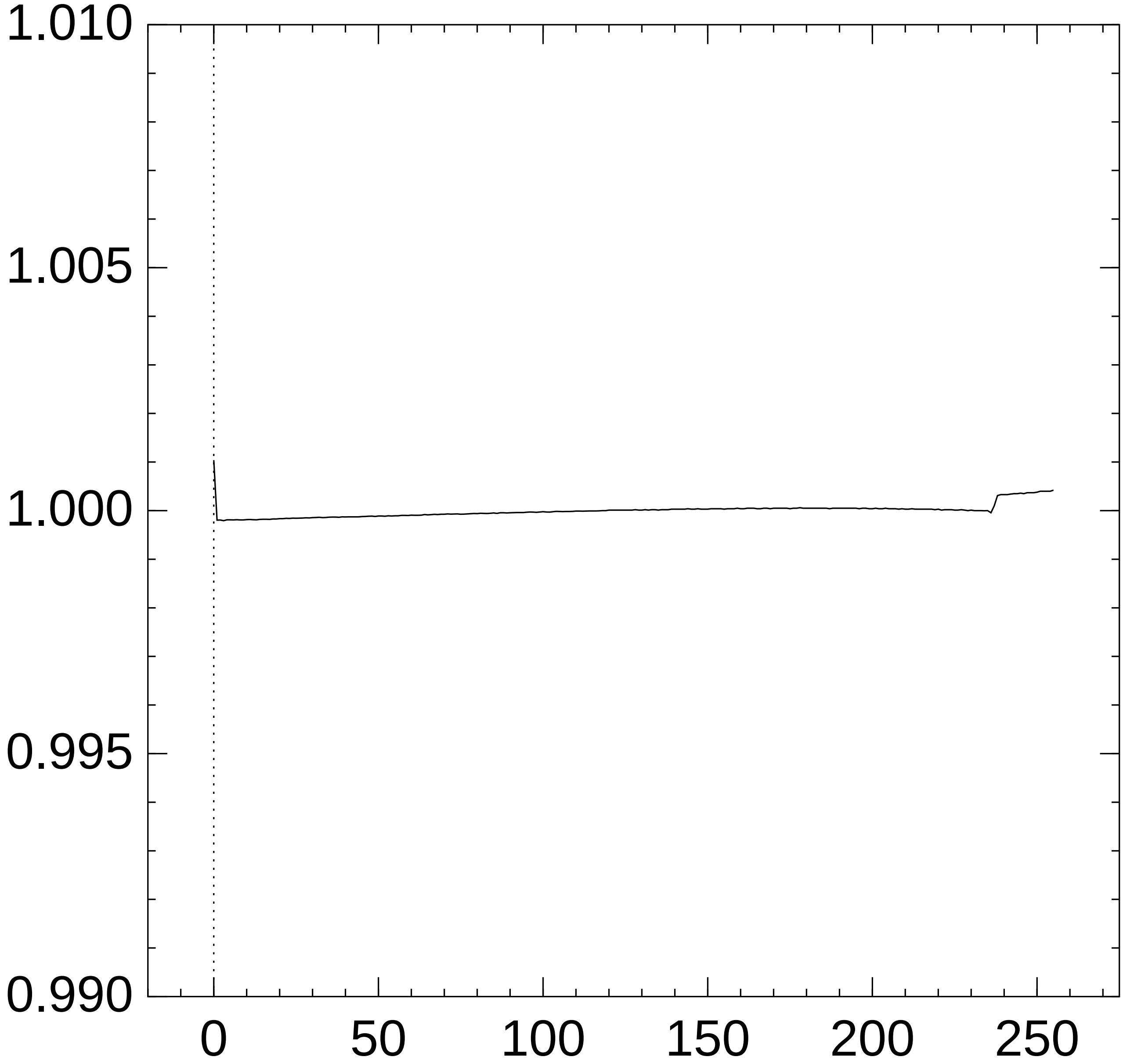
Graph of $256\,\mathrm{Pr}[z_{235} = x]$:



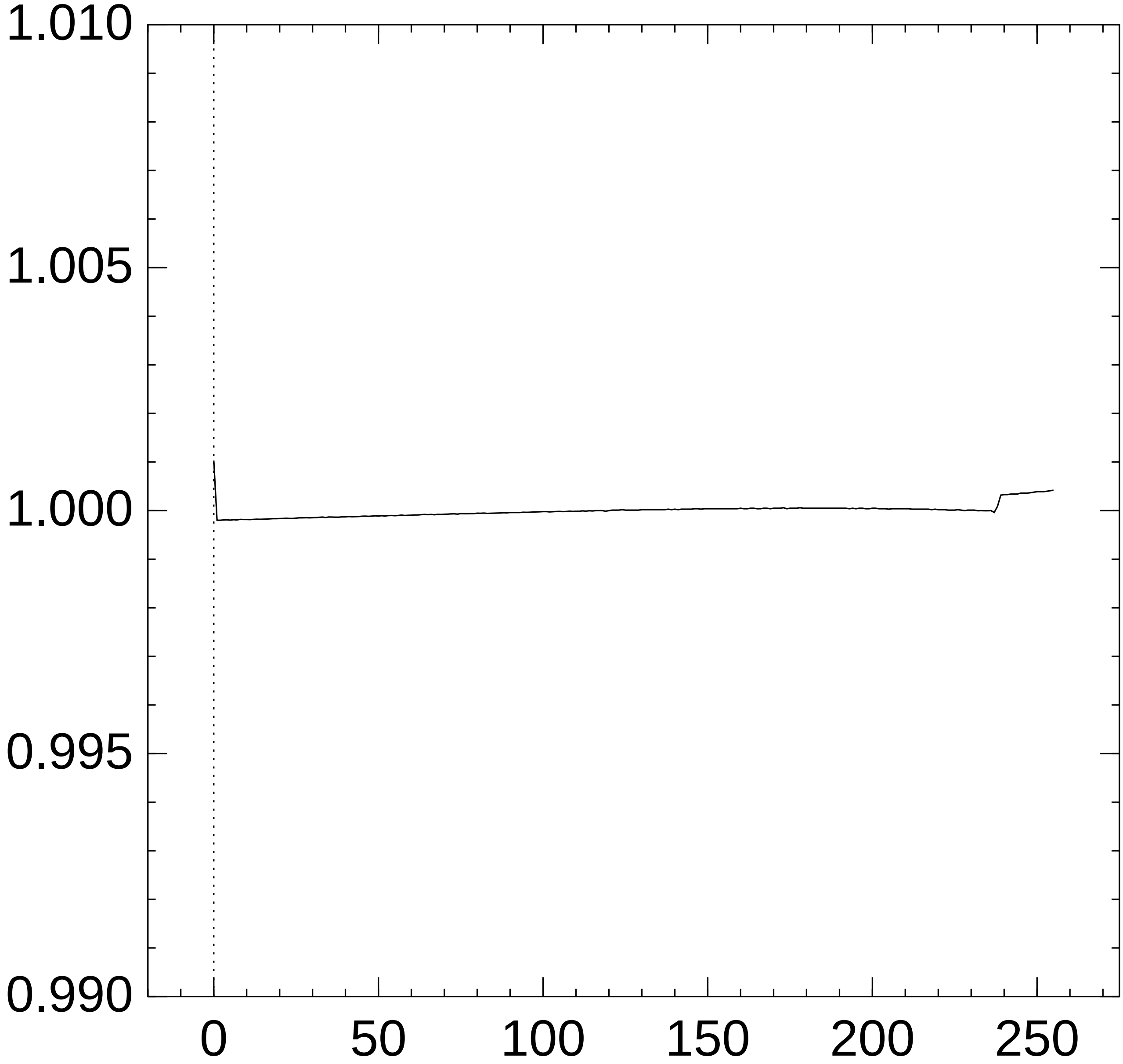
Graph of $256\,\Pr[z_{236} = x]$:



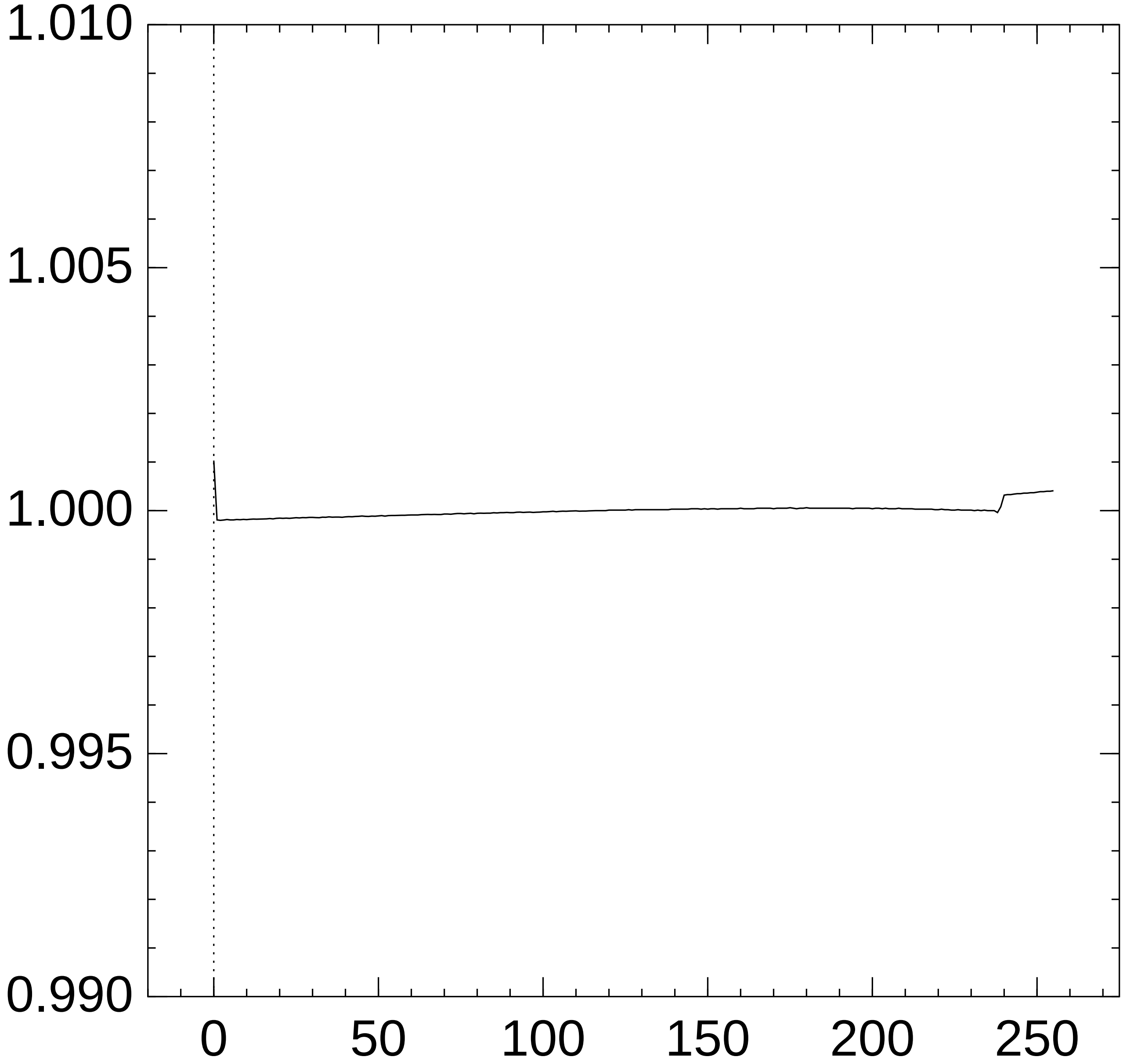
Graph of $256\,\Pr[z_{237} = x]$:



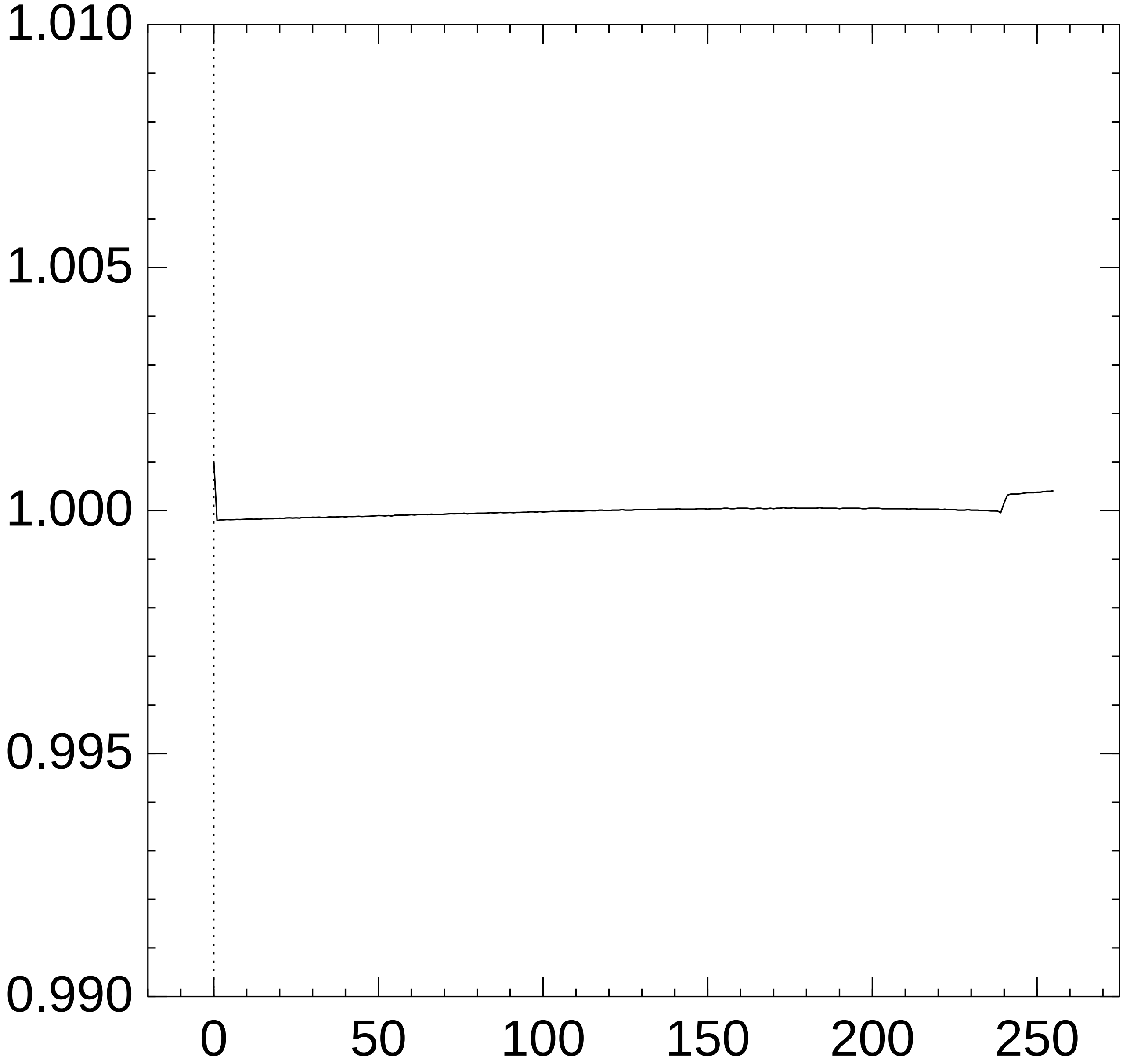
Graph of $256\,\Pr[z_{238} = x]$:



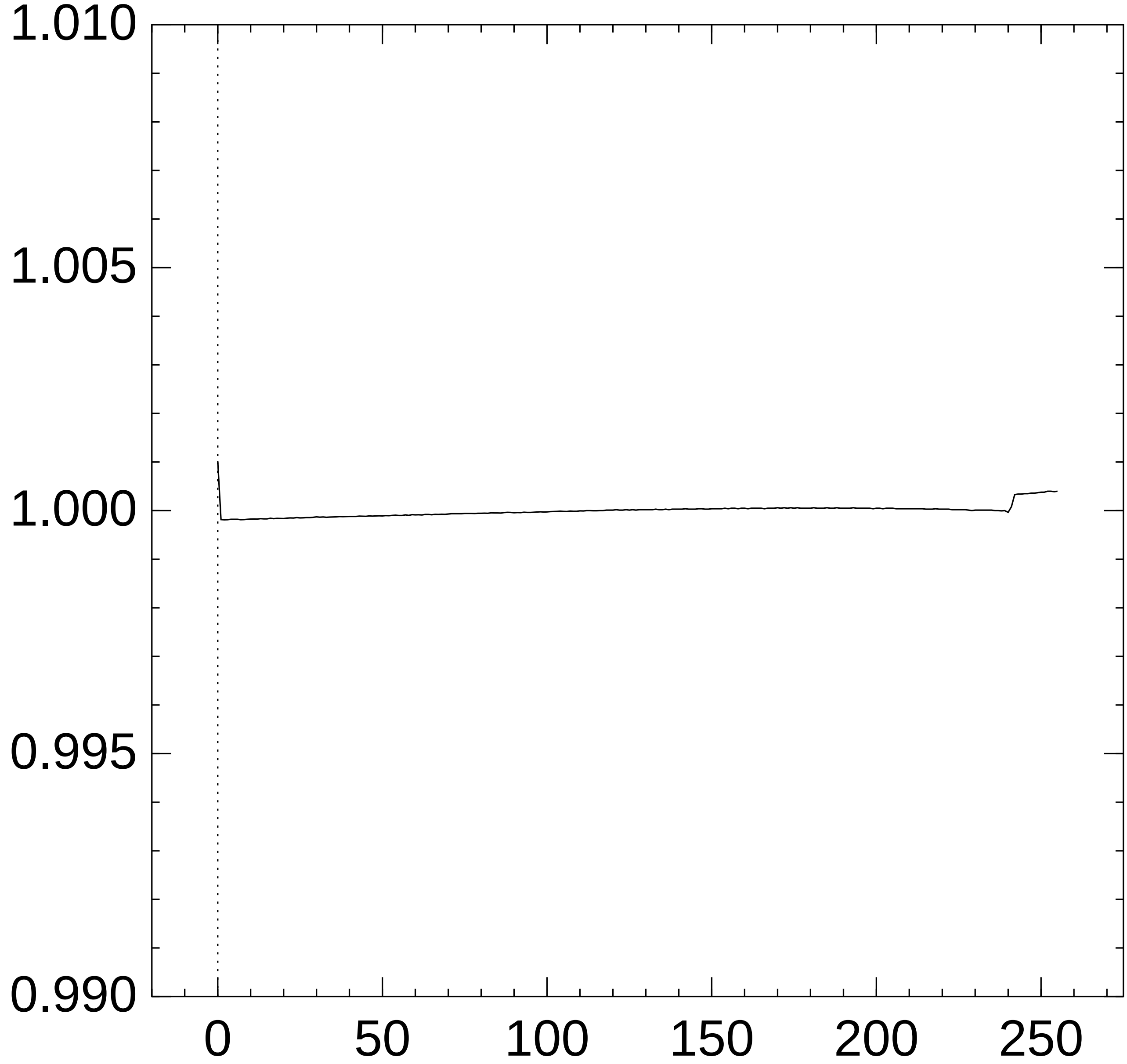
Graph of $256\,\Pr[z_{239} = x]$:



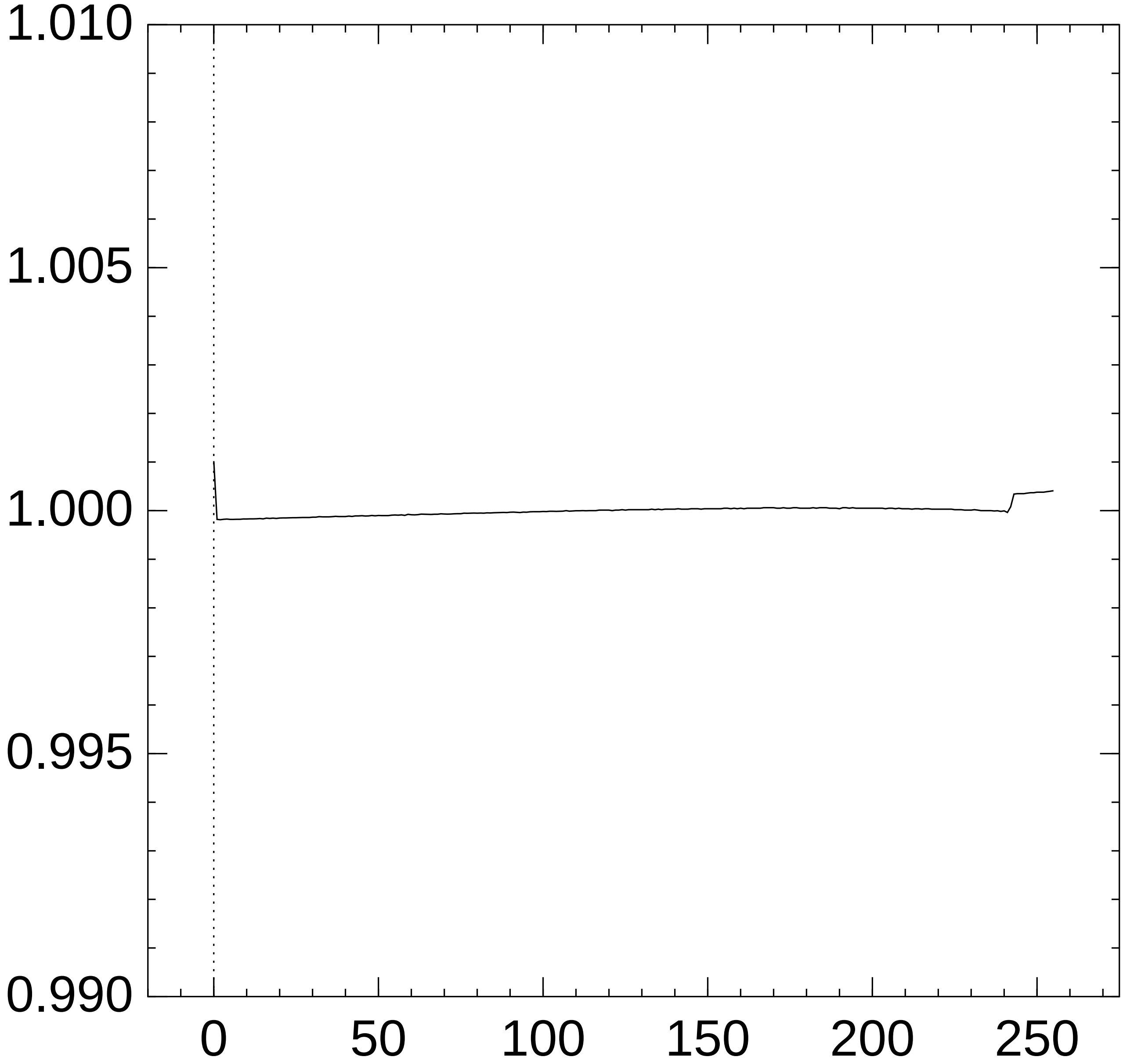
Graph of $256\,\Pr[z_{240} = x]$:



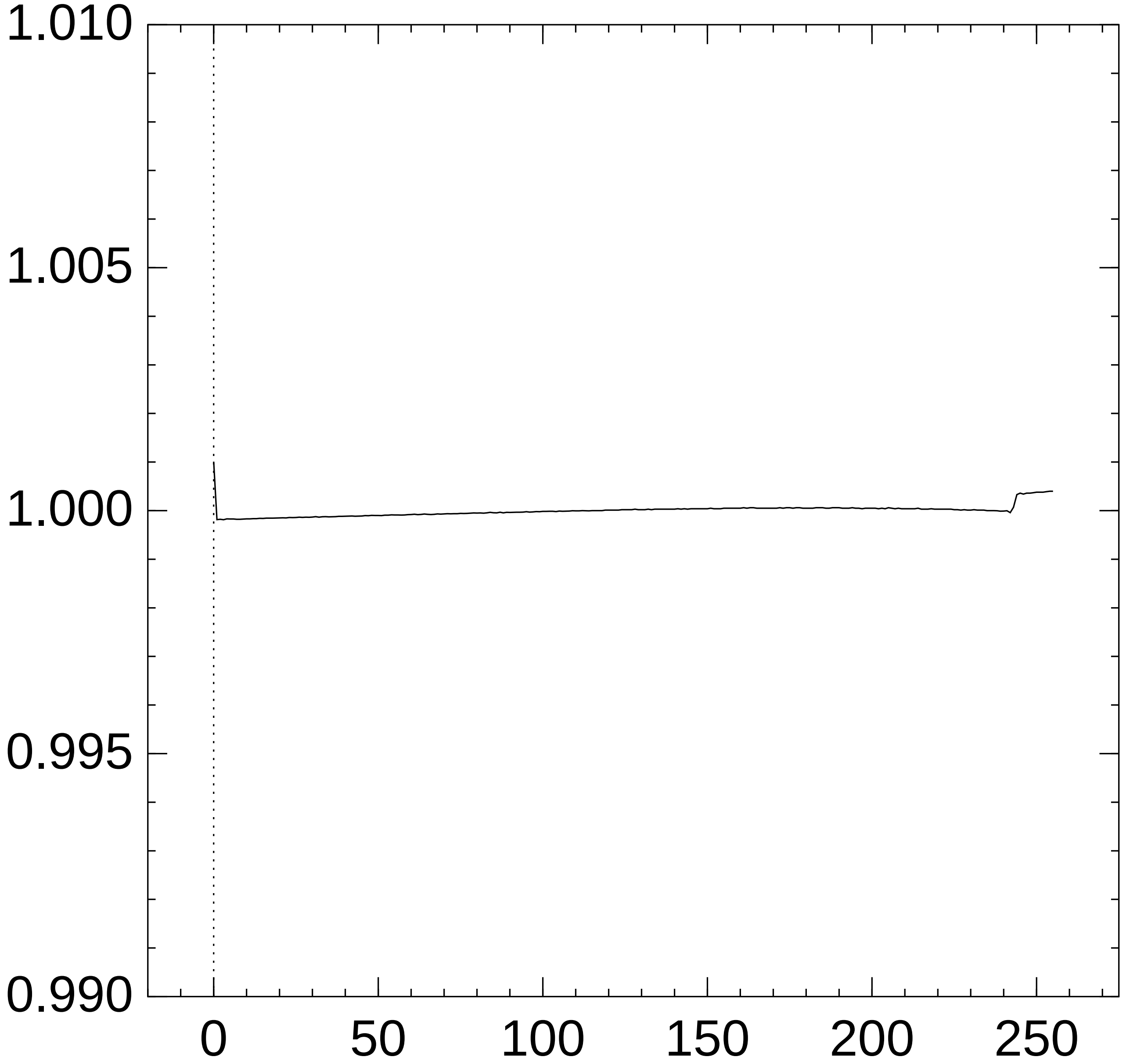
Graph of $256\,\Pr[z_{241} = x]$:



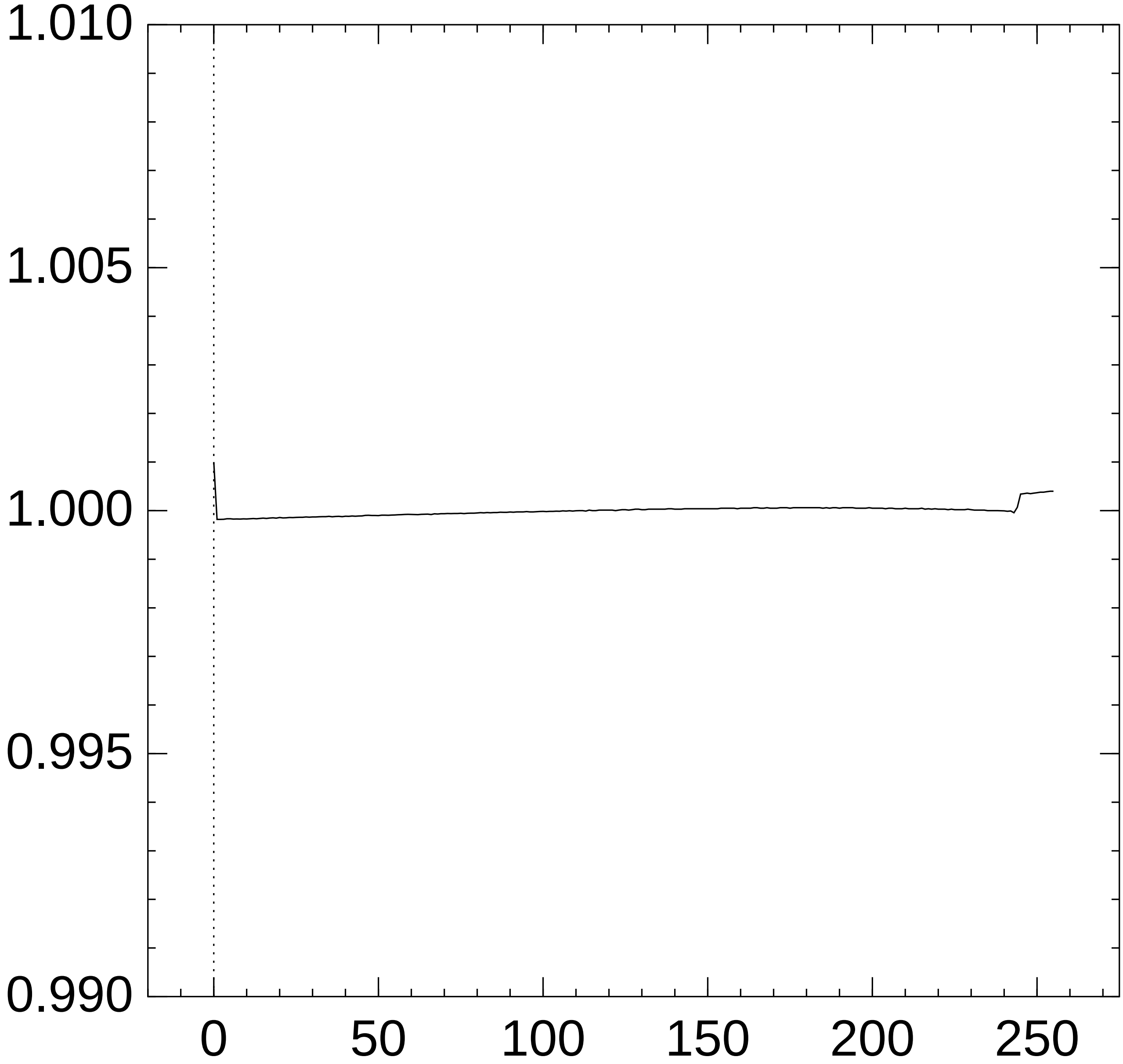
Graph of $256 \Pr[z_{242} = x]$:



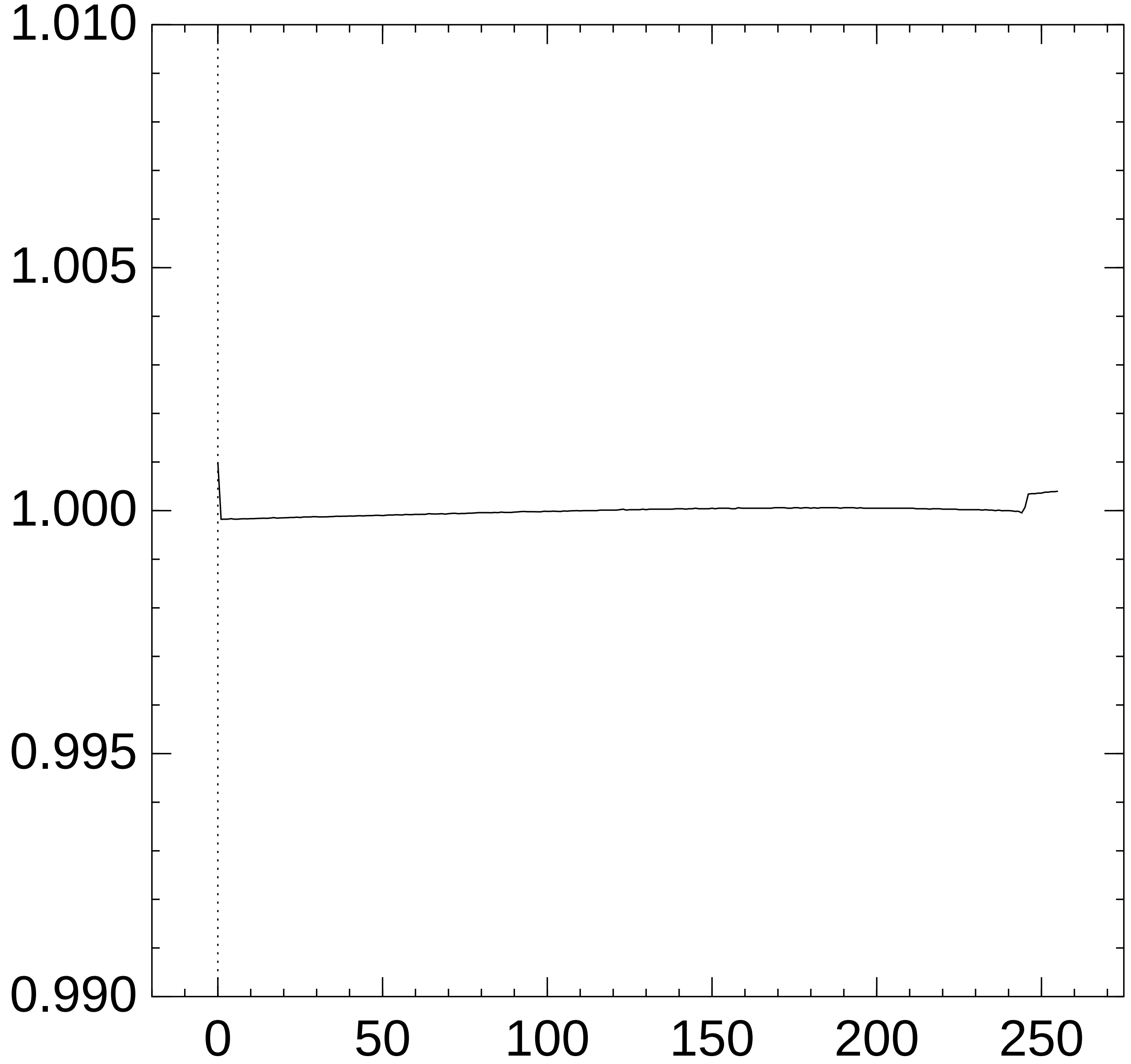
Graph of $256\,\Pr[z_{243} = x]$:



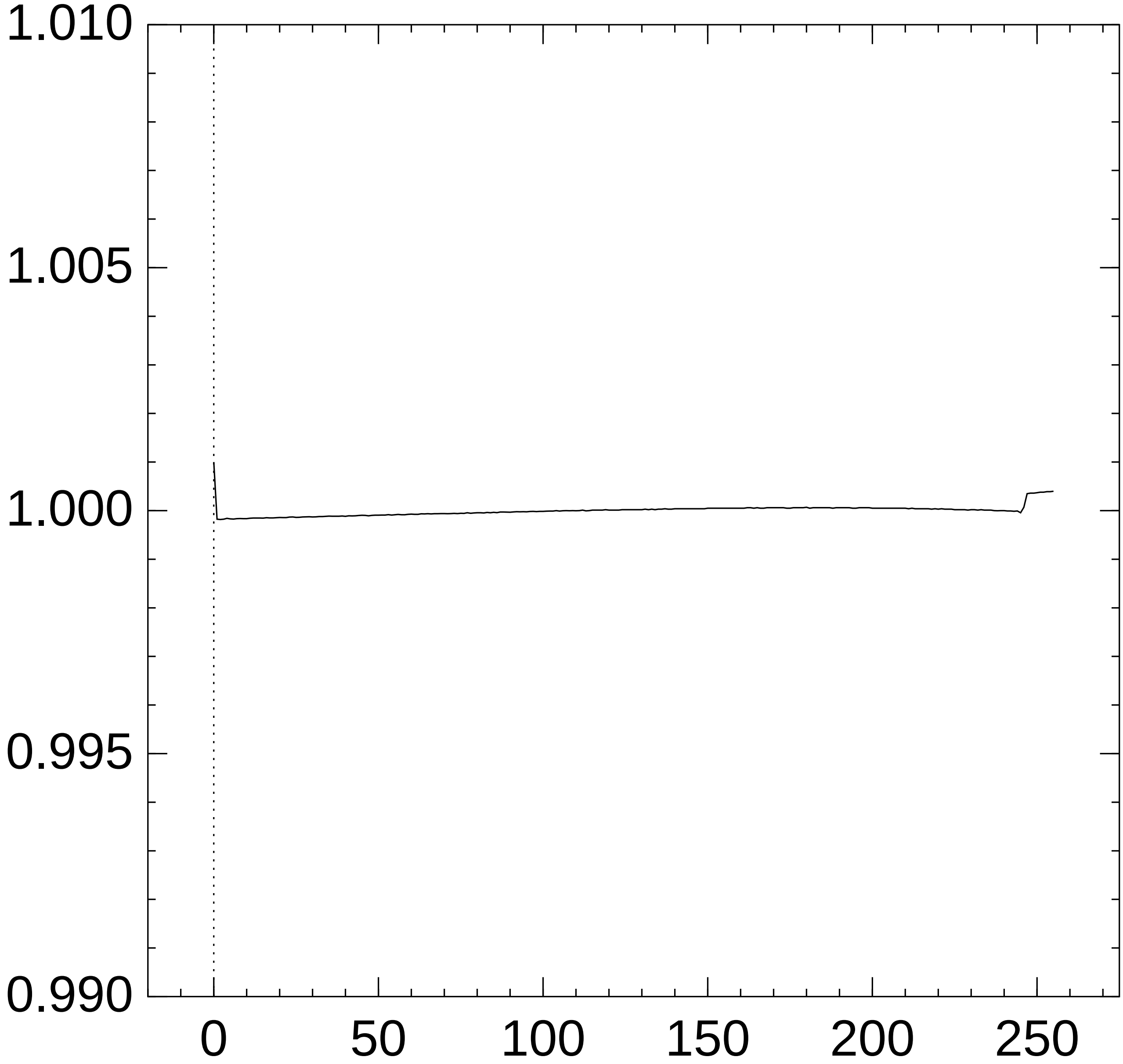
Graph of $256\,\Pr[z_{244} = x]$:



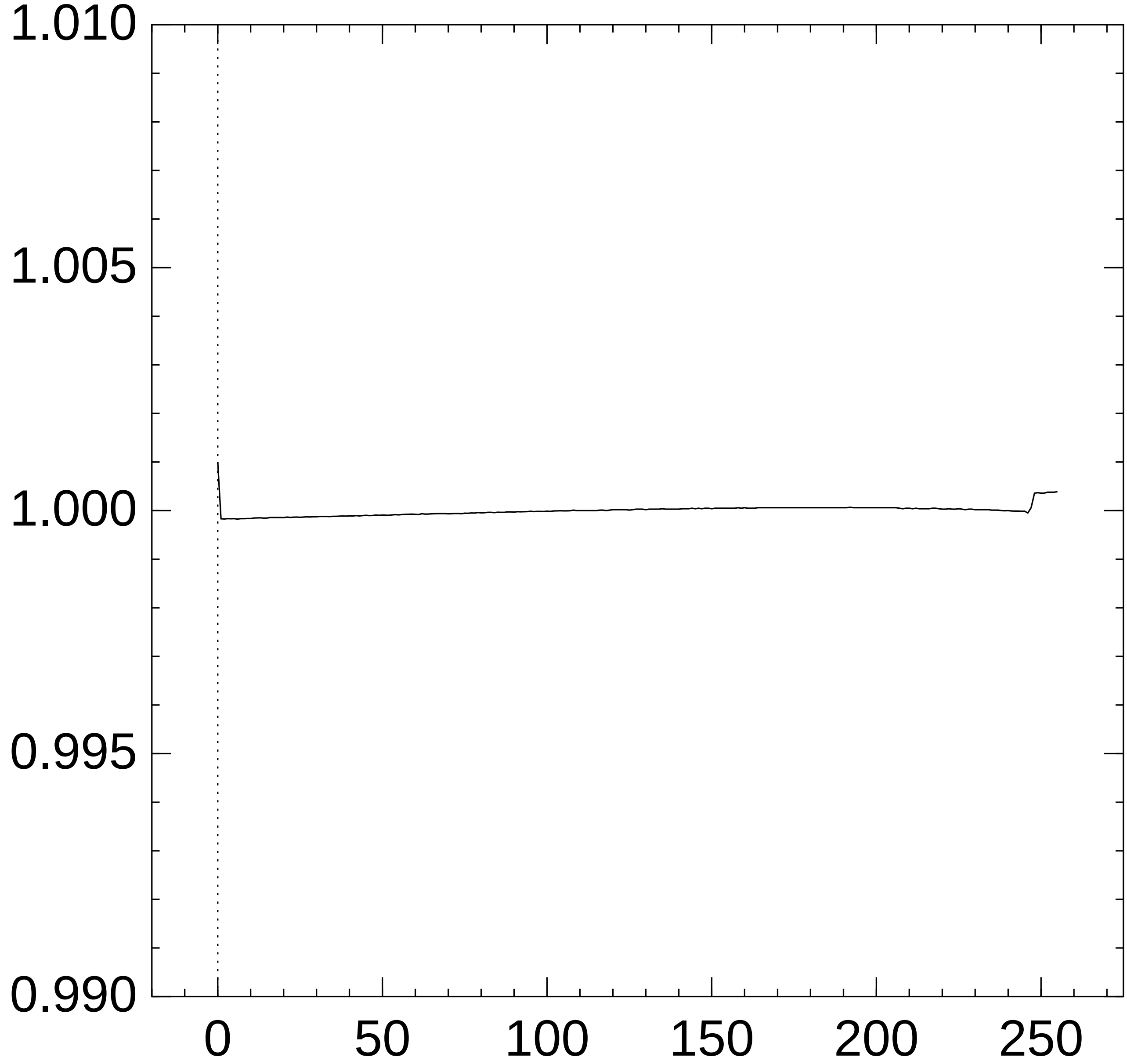
Graph of $256\,\mathrm{Pr}[z_{245} = x]$:



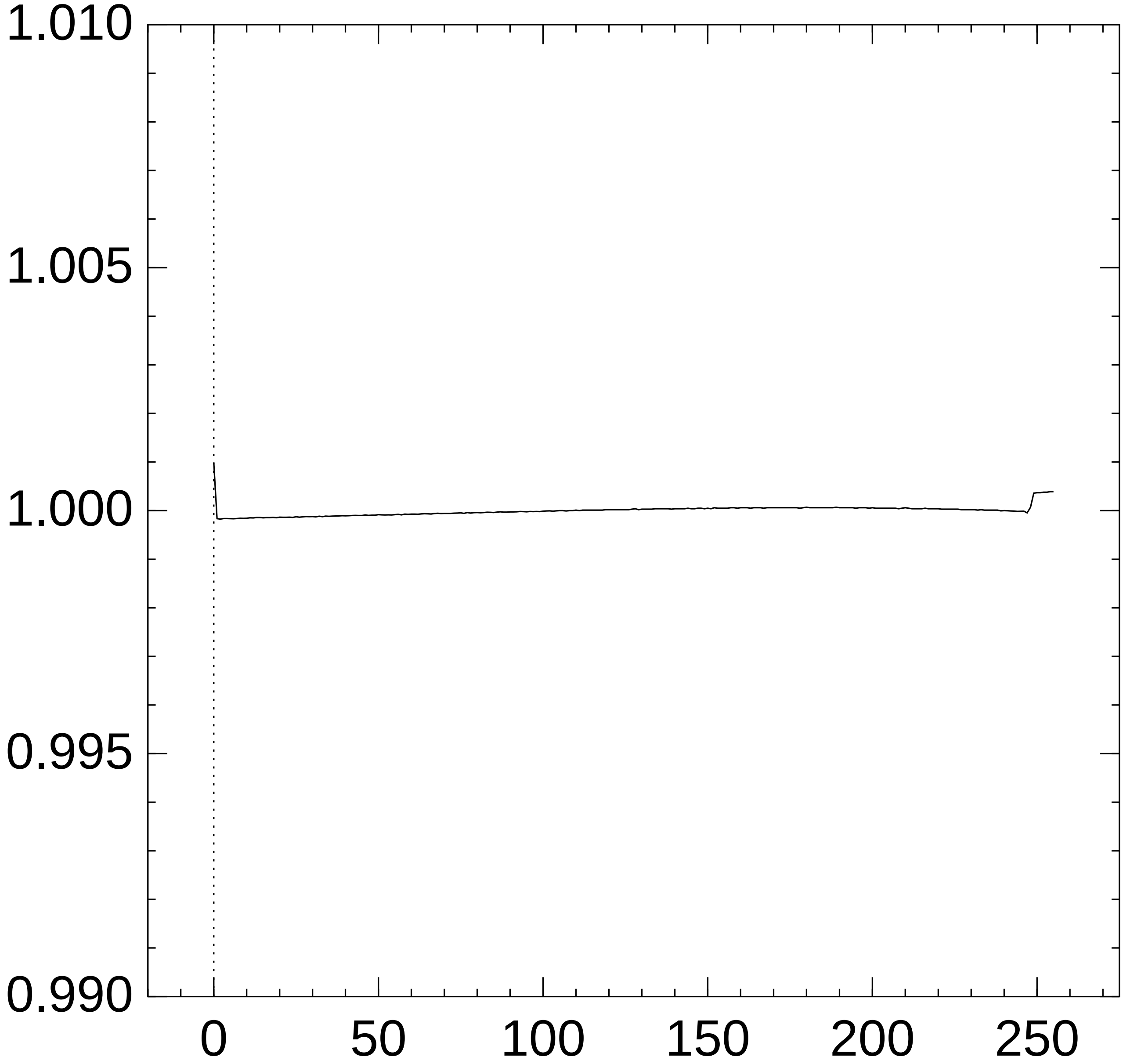
Graph of $256\,\Pr[z_{246} = x]$:



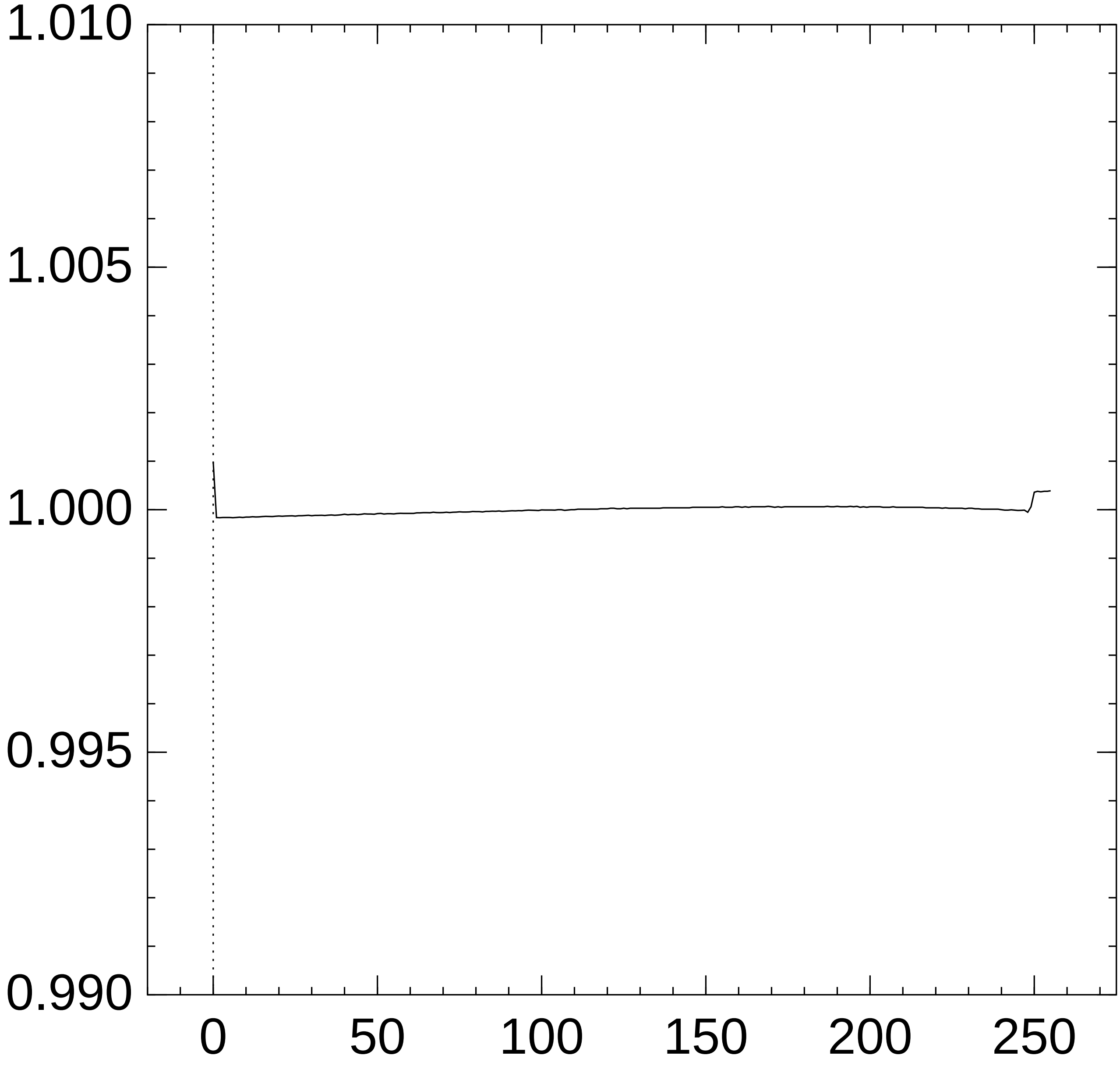
Graph of $256\,\Pr[z_{247} = x]$:



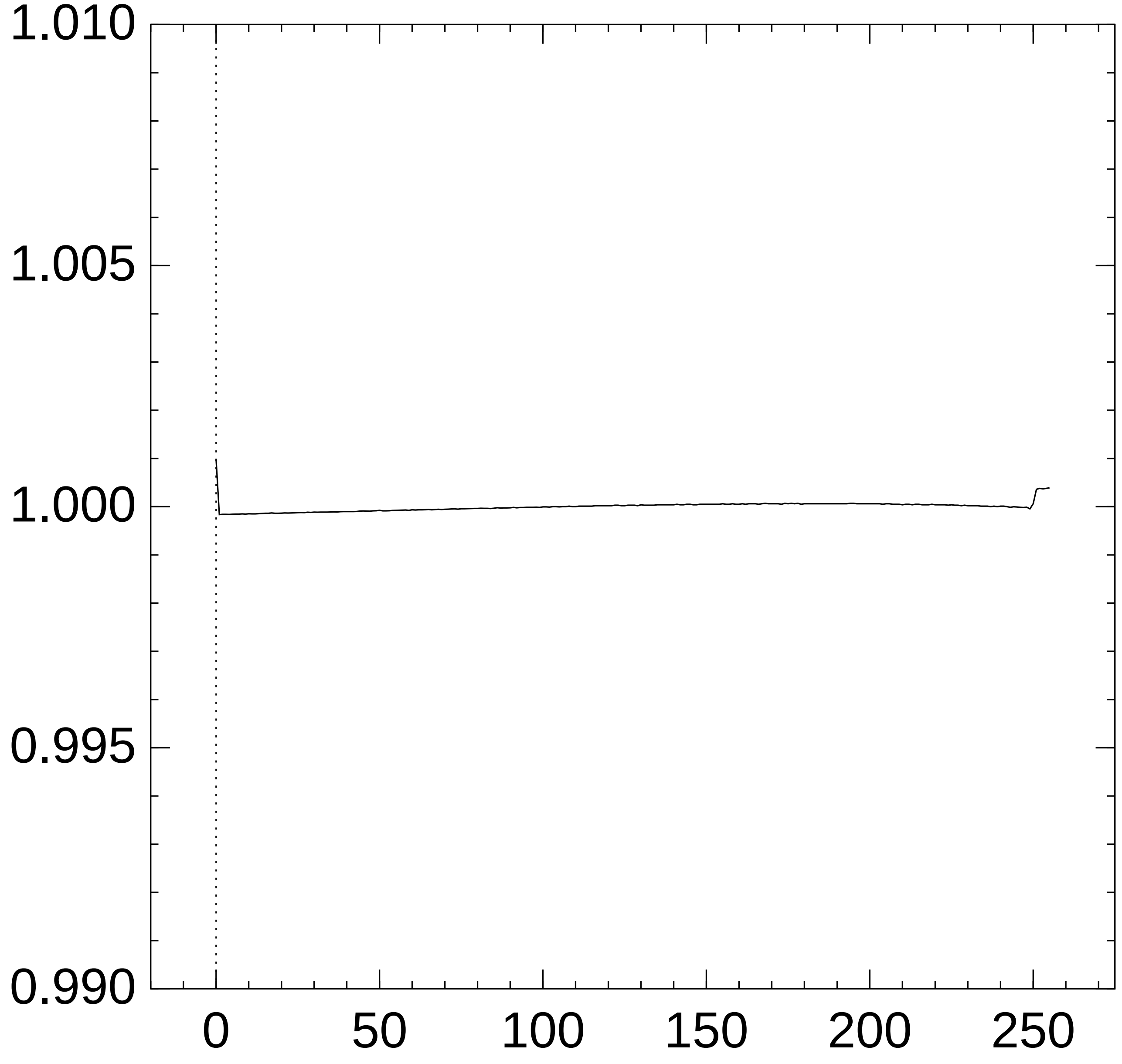
Graph of $256\,\Pr[z_{248} = x]$:



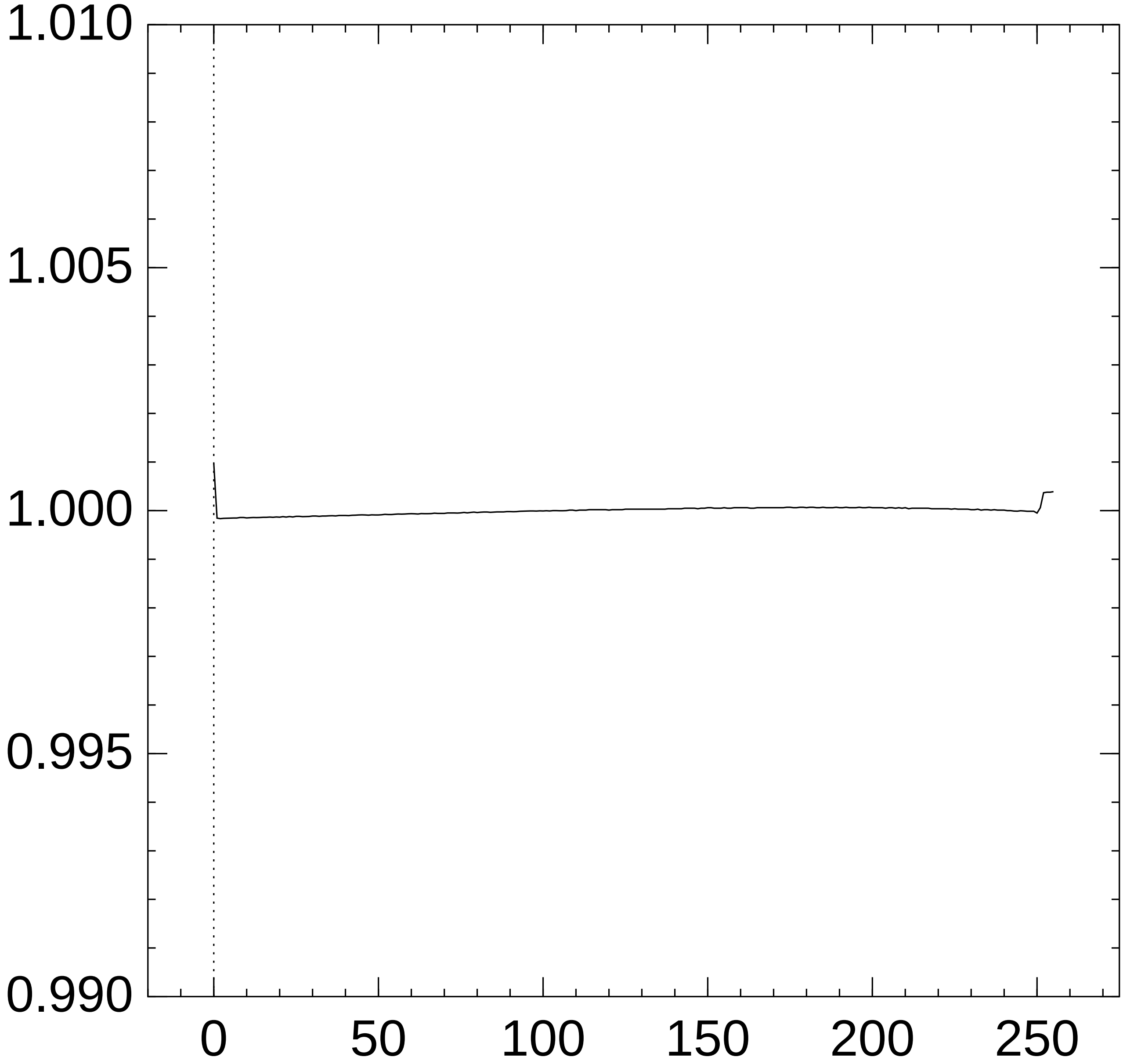
Graph of $256\,\Pr[z_{249} = x]$:



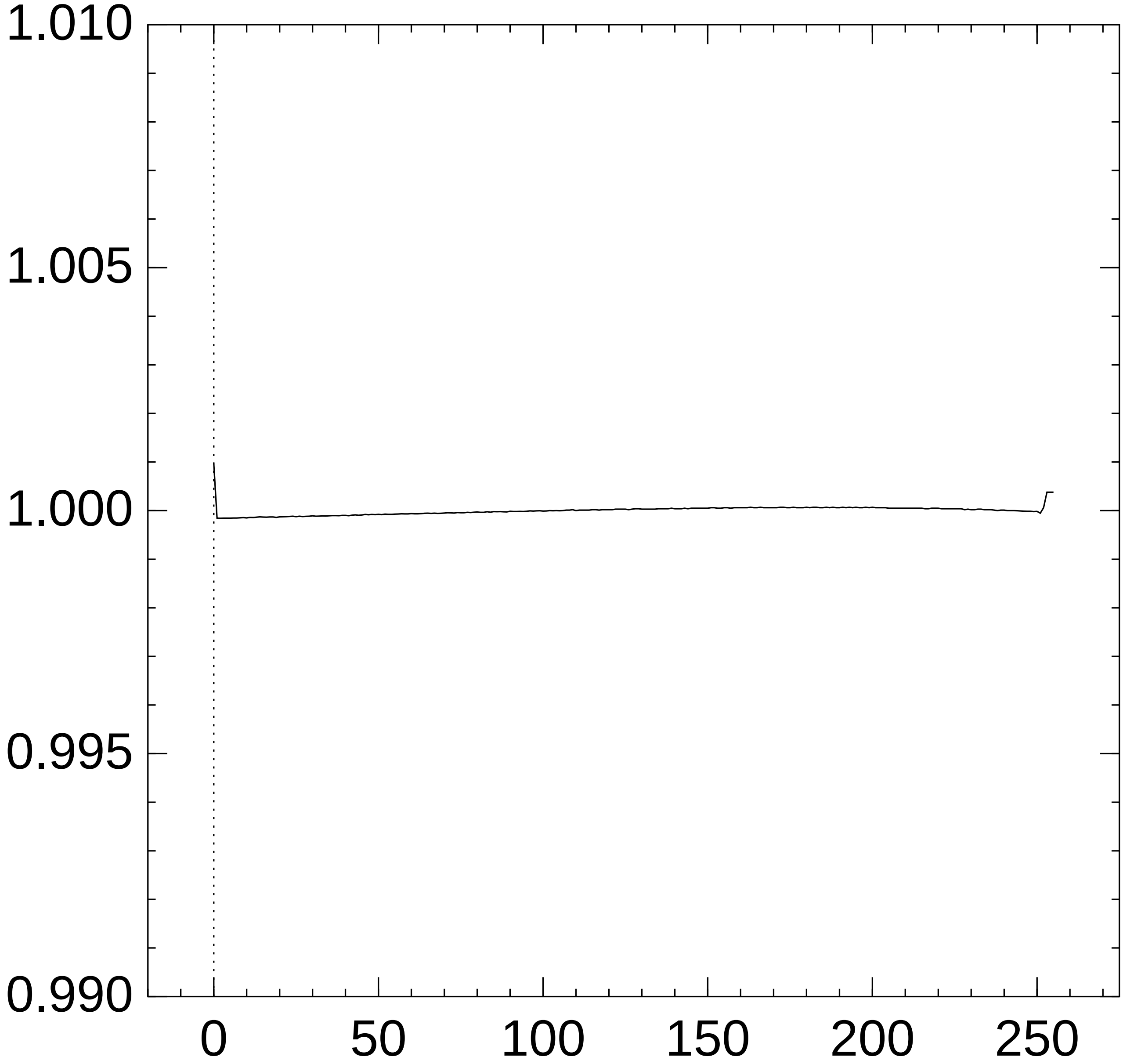
Graph of $256\,\Pr[z_{250} = x]$:



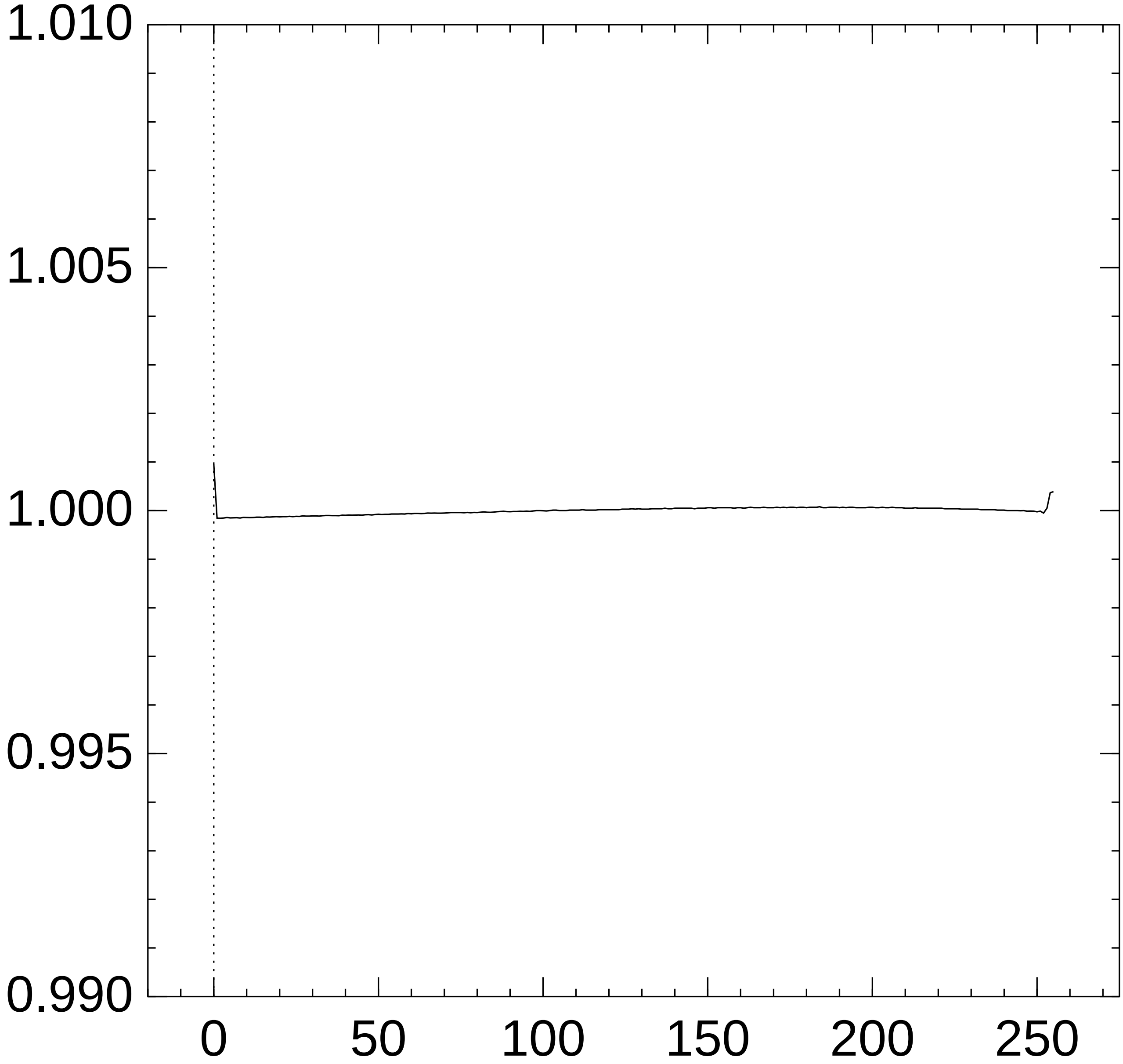
Graph of $256\,\mathrm{Pr}[z_{251} = x]$:



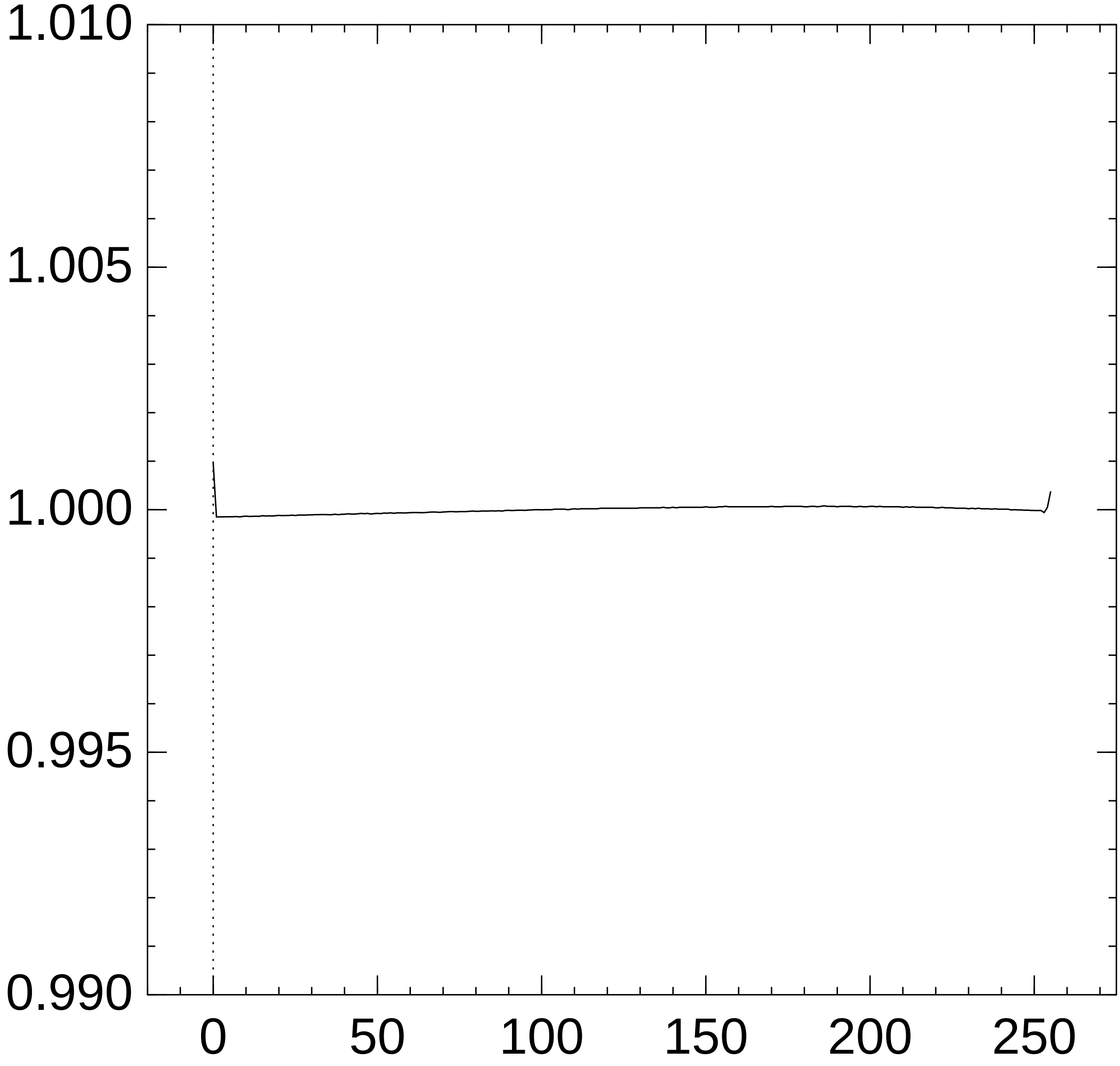
Graph of $256\,\Pr[z_{252} = x]$:



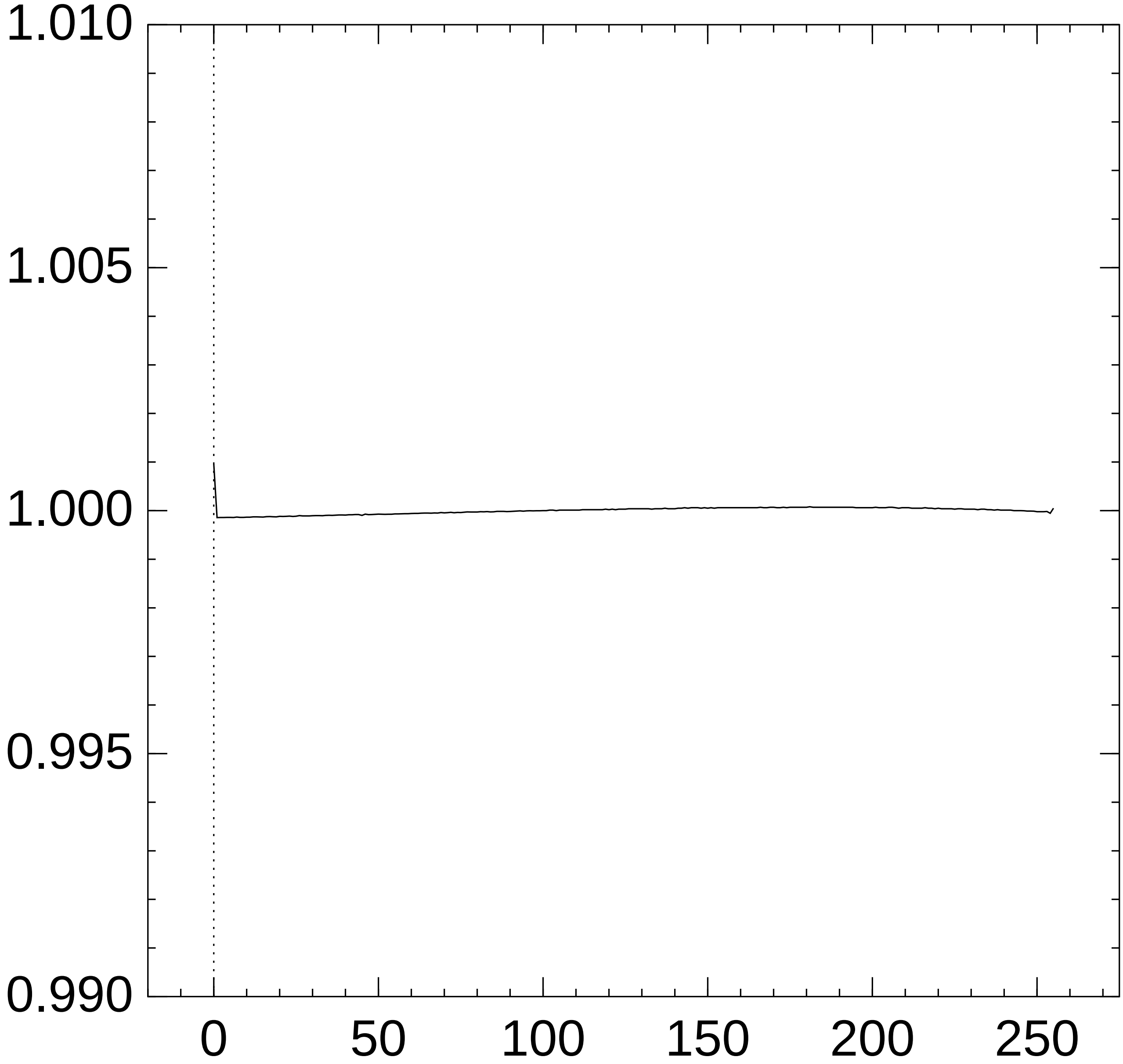
Graph of $256\,\Pr[z_{253} = x]$:



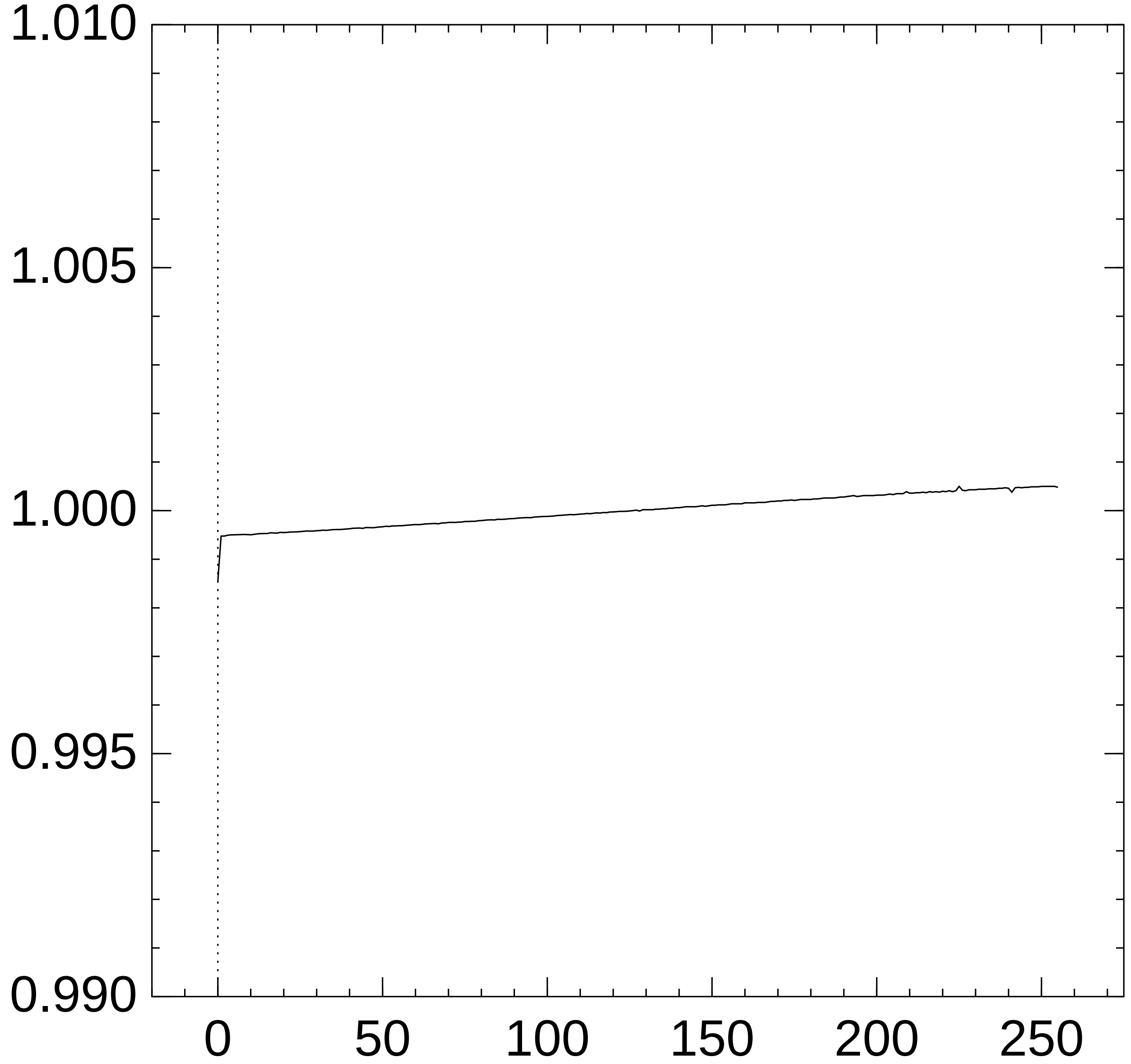
Graph of $256\,\Pr[z_{254} = x]$:



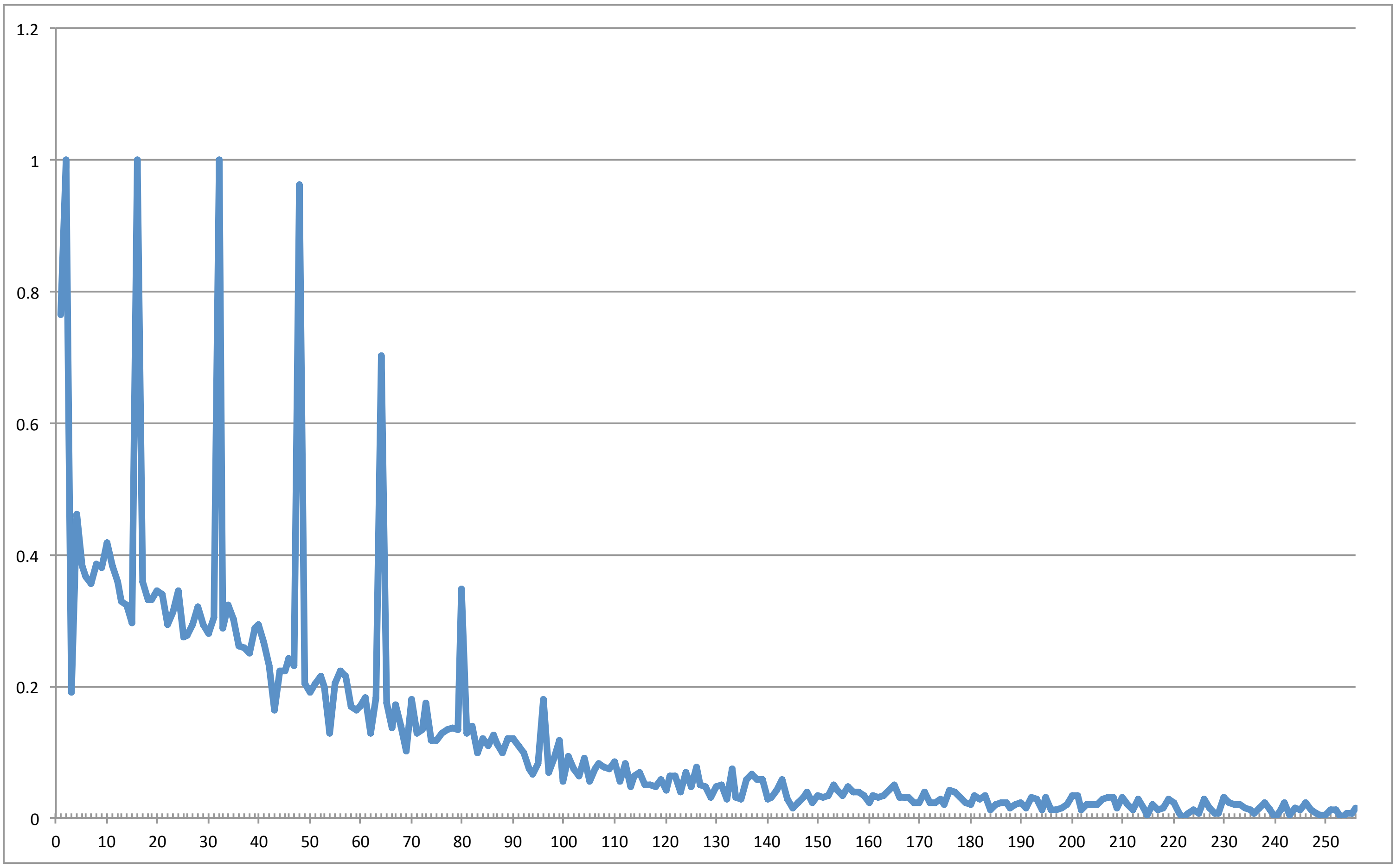
Graph of $256\,\Pr[z_{255} = x]$:



Graph of $256\,\Pr[z_{256} = x]$:



2013 AlFardan–Bernstein–Paterson–Poettering–Schuldt success probability (256 trials) for recovering byte x of plaintext from 2^{24} ciphertexts (with no prior plaintext knowledge):



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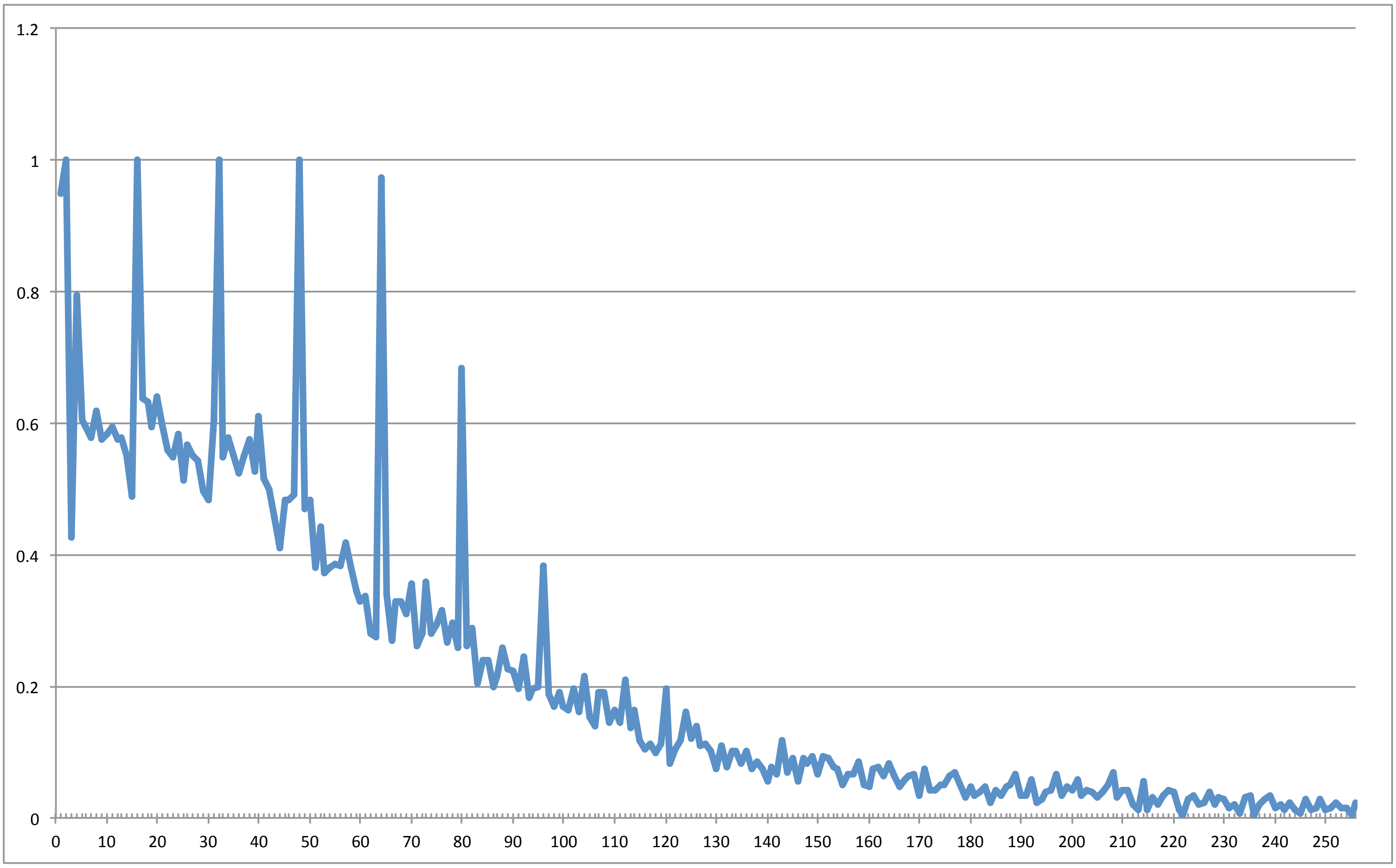
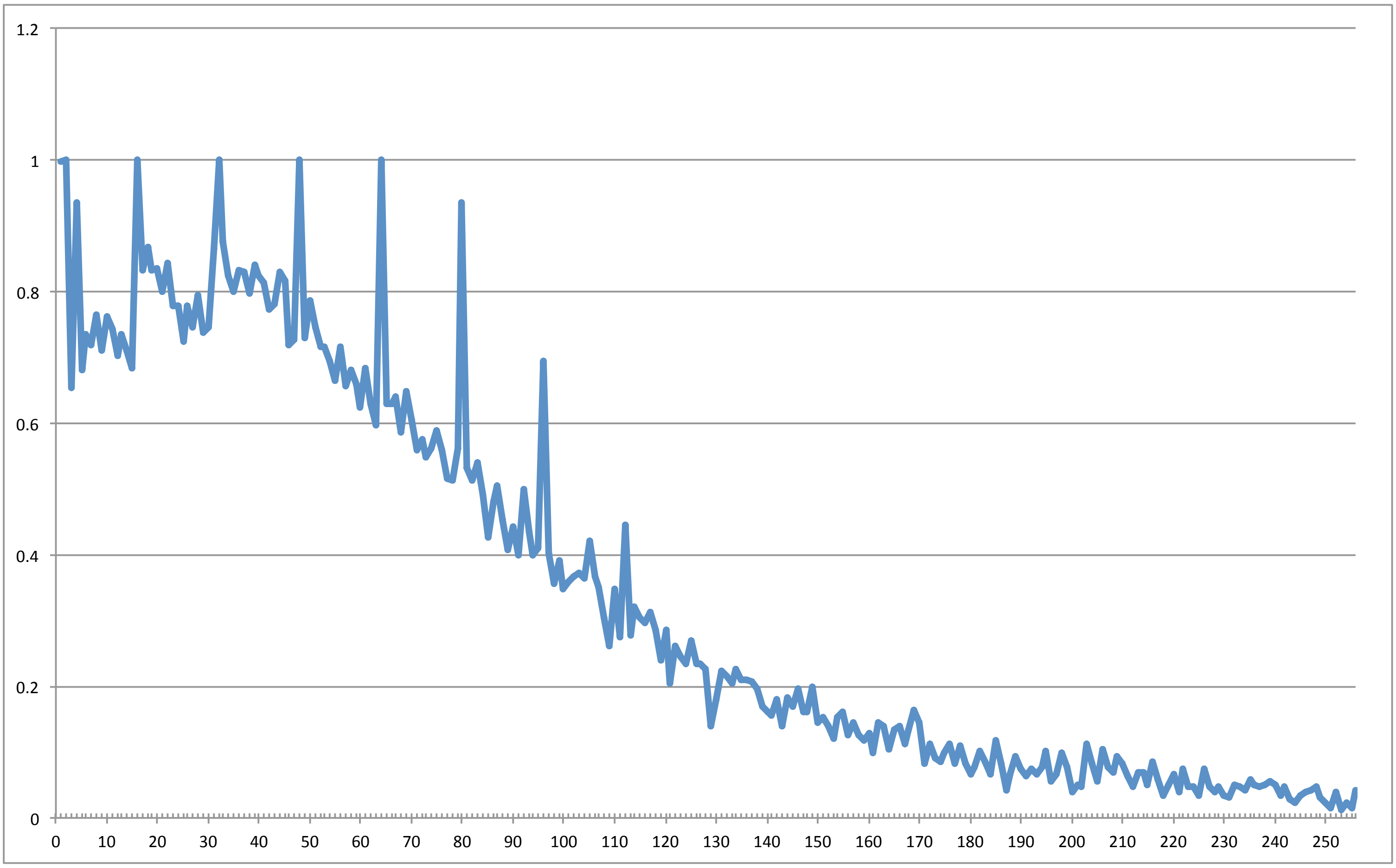
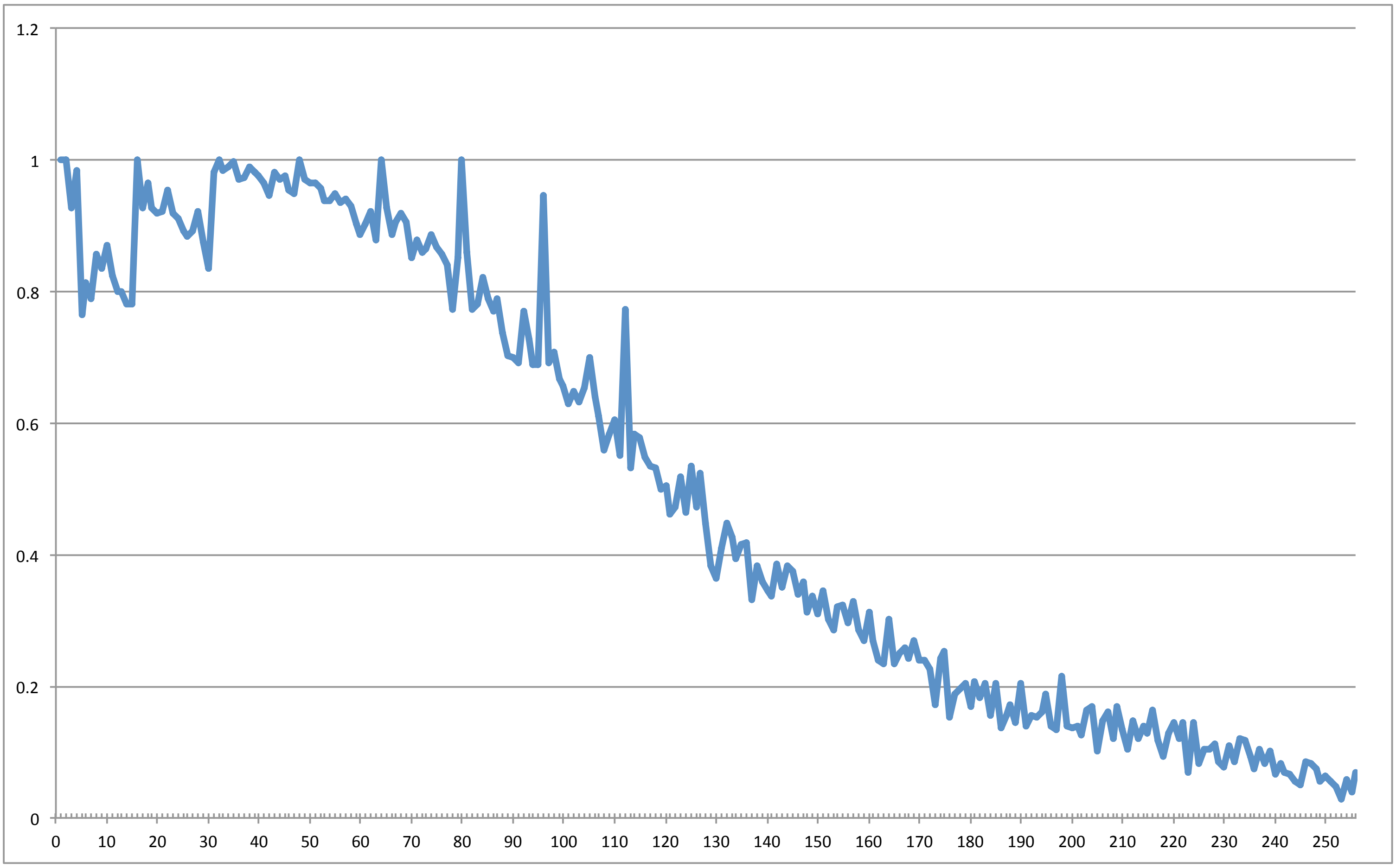


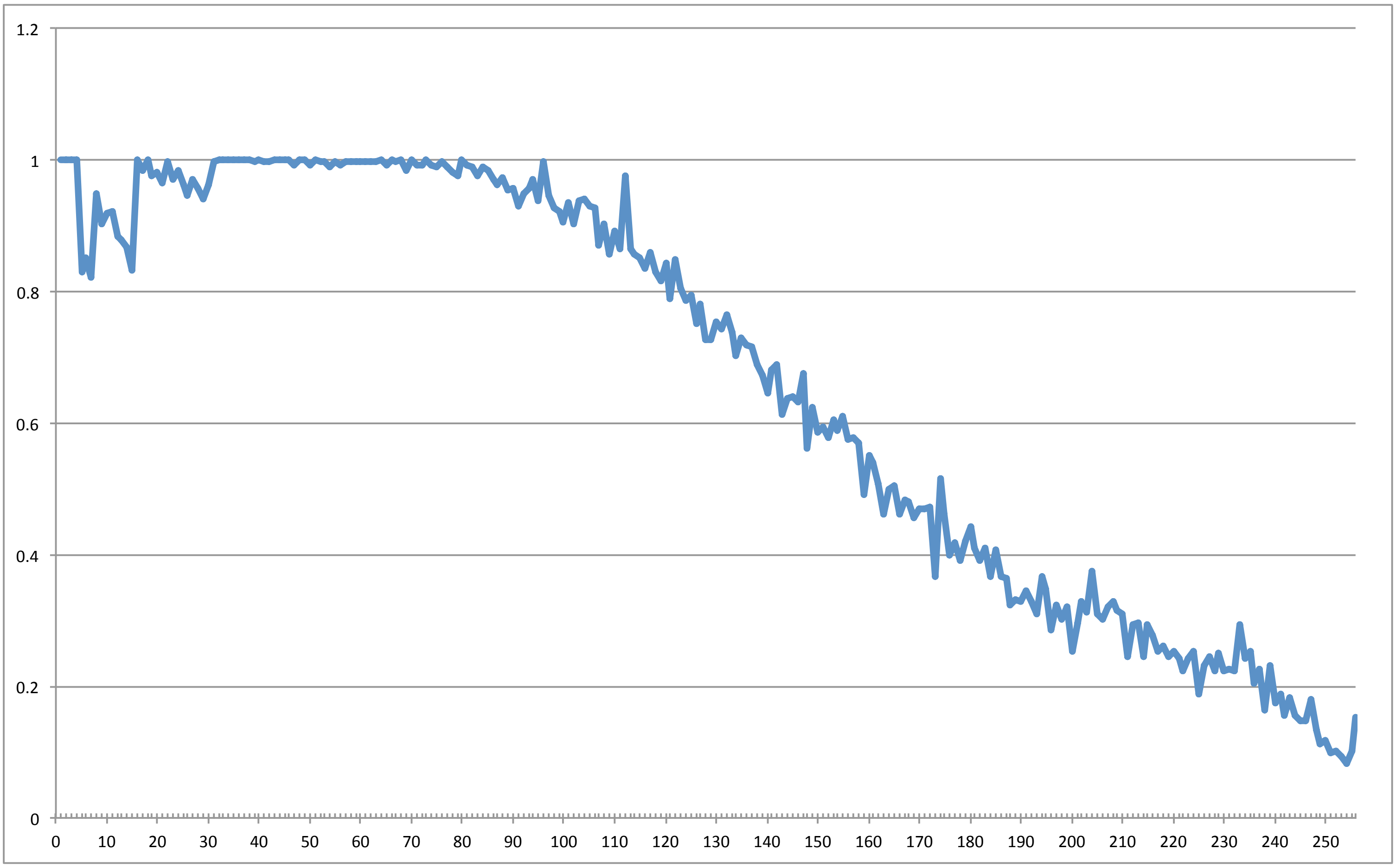
2013 AlFardan–Bernstein–
Paterson–Poettering–Schuldt
success probability (256 trials)
for recovering byte x of plaintext
from 2^{26} ciphertexts (with
no prior plaintext knowledge):



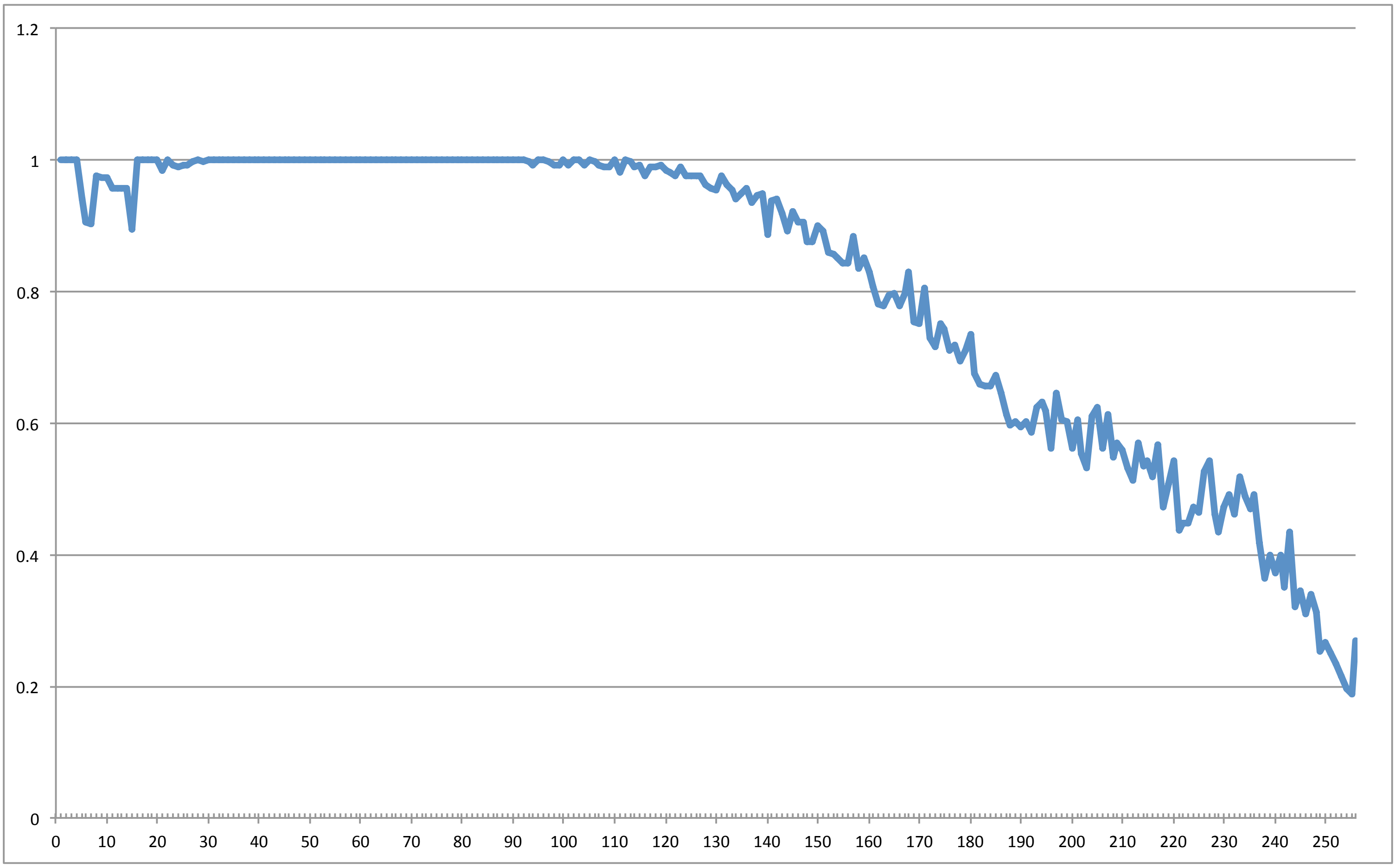
2013 AlFardan–Bernstein–Paterson–Poettering–Schuldt success probability (256 trials) for recovering byte x of plaintext from 2^{27} ciphertexts (with no prior plaintext knowledge):



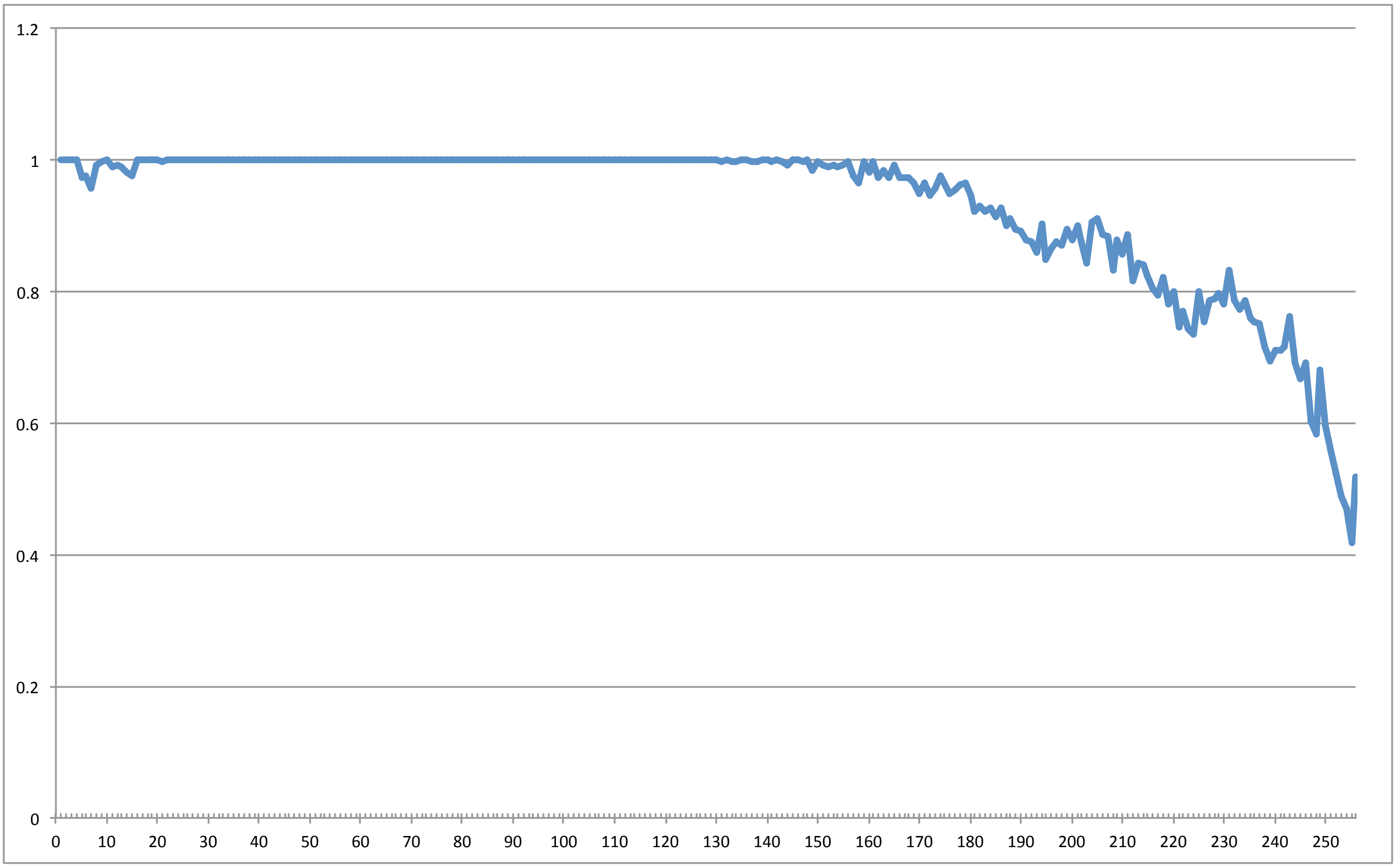
2013 AlFardan–Bernstein–Paterson–Poettering–Schuldt success probability (256 trials) for recovering byte x of plaintext from 2^{28} ciphertexts (with no prior plaintext knowledge):



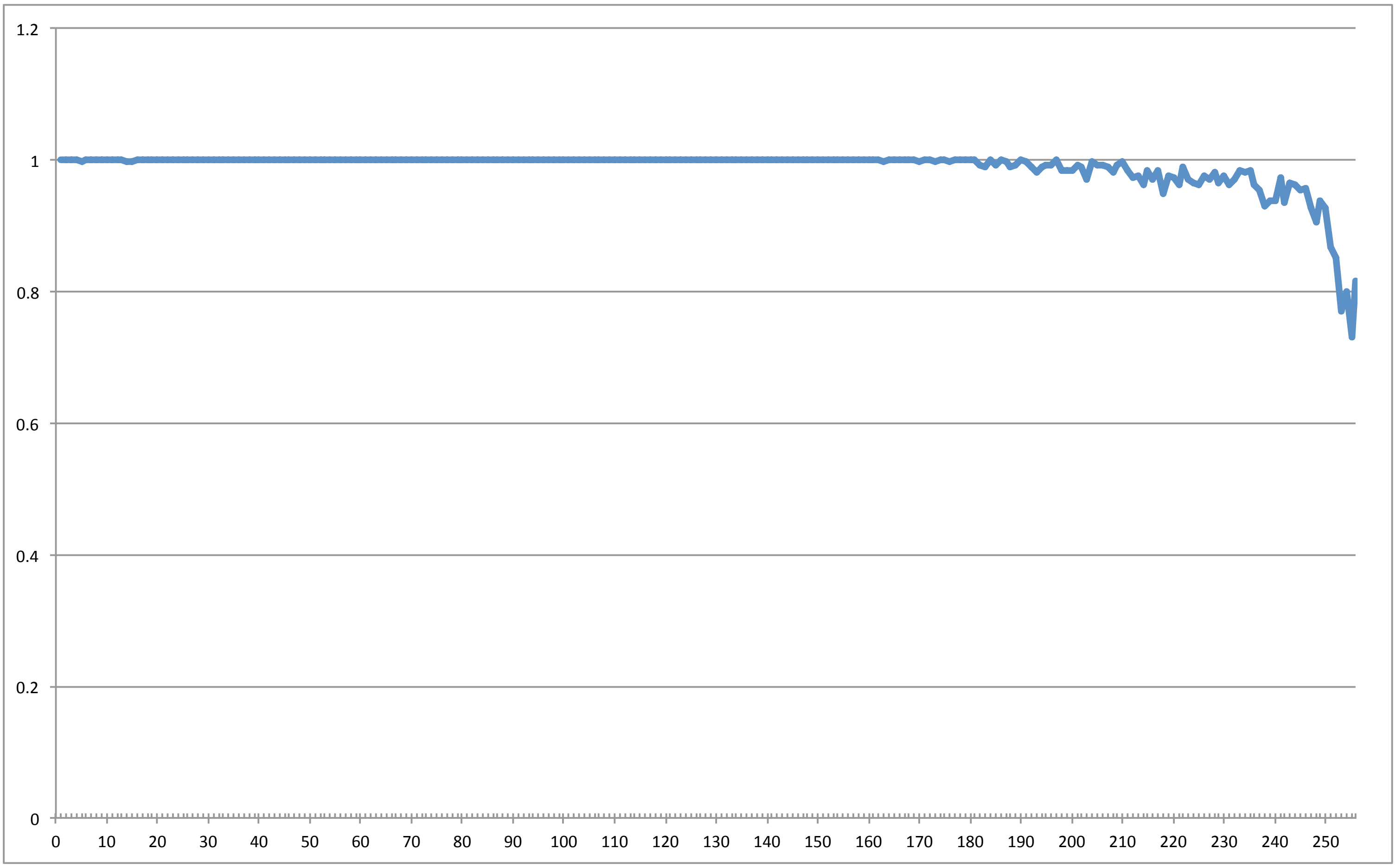
2013 AlFardan–Bernstein–Paterson–Poettering–Schuldt success probability (256 trials) for recovering byte x of plaintext from 2^{29} ciphertexts (with no prior plaintext knowledge):



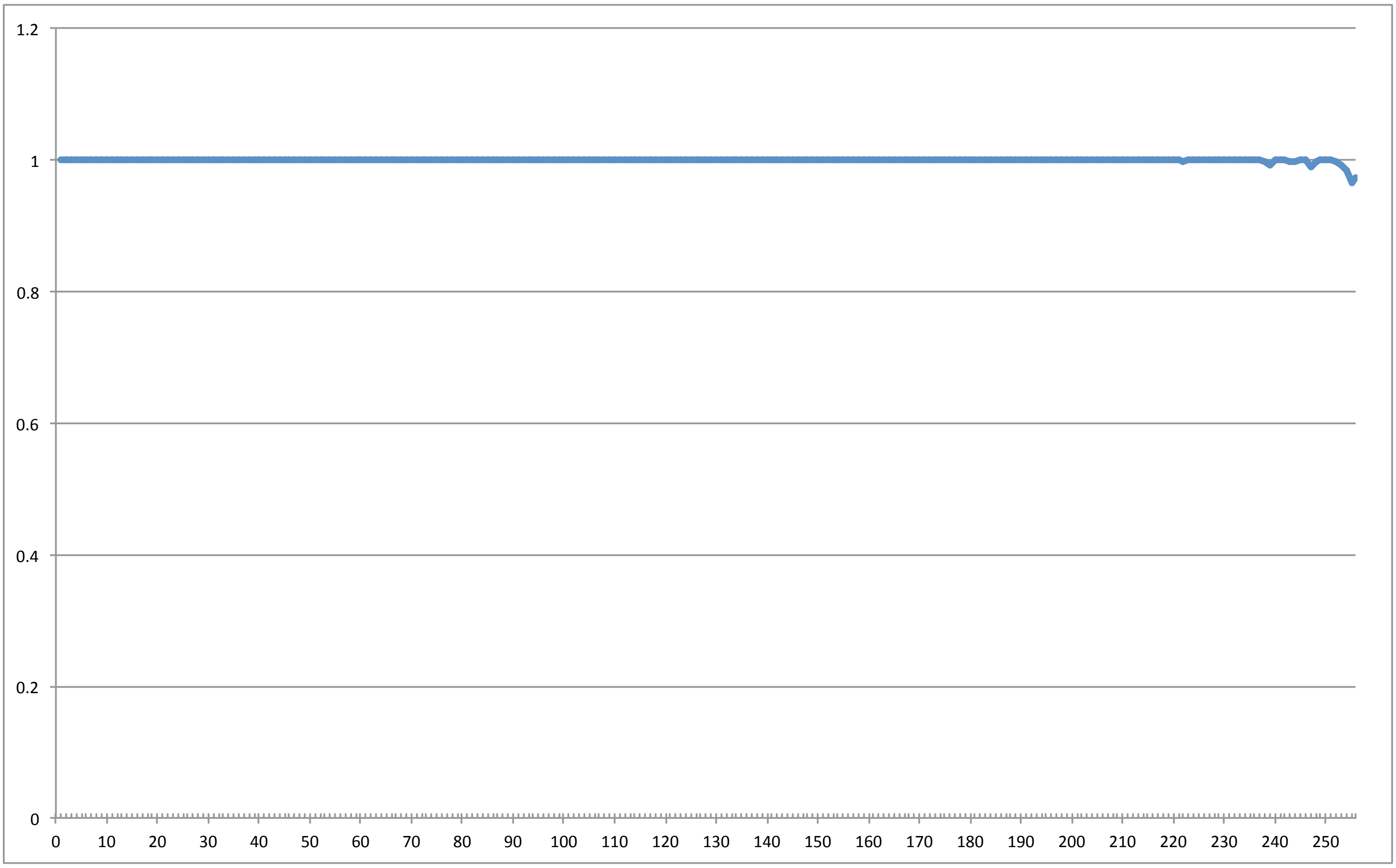
2013 AlFardan–Bernstein–Paterson–Poettering–Schuldt success probability (256 trials) for recovering byte x of plaintext from 2^{30} ciphertexts (with no prior plaintext knowledge):



2013 AlFardan–Bernstein–
Paterson–Poettering–Schuldt
success probability (256 trials)
for recovering byte x of plaintext
from 2^{31} ciphertexts (with
no prior plaintext knowledge):



2013 AlFardan–Bernstein–Paterson–Poettering–Schuldt success probability (256 trials) for recovering byte x of plaintext from 2^{32} ciphertexts (with no prior plaintext knowledge):



Why does this happen?

For years we’ve had AES; AES-GCM; defenses against various side-channel attacks.

We simply have to educate the software and hardware engineers choosing crypto primitives, right?

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Does AES-GCM actually do
what the users need?

Often it doesn't.
Most obvious issue: performance.

e.g. 2001 Rivest: “The ‘heart’ of RC4 is its exceptionally simple and extremely efficient pseudo-random generator. . . . RC4 is likely to remain the algorithm of choice for many applications and embedded systems.”

e.g. OpenSSL still uses table-based implementations of AES for speed on most CPUs, leaking many key bits; see, e.g., 2012 Weiß–Heinz–Stumpf.

e.g. RFIDs need small ciphers.

Major research direction:
achieve better performance
than AES-GCM
without sacrificing security.

Fit into low power (watts),
low area (square micrometers),
sometimes low latency (seconds);
minimize area$\times$seconds/byte;
minimize energy (joules)/byte.

Many different CPUs, FPGAs,
ASIC manufacturing technologies.

Many different input sizes,
precomputation possibilities, etc.

Can one design do very well
in hardware *and* software?

Some inspirational examples:
Trivium and Keccak
are “hardware” designs
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Trivium and Keccak
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Another approach:
replace ARX with "ORX".
Skein-type mix doesn't work
but can imitate Salsa20:
compose `a^=((b|c)<<<r)`.
Needs a few more rounds,
but friendlier to hardware.

Another major research direction:
achieve better security
than AES-GCM
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Typical 128-bit blocks
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Limit impact of collisions?
Use larger blocks?

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Limit reforgeries? Use wider pipe?

Has anyone tried optimizing
192-bit/256-bit poly hashes?

Allow repeated message numbers?

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Is this protection compatible with fast forgery rejection?

Many ciphers integrate
"free" message authentication:
e.g., AES-OCB, Helix, Phelix.

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One approach: build
$HFFH$ Feistel block cipher;
reuse first H for fast auth
with repeated message numbers;
reuse last H for another auth
with fast forgery rejection.
But this consumes bandwidth.

Many more directions
in authenticated ciphers.

AES-GCM is clearly not
the end of the story.

Can build better modes
using same MAC, cipher.

Can build better MACs,
combine with same cipher.

Can build better
block ciphers, stream ciphers.

Can build better integrated
authenticated ciphers.

CAESAR

“Competition for Authenticated Encryption: Security, Applicability, and Robustness”

`competitions.cr.yp.to`

Mailing list: `crypto-competitions+subscribe@googlegroups.com`

NIST is much too busy to run another competition but has generously provided a $333099 “Cryptographic competitions” grant to UIC.

Competition scheduling

AES schedule:

M0: 15 submissions.

M14: 5 finalists.

M28: 1 winner.

eSTREAM schedule:

M0: 34 submissions.

M11: 27 round-2 ciphers.

M24: 16 finalists.

M36: 8 portfolio ciphers.

M41: 7 portfolio ciphers.

SHA-3 schedule:

M0: 64 submissions.

M9: 14 round-2 functions.

M26: 5 finalists.

M48: 1 winner.

Tentative CAESAR schedule:

M0, 2014.01.15: submissions.

M11: round-2 candidates.

M23: round-3 candidates.

M35: finalists.

M47: portfolio.

Workshops

2012.07.05–06, Stockholm:
ECRYPT workshop on Directions
in Authenticated Ciphers.

DIAC 2013 in Chicago,
maybe 2013.08.12–13,
maybe 2013.08.26–27.
2013.08.14–16 is SAC;
2013.08.18–22 is Crypto;
2013.08.20–23 is CHES.

DIAC 2014: maybe San Diego?
DIAC 2015, 2016, 2017: TBA.